

Combatting nutrient pollution through the housing market*

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Nutrient pollution is a major threat to biodiversity. Policies to address nutrient pollution in water bodies usually target agriculture. We study a novel policy in England – called ‘Nutrient Neutrality’ – that instead combats residential pollution by targeting local housing construction. We document both direct effects and leakage: in treated locations, nutrient pollution improves modestly, while housing completions fall, and house prices increase. We find strong evidence of leakage in polluters, but not in pollution: housing completions increase nearby, while nutrient levels does not. This absence of any accompanying leakage in pollution casts doubt on the link between housing construction and nutrient pollution. In fact, we find large improvements in nutrient pollution and relatively more modest reductions in housing construction in locations where local authorities facilitate offset schemes that convert land use away from agriculture. In contrast, locations where no offset schemes are offered see the largest reductions in housing, without statistically significant improvements in nutrient pollution. Empirically, local authorities that do offer offset schemes either establish a nutrient credit trading platform or convert land uses ‘off-site’ from new housing construction themselves. While off-site offset programs appear more effective at reducing local pollution, these locations also experience larger reductions in housing construction relative to those with nutrient credit schemes. Overall, we find Nutrient Neutrality policy to reduce nutrient pollution by burdening developers, local authorities and future residents, thereby likely violating the polluter-pay-principle.

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1 Introduction

Clean water is essential for life. The quality of water is therefore of utmost importance. One of the most common threats to water quality is nutrient pollution.¹ High nutrient pollution can lead to local ecosystem collapse in water bodies, called eutrophication.² Yet, a consensus on how to effectively address nutrient pollution remains elusive.

Past policy initiatives centred on agriculture, the largest emitter of nutrient pollution, as well as wastewater treatment plants, land conversion and land conservation.³

In this paper, we study a novel policy approach in England – ‘Nutrient Neutrality’ – that combats nutrient pollution in water bodies by targeting local housing construction. Three features of the policy stand out: first, Nutrient Neutrality targets housing construction to reduce nutrient pollution from future residents’ wastewater. Second, and in contrast to pure command-and-control policies, house developers are offered the option to offset (‘neutralise’) the additional nutrient burden from new housing to avoid local construction bans. In this sense, the policy imposes an implicit tax on new residential construction. Third, the policy only affects highly polluted, ecologically vulnerable, predominantly rural locations in breach of nutrient target levels, opening up the possibility of leakage of polluters (new houses) and pollution (nutrients) to neighbouring, unregulated parts of the economy (Bushnell & Mansur, 2011).

Can nutrient pollution be addressed through regulating the housing market? To investigate this question, we assemble a novel dataset and exploit the staggered roll-out of Nutrient Neutrality policy across English localities since 2017. We find that treated localities experience moderate improvements in nutrient pollution: total nitrogen decreases, whereas total phosphorus does not change significantly. On the housing market, housing completions drop in treated localities and house prices increase. We detect clear evidence of leakage in *polluters*: housing completions are displaced almost one-for-one to neighbouring untreated localities. However, we fail to detect leakage in *pollution*: the displacement of housing to untreated neighbours is not accompanied by an uptick in nutrient pollution. This casts doubt on the mechanism at the heart of the policy: that residential wastewater from new houses would

¹Nutrient pollution is the “most widespread water quality problem facing the US” (EPA, 2025) and “a major environmental issue” in England (Natural England, 2022b) and the EU (EC, 2022).

²Globally, anthropogenic nitrogen flows have crossed planetary boundaries (Steffen et al., 2015).

³See Paudel and Crago (2020) for fertilizer, Raff and Meyer (2021) and Chen et al. (2024) for animal manure, Cohen and Keiser (2017) for interactions with wastewater treatment plants, and Jacobson (2014) and Liu et al. (2023) for land conservation policies.

contribute meaningfully to nutrient pollution in local water bodies.

In fact, we find evidence that the policy achieves improvements in nutrient pollution through a related but different mechanism: offset schemes. To investigate local authorities' response to the policy, we manually codify every treated local authority's behaviour in the aftermath of receiving Nutrient Neutrality guidance. Empirically, we find three main types of responses at the local level: first, some authorities operate nutrient trading platform ('offset credit schemes') that aim to facilitate the matching between demand and supply of nutrient reductions such as between developers aiming to construct houses and farmers willing to convert agricultural land (e.g., Partnership for South Hampshire, 2021; Breckland Council, 2026; Norfolk Environmental Credits, 2026). Second, some authorities design large-scale nutrient reduction interventions ('off-site offset schemes'), for example by purchasing and converting agricultural land to conservation use or by regulating agricultural practices on council-owned land, essentially providing sufficient offset capacity themselves (e.g., Dorset Council & Bournemouth, Christchurch and Poole Council, 2024; Dorset Council, 2026). Third, other authorities do not seem to provide any institutional schemes to support house developers in abiding by Nutrient Neutrality policy (e.g., North Warwickshire Borough Council, 2026; Lichfield District Council, 2026), essentially leaving house developers on their own to either design nutrient-neutral housing, generate their own offset measures, or refrain from building in these locations in the first place.

We find that locations without any offset program experience the largest decline in housing completions, yet show no significant reduction in nitrogen pollution, consistent with the decline in construction having limited effect on nutrient levels. In contrast, locations where local authorities established credit-based or council-run off-site offset schemes experience significant reductions in nitrogen, with off-site schemes showing the largest environmental effects. Nitrogen pollution improving the most in locations where offset activity is greatest, instead of in locations where construction falls the most, provides evidence that offsets rather than the reduction in housing plausibly drive the observed environmental improvements.

In addition, novel legislation on wastewater treatment plants (WWTP) forces plants in Nutrient Neutrality locations to abide by the highest technical standards for nutrient removal by 2030 (DEFRA, 2023). Such future WWTP efficiency improvements already reduce the necessary nutrient offset per housing unit since a more efficient WWTP will reduce a given housing unit's lifetime nutrient contribution to

freshwater bodies, effectively reducing the cost of house building in Nutrient Neutrality locations. Consistent with the reduction in offset requirements, we find that housing completions drop substantially more in treated locations without WWTP improvement potential than in those with future upgrades. In line with these upgrades concerning future WWTP efficiency, contemporaneous environmental effects are less clear-cut: nitrogen decreases more in locations without WWTP potential, where more offset per constructed unit is required, but estimates are imprecise and fail to capture the full environmental effect of WWTP upgrades. We leave this analysis for future work after 2030, once improvements are implemented.

In response to vocal opposition from architects, developers and local councils in England pointing to the likely role of Nutrient Neutrality policy in depressing local residential construction (RIBA, 2022; FT, 2023a, 2023b, 2024, 2025), the policy is currently under parliamentary review (Wentworth, 2025). Our findings suggest that the environmental benefits of Nutrient Neutrality are not attributable to the restriction of housing construction *per se*, but rather to investments in nutrient offsets that the policy incentivises. Local authorities that establish offset schemes enable developers to continue building, while funding nutrient mitigation measures that appear to genuinely reduce nitrogen pollution. In this sense, offset schemes represent the policy’s principal success: these schemes channel private and/or public investment into nutrient abatement activities such as wetland regeneration and agricultural land conversion that would not have occurred in the absence of the policy. However, the policy’s initial reliance on local initiative to design and implement these schemes meant that smaller, more rural authorities often failed to establish offset programs at all, resulting in *de facto* housing construction bans (e.g., Ashford Borough Council (2025) referring to the infamous ‘Stodmarsh Ban’), while failing to achieve any accompanying, measurable improvement in nutrient pollution. Moreover, the cost of nutrient abatement falls on housing developers and future residents rather than on agricultural producers, the dominant source of nutrient pollution, violating the polluter pays principle.^{4,5} Our findings therefore call for a more structured approach to combat nutrient pollution through the housing market: first, future policy should provide clear national guidance and institutional support regarding the design and

⁴Recent projections by the UK Environment Agency (2024b) confirm that agriculture is the most consequential polluter with respect to nutrient pollution across England’s water body catchments.

⁵See the ‘gilets jaunes’ in France (Boyer et al., 2020) and EU farmer protests (Finger et al., 2024).

operation of offset schemes, ensuring that the mechanism through which the policy actually works – offset investments – is readily available in all affected localities. Second, institutionalised offset schemes should help to realign the burden of abatement costs with the sources of pollution.

Our work contributes to three strands of literature. First, we contribute to a large literature on water quality and nutrient pollution in environmental economics. Following Segerson and D. Walker’s (2002) delineation of the role of economics in understanding the causes and consequences of nutrient pollution, recent literature reviews (Garnache et al., 2016; Del Rossi et al., 2023) highlight a strong focus on interventions targeting agriculture as a major source of nutrient emissions. Most closely related to ours are studies establishing a causal link between agriculture and nutrient pollution in water bodies, e.g., regarding fertilizer (Paudel & Crago, 2020) or animal waste from large-scale commercial establishments (Raff & Meyer, 2021). We contribute the first investigation of a policy that regulates the housing market, not agricultural operations or practices, to combat nutrient pollution. Nutrient Neutrality policy also differs from the dominant type of command-and-control environmental policy implemented elsewhere (Cohen & Keiser, 2017), since its design offers flexibility to house developers and local authorities through an explicit offset margin. Such flexibility and discretion in water policy has been shown to be effective, e.g., in the form of nutrient management plans in the US state of Wisconsin (Skidmore et al., 2023). Our work contributes the analysis of an environmental policy best understood as a command-and-control policy with considerable local flexibility.

Second, we contribute to ongoing academic and policy discussions on leakage in environmental policy. Similar to other environmental policies, the regulation of nutrient pollution is prone to incomplete regulation (Fowlie, 2009) which can cause leakage, spillovers and unintended consequences. Nutrient pollution in water is a local phenomenon, unlike global pollutants such as CO₂. Hence, even national policy designed to address nutrient pollution will inevitably lead to variation in regulation stringency across locations (Keiser & Shapiro, 2019; Currie & Walker, 2019), and risk spatial spillovers. Jacobson (2014) documents spillovers in land conservation policy (albeit temporal, not spatial spillovers), whereas Cohen and Keiser (2017) show leakage of phosphate purchases to unregulated locations. Chen et al. (2024) find that incomplete regulation on animal feeding operations leaked nutrient pollution from regulated to unregulated polluters within locations. In addition, Liu et al. (2023)

highlight how the complexity of water body systems means that seemingly effective water policy can have unintended consequences due to biochemical feedback loops.

In our case, Nutrient Neutrality policy specifically targets locations that are non-compliant in water pollution levels and restricts new housing developments in those locations, potentially giving rise to leakage in the form of spatial displacement of pollution sources to neighbouring (compliant) locations. Since the policy only targets two types of pollution (nitrogen and phosphorus, instead of a broader suite of water quality measures), and only one type of polluter (residential housing, instead of the much larger agricultural or industrial polluters, cf. Keiser (2020)), unintended consequences also loom large.⁶

Third, we contribute to a growing literature in urban economics studying the direct and spillover effects of place-based environmental policies. Recent work on road closures in central Paris documents displacement of polluters and pollution to nearby, unregulated roads (Bou Sleiman, 2025), adding to the larger literature on the direct effects and spillovers of low- and ultra-low emissions zones (Wolff & Perry, 2010; Wolff, 2014; Zhai & Wolff, 2021). In addition, there is ample evidence on the displacement of plants and employment following increased stringency of regulation from falling under non-attainment status under the US Clean Air Act (Henderson, 1996; Becker & Henderson, 2000; Walker, 2011).

Beyond environmental regulation, place-based construction regulation has been documented to reduce housing supply, e.g., Jun (2004) on urban boundaries in Portland, US, Hilber and Vermeulen (2015) on planning regulation and Koster (2023) on greenbelts, both in the UK. Our work provides two new angles to this literature at the intersection of urban and environmental economics: we provide the first evidence of substantial displacement of residential housing construction following an increase in environmental regulatory stringency; and we provide the first evidence on residential construction displacement in the mostly rural areas covered by Nutrient Neutrality.

The remainder of this paper is organized as follows. Section 2 provides context and details on Nutrient Neutrality policy. Section 3 introduces our data and empirical strategy. Section 4 presents empirical results, including on direct effects (Section 4.1), robustness (Section 4.2) and results on leakage (Section 4.3). Section 5 investigates the underlying mechanism, before Section 6 concludes.

⁶A report commissioned by the Home Builders Federation, estimates that only 0.29% of average nutrient pollution can be attributed to new housing developments (Brookbanks, 2023).

2 Setting and Nutrient Neutrality policy

Achieving water of good quality continues to pose a significant challenge. For instance, only 16% of surface waters in England, including rivers, lakes and estuaries, are classified as having ‘good’ ecological status (Environment Agency, 2024a). In addition, recent river and coastal pollution incidents in England have brought water quality into public focus (Natural England, 2022b), warranting policymaker attention.

Similar to other high-income countries, England has a long history of policies attempting to improve water quality (Burt et al., 2011). Their efficacy, however, remains unclear: levels of nitrogen, the most widespread pollutant in English rivers, barely decreased over the last four decades (Whelan et al., 2022). High levels of nutrient pollution, most commonly nitrogen and phosphorus, risk oxygen depletion and eutrophication of water bodies, i.e., their ecological degradation and potential collapse.⁷ Across advanced economies, the three main contributors to nutrient pollution in water bodies are agriculture, industrial wastewater and residential wastewater. While all three sources contribute to the problem, their relative importance varies considerably. Agriculture, primarily through fertiliser run-off, accounts for approximately 70% of nitrogen entering English rivers, with existing residential and industrial wastewater contributing the remainder (Environment Agency, 2024a). For phosphorus, wastewater treatment works are the dominant point source. By contrast, the government’s own assessment estimates that new housing developments contribute approximately 4% of the total nutrient load, with housing industry estimates suggesting figures as low as 0.3% for nitrogen and 0.7% for phosphorus from new residential construction.⁸

We study the most recent attempt to address water quality in England by means of a new environmental policy called ‘Nutrient Neutrality,’ designed by Natural England, a non-departmental public body funded and overseen by the UK Department for Environment, Food and Rural Affairs (DEFRA). The policy takes a novel approach to reducing nutrient pollution: it targets new residents and their associated wastewater through regulating residential housing construction. Natural England assigns a local authority (called Local Planning Authority, LPA) to fall under their Nutrient Neutrality guidance whenever there is a designated site in ‘unfavourable condition’

⁷In addition to posing grave danger to biodiversity, water body eutrophication also represents an adverse amenity shock to local residents and visitors, and can affect downstream locations as well.

⁸See research commissioned by the Home Builders Federation, assuming 230,000 annual completions nationally (<https://www.hbf.co.uk/news/nutrient-pollution-review/>).

within a water body catchment area (WBC).⁹ In particular, Nutrient Neutrality mandates that a given LPA should withhold planning approval for new residential housing developments unless the additional nutrient emissions of new residents are mitigated, e.g., by investments in local wetland restoration or equivalent projects (Natural England, 2022a), such that the new developments become ‘neutral’ in terms of nutrient pollution.¹⁰

The legal foundations of the policy lie in the Conservation of Habitats and Species Regulations 2017, which require local planning authorities to undertake a Habitats Regulations Assessment (HRA) before granting permission for any project likely to have a significant environmental effect on a protected site (e.g., new residential housing construction). Natural England began issuing Nutrient Neutrality guidance on a case-by-case basis as early as 2017, initially targeting the most degraded catchments such as Poole Harbour. The scope and urgency of this advice increased substantially following two rulings by the Court of Justice of the European Union (CJEU) in 2018 that required Habitats Regulations Assessment (HRA) to be more stringent. In ‘People Over Wind’ (Case C-323/17, April 2018), the Court ruled that mitigation measures may not be considered at the screening stage of an HRA but required a full appropriate assessment for a much wider range of developments. In the ‘Dutch nitrogen’ cases (Cooperatie Mobilisation for the Environment, Joined Cases C-293/17 and C-294/17, November 2018), the Court held that an appropriate assessment must contain “complete, precise and definitive findings” removing “all reasonable scientific doubt” about adverse effects, and that anticipated conservation benefits whose realisation remains uncertain cannot satisfy this standard. Both rulings were retained in domestic law after Brexit via the European Union (Withdrawal) Act 2018. The project-level nature of HRA obligations is a crucial design feature: housing developments constitute assessable ‘projects’, while diffuse agricultural pollution (the dominant source of nutrients) does not, a distinction that, as we discuss in Section 5, generates a fundamental tension between the regulatory burden and the actual sources of nutrient pollution. Facing substantially heightened risk from the changing legal environment, Natural England systematised and expanded its advice, issuing formal guidance in a staggered fashion reaching 74 LPAs in 2022. Currently 19% of LPAs

⁹A designated site is a Special Protection Area (SPA), a Special Area of Conservation (SAC) or a Ramsar site as designated under the Habitat Regulations 2017.

¹⁰Notably, this advice by Natural England on how Nutrient Neutrality could be achieved in practice was only published in 2022, five years after the first water body catchment areas were treated.

covering more than 13% of England’s total land area fall under the policy. Figure 1 provides an overview of the staggered roll-out of the policy across time and space. Nutrient Neutrality guidance was first imposed on the Poole Harbour SPA/Ramsar in the second quarter of 2017 with six additional catchments being targeted until 2021 (covering 7% of total land area in England). Following a comprehensive review, Nutrient Neutrality guidance was issued for a further 20 catchments in 2022 and has not been revoked for any location thus far (see Appendix Table A.1 for a detailed overview of treatment timing and cumulative coverage).

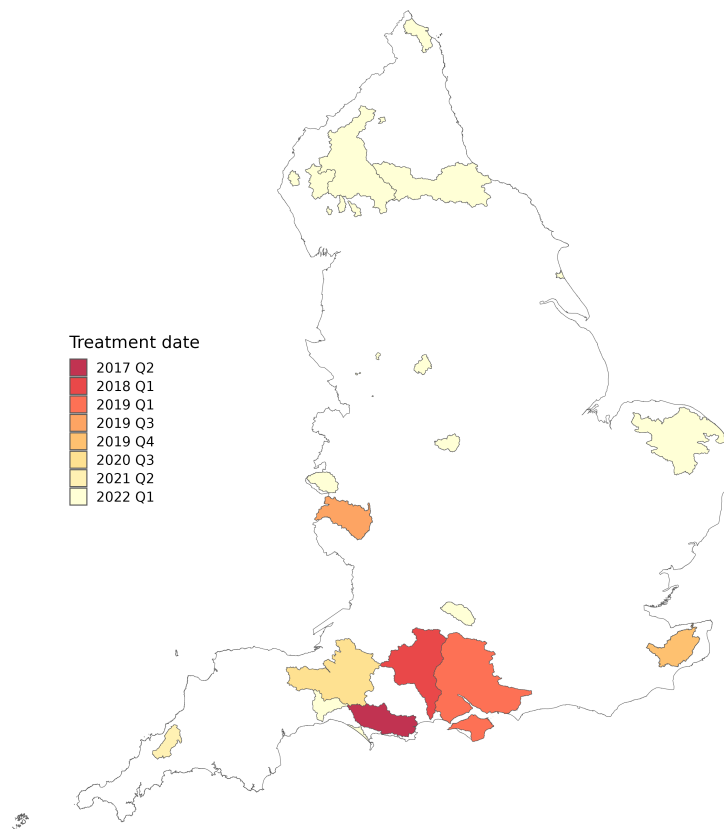


Figure 1: Nutrient Neutrality treatment status by water catchment area

This figure displays the issuance of Nutrient Neutrality guidance by Natural England across space and over time (see Appendix Table A.1 for further details).

In practice, once a location fell under Nutrient Neutrality guidance developers had to include a plan for offsetting the additional nutrients from the new development together with their planning application. While the policy was designed by Natural

England and imposed on local authorities, there was no practical national-level guidance on how to implement this offset mandate, such that it was up to developers and local planning authorities (LPAs) to find ways to comply with this novel regulation. Without guidance from LPAs this often resulted in a *de facto* ban of new developments, as developers were missing both the necessary details on what exactly was required to comply with the regulation as well as the capabilities to do so (Ashford Borough Council, 2025). In order to escape these *de facto* bans LPAs started to explore various avenues to make it easier for local developers to comply with the regulation. Since many protected sites cross various LPAs many of these schemes involve collaborations of several LPAs.¹¹

The two most common approaches were to create ‘off-site offset’ schemes and to establish ‘nutrient trading platforms’. Off-site offset schemes, such as the one created by Bournemouth Christchurch and Poole Council (BCP Council) and Dorset Council for the Poole Harbour site, involve the local LPA buying land to take it out of intensive agricultural use and rewilding it, forcing agricultural tenants on council land to move to less nitrogen-intensive production processes, and similar measures directly implemented by LPAs (Planning Policy, 2022). Nutrient trading platforms, on the other hand, represent platforms provided by the LPA where private providers can offer nutrient credits in the form of mitigation measures (e.g., a farmer could stop using land for agricultural purposes and sell the resulting nutrient credits to developers), without the LPA itself offering any nutrient credits. Both approaches by LPAs make it much easier for developers to comply with the regulation. A LPA-operated offsite offset scheme is likely to be most reliable source of nutrient credits as the LPA itself generates their supply. However, these LPA-operated off-site offset schemes are also likely to be more expensive per unit of offset than a private market solution such as a nutrient trading scheme. Some LPAs also combined both schemes, providing credits themselves and making it easier for private actors to sell nutrient credits. In the absence of any action by the LPA, local developers would either need to provide offsets on-site or find ways to provide offsets in other ways, both of which are costly and not unlikely to be infeasible for the average developer.

Following the initial roll-out of Nutrient Neutrality guidance, the UK government announced a series of complementary measures in 2022. In particular, the government

¹¹For example, the ‘Partnership for South Hampshire’ is comprised of twelve local authorities around the Solent (<https://www.push.gov.uk/>).

requires water companies to upgrade wastewater treatment plants in nutrient neutrality catchments to the highest technically achievable limits by 2030. Even though these wastewater treatment plant upgrades have not yet been implemented they already affect offsets for new residential housing, as developers need to offset the expected nutrient pollution of the development over the next 80 years. Therefore, catchments that host wastewater treatment plants with agreed future upgrades require less nutrient offset per additional housing unit constructed from the time of announcement, hence likely reducing any negative effects of the policy on housing construction.

3 Data and empirical strategy

3.1 Data description

To study the effect of Nutrient Neutrality on the local environment and housing market we construct a novel, spatially disaggregated dataset that features rich information on environmental and housing market outcomes from five primary datasets.

The first dataset contains information on the ‘Nutrient Neutrality’ policy, in particular which water bodies were affected by the policy and when. Since there are limited public records on the issuance of Nutrient Neutrality guidance by Natural England, especially at the initial stage of the policy roll-out, this dataset was obtained in direct correspondence with Natural England (see Figure 1 and Appendix Table A.1 for details). The treatment areas designated by Natural England are issued for existing special protection areas, which are formed from groupings of individual water body catchment areas (WBCs). WBCs in turn, are defined as an area of land from which all surface run-off flows through a series of streams, rivers and, possibly, lakes to a particular point in the water course such as a river confluence.¹² Therefore, WBCs represent the smallest spatial unit covering an integrated local water system – the median WBC in our sample covers approximately 7×7 km in extent. While treatment is defined for groups of WBCs that in turn cover either parts or the entirety of larger water management catchment areas (WMCs), our unit of observation in the paper is the most granular one for which data is available: the level of WBCs at quarterly frequency.

Second, while Nutrient Neutrality guidance was assigned by a national body, there

¹²Although WBCs do not necessarily align with wastewater treatment plants’ catchment areas, which treat residential nutrient pollution, both are highly correlated due to shared spatial features.

was no guidance on how local planning authorities (LPAs) could help developers to comply with the new regulation, which led to very heterogeneous responses by LPAs. Based on qualitative research we created a novel dataset classifying the reaction of LPAs into those that created an “off-site offset” program, those that created a nutrient credit trading platform and those that did not provide any assistance to developers to offset the additional nutrient burden from construction at all.

The third dataset stems from the Water Quality Archive maintained by the Department for Environment, Food and Rural Affairs (DEFRA). It contains water quality samples collected by the UK Environment Agency from locations across England, including coastal and estuarine waters, rivers, lakes, ponds, canals, and groundwater sources. These samples serve multiple purposes, such as assessing compliance with discharge permits, investigating pollution incidents, and conducting environmental monitoring. The archive contains data on measurements and samples dating back to 2000 and contains information on the levels of various nutrients, which will be our main environmental outcomes of interest. It contains information on the targeted pollutants nitrogen (in mg/l) and phosphorus (in mg/l). It also includes measurements of a number of other environmental indicators of water quality such as dissolved oxygen, biochemical oxygen demand, pH value and chlorophyll-a. In addition the Water Quality Archive also contains samples of (sub-)pollutants not directly targeted by the policy, such as nitrate, ammonia, nitrite and orthophosphate. For our main results we use the mean reading across samples within a WBC-quarter, while we additionally report the results for the median, minimum and maximum readings in the Online Appendix. Each sample comes with an exact time and location that we aggregate up to the WBC-quarter level. Since samples are not taken every quarter in every WBC but at irregular intervals this is an unbalanced panel. During the initial outbreak of the Covid pandemic (i.e., the second and third quarters 2020) no samples were taken at all, so these quarters are implicitly dropped from the sample.

Fourth, we obtain data on finished housing constructions from newly issued Energy Performance Certificates (EPC) and aggregate those to the WBC-quarter level. EPCs issued for new buildings include information on the postcode of the new building, its type and size and issuance date. From the postcode, we can derive for any new building its approximate location and map their postcode to the WBC that contains it. In this way, we can derive the number of house completions at the WBC-quarter level, as well as the number (and share) of completions by building type as well as

individual and total WBC-quarter newly built floor area.

Fifth, we create a more standard dataset to arrive at WBC-quarter level house prices by leveraging the universe of residential transactions from the Land Registry and link these transactions to the micro-geographic price index developed by Ahlfeldt et al. (2023). The resulting index provides quarterly, local house price measures that are explicitly mix-adjusted: it tracks the price per square meter of a constant-quality dwelling by controlling for observable housing characteristics (using EPC-linked information such as floor area and related attributes), rather than reflecting shifts in the composition of transacted homes. This dataset suits our empirical setting well since Nutrient Neutrality may affect both market activity and the mix of properties that trade (and are developed) in treated areas. Therefore, a constant-quality index helps ensure that estimated price responses are not mechanically driven by compositional changes. Finally, the index is explicitly designed to be constructed at very fine geographic scales and at high temporal frequency, allowing us to measure housing market dynamics at the same spatial and temporal granularity as our other main outcome variables of interest introduced above.

The combined, novel dataset covers all English WBCs at quarterly frequency from 2012 until 2023, and allows us to track the effects of the policy on both local environmental outcomes and the housing market at the same spatial and temporal frequency.

3.2 Identification and estimation

In the absence of any treatment heterogeneity or staggered roll-out of treatment across locations over time, the direct effects of the policy on the housing market and targeted pollutants in treated locations could be estimated by means of a standard two-way fixed effects specification:

$$y_{ct} = \beta (Post_t \times Treatment_c) + \gamma_t + \gamma_c + \varepsilon_{ct} \quad (1)$$

where y_{ct} denotes the outcomes variables of interests in water body catchment area c and quarter t : housing completions, local house price index, phosphorus levels and nitrogen levels. γ_t and γ_c represent quarter and WBC fixed effects, respectively. For housing completions, the start of the treatment period needs to be shifted to account for the fact that the policy only affects new planning applications, which take on

average two years in our sample to proceed from planning application to completion.

In all analyses, we drop London from our sample since no areas within the Greater London area were treated by Nutrient Neutrality, and no other treated area displays a similar level of urbanisation as London. Furthermore, the London housing market is likely to be driven by a number of other factors, such as geopolitics and international capital flows, that are distinct from the housing market in the rest of the country (Badarinza & Ramadorai, 2018). We further restrict our estimation sample to only quarters for which data from at least two treated locations is available to avoid our results being driven by idiosyncratic shocks to any single location.

However, to account econometrically for both the staggered nature of the Nutrient Neutrality roll-out and the expected heterogeneous treatment effects across locations, we employ the dynamic, doubly-robust difference-in-differences estimator developed by Callaway and Sant’Anna (2021). This estimator addresses the problem of ‘negative weights’ in standard two-way fixed effects estimators (Borusyak & Jaravel, 2017; Callaway & Sant’Anna, 2021; De Chaisemartin & d’Haultfoeuille, 2024) that emerge in Equation 1 when employed in settings with multiple treatment periods, such as the roll-out of Nutrient Neutrality guidance across water catchments in England.

Following Callaway and Sant’Anna (2021), we impose a parallel trends assumption of treated locations with never-treated locations (where $C = 1$), which gives rise to the following group-time average treatment effects $ATT(g, t)$ for all quarters $t \geq g$:

$$ATT(g, t) = E[Y_t - Y_{g-1} | G = g] - E[Y_t - Y_{g-1} | C = 1]$$

Throughout the paper, we dynamically aggregate the above group-time average treatment effects to arrive at the average treatment effect on the groups of water body catchment areas that have been treated for exactly e quarters:

$$\theta_D(e) := \sum_{g=2}^T \mathbf{1}\{g + e \leq T\} ATT(g, g + e) P(G = g | g + e \leq T) \quad (2)$$

We produce standard event study graphs that display dynamic average treatment effects for various values of e throughout the paper.

The key identifying assumption for our dynamic difference-in-differences design is that, in the absence of the Nutrient Neutrality policy, treated and never-treated con-

trol water catchments would have followed parallel trends in the outcomes of interest. To support this assumption we present event study graphs that display pre-treatment dynamics that enable a visual assessment of differential pre-trends; reassuringly, the estimates in the pre-treatment periods are close to zero and statistically insignificant across all main outcomes.

Moving beyond parallel trends, Table 1 presents pre-treatment balance tests comparing treated and control water body catchments across housing market characteristics. Panel A shows that, in the full sample, treated water catchments tend to have fewer housing completions and are less urban, consistent with Nutrient Neutrality designations targeting predominantly rural catchments. House prices are statistically indistinguishable between treated and never-treated locations. This is consistent with the policy targeting ecologically sensitive sites in more rural locations rather than polluted ones, and underscores the importance of the parallel trends assumption: our identification relies on common trends, not common levels. However, Panel B demonstrates that restricting the sample to rural areas eliminates the housing market imbalances as none of the pre-treatment means for completions, floor area, or prices differ significantly across treated and control variables. To make sure that none of our results are driven by differential reactions of urban or rural areas to contemporaneous shocks we show results for the rural only sample as a key robustness exercise in Section 4.2. Zooming in even further, Panel C compares treated water body catchments to their geographic neighbours within 10km, providing a balance check for the spillover analysis presented in Section 4.3. Results are similar to the rural-only sample: no differences in housing market outcomes at baseline can be detected.

We present our main results on the direct effects of the policy in Section 4.1 below, either in event study graphs or by reporting the aggregate dynamic ATT estimator in Equation 2. We cluster standard errors at the level of the Nutrient Neutrality treatment, that is the group of water body catchment (WBC) areas that fall within the boundaries of a larger water management catchment (WMC) area.¹³

To transparently highlight how negative treatment weights in multi-period difference-

¹³Note that Nutrient Neutrality treatment areas, as shown in Figure 1, align closely with the boundaries of water management catchment areas (WMCs) in England. WMCs can be further split into water operational catchments (WOCs), which in turn can be split into water body catchment areas (WBCs). The highest level of water catchments in England are river basin districts (RBDs), i.e., aggregations of WMCs. Our analysis is performed at the lowest level of water catchment units, that is the WBC.

Table 1: Housing market characteristics across treated and control locations

	Treated	Control	Difference	SE	<i>p</i> -value
<i>Panel A: Full sample ($N_{\text{treat}} = 549, N_{\text{ctrl}} = 3564$)</i>					
Completions (quarterly mean)	5.87	9.65	-3.77	1.10	0.001
Completions: houses	4.04	5.34	-1.30	0.41	0.002
Completions: flats	1.83	4.31	-2.48	0.90	0.006
Completions: detached	1.75	2.78	-1.02	0.29	0.001
Completions: semi-detached	1.23	1.67	-0.45	0.14	0.002
Completions: terraced	1.98	3.07	-1.10	0.34	0.001
Total floor area (sqm)	537	845	-308	83.42	0.000
Price per sqm (GBP)	2,310	2,296	14.27	30.04	0.635
Urban share	0.20	0.30	-0.10	0.02	0.000
<i>Panel B: Only rural locations ($N_{\text{treat}} = 417, N_{\text{ctrl}} = 2376$)</i>					
Completions (quarterly mean)	1.92	2.00	-0.09	0.23	0.698
Completions: houses	1.63	1.72	-0.09	0.19	0.644
Completions: flats	0.28	0.28	0.00	0.04	0.988
Completions: detached	0.72	0.77	-0.05	0.08	0.551
Completions: semi-detached	0.42	0.45	-0.03	0.06	0.621
Completions: terraced	0.54	0.53	0.00	0.08	0.952
Total floor area (sqm)	204	217	-13.65	22.20	0.539
Price per sqm (GBP)	2,330	2,330	0.06	34.09	0.999
<i>Panel C: Treated vs. neighbouring locations (10km) ($N_{\text{treat}} = 549, N_{\text{ctrl}} = 1019$)</i>					
Completions (quarterly mean)	5.87	5.40	0.47	0.74	0.522
Completions: houses	4.04	3.69	0.36	0.44	0.421
Completions: flats	1.83	1.71	0.12	0.38	0.761
Completions: detached	1.75	1.68	0.07	0.20	0.709
Completions: semi-detached	1.23	1.12	0.11	0.15	0.479
Completions: terraced	1.98	1.71	0.27	0.28	0.346
Total floor area (sqm)	537	492	45.00	60.46	0.457
Price per sqm (GBP)	2,310	2,286	24.15	33.42	0.470
Urban share	0.20	0.22	-0.02	0.02	0.250

Notes: Pre-treatment WBC-level means (before 2017 Q2). Difference = Treated – Control. *p*-values from Welch’s *t*-test. Panel A includes all WBCs. Panel B restricts to rural WBCs (urban share $\leq 50\%$). Panel C compares treated WBCs against untreated WBCs within 10km of a treated WBC.

in-differences settings such as ours could potentially bias results, we also report results from the standard two-way fixed effects estimator (Equation 1) in robustness exercises in Section 4.2 below.

4 Results

4.1 Direct effects

Our main results estimated using doubly-robust dynamic difference-in-differences are displayed in Figure 2. On nutrient pollution, we find mixed results: while nitrogen decreases by 0.79 mg/l, the noisy effect on phosphorus (a decrease of 0.01 mg/l) is not statistically significantly different from zero.

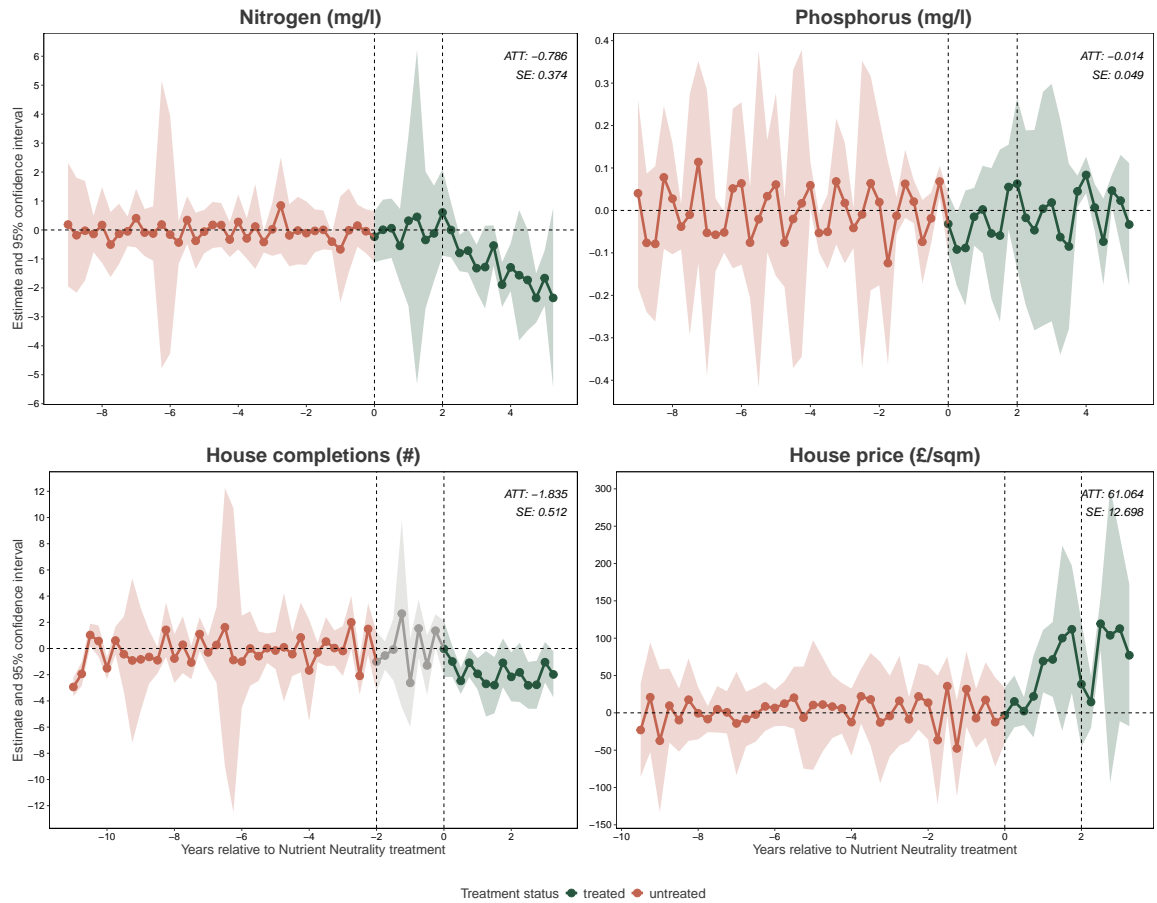


Figure 2: Event studies of main outcomes on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of issuance of ‘Nutrient Neutrality’ guidance on mean level of nitrogen, mean level of phosphorus, number of housing completions and house prices based on Equation 2.

In the housing market, we find significant effects with the number of completions decreasing by 1.8 new housing completions per quarter in treated areas, which is equivalent to a 19% decrease in the mean treated area. In line with a contraction of housing supply we find that house prices increase by £61 per m², which is equivalent

to a 2% increase in the median WBC. This increase is gradual, but starts shortly after the implementation of the policy. Given the average two-year lag between planning application and housing completion in this context, it is reassuring that no treatment effect on housing completions can be detected in the first eight quarters after treatment assignment (the gray estimates in Figure 2, bottom left), whereas consistent decreases in housing completion appear from the ninth quarter post-treatment onward. These results are consistent with an upward sloping housing supply curve, and highlight the trade-off between environmental benefits and economic costs in the direct effects of the policy.¹⁴

We provide further results for the direct effects of Nutrient Neutrality policy on different components of nitrogen and phosphorus (‘sub-pollutants’) in Appendix Figure A.3 and Appendix Table A.4. In line with the overall decrease in nitrogen, nitrate and ammonia fall, although not statistically significantly so except for ammonia at semi-annual frequency. The phosphorus component orthophosphate increases in treated areas, albeit only significantly at semi-annual frequency. These heterogeneous effects on targeted pollutants are in line with recent findings by Liu et al. (2023) on the effects of the Environmental Quality Incentives Program in the US, where improvements in nitrogen co-occur with increases in phosphorus. This finding highlights the importance of biochemical feedback processes caused by reduced nitrogen in water bodies, as well as pointing to inadvertent effects of nutrient pollution policy that have the potential to undermine effective policy design.

Ultimately, the goal of Nutrient Neutrality policy is to decrease nutrient pollution in order to improve water quality and to prevent the risk of eutrophication in water bodies. To this end, Figure 3 provides an overview of the dynamic effects of Nutrient Neutrality on measures of water quality not directly targeted by the policy in treated locations. We test four common proxies of water quality with good coverage over our sample period: dissolved oxygen (DO), a measure of the oxygen content of water bodies; biochemical oxygen demand (BOD), a measure of aerobic bacteria’s oxygen consumption, and thus a proxy for organic water pollution; pH value, a measure of acidity or basicity of water; and chlorophyll, a measure of the presence of algae and plants in water. Although we cannot detect any significant aggregate effects on either

¹⁴Observational studies link water quality to house prices (Moore et al., 2020; Mamun et al., 2023). However, such hyperlocal, ‘lakeside’ amenity effects of water quality improvements are unlikely to drive our catchment area-wide effects on house prices that even extend to neighbouring areas.

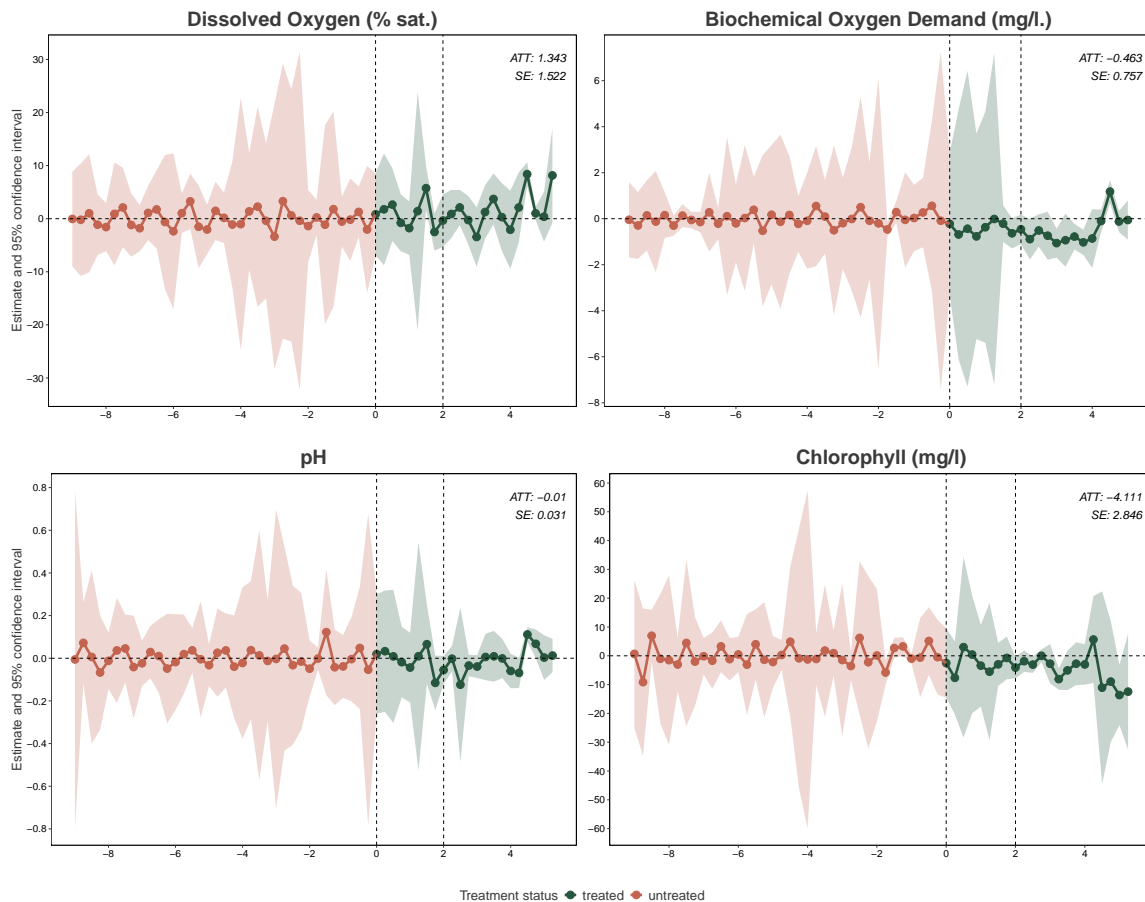


Figure 3: Event studies of water quality outcomes on Nutrient Neutrality treatment
This figure displays average treatment effects on the treated of issuance of ‘Nutrient Neutrality’ guidance on mean levels of dissolved oxygen, BOD, pH and chlorophyll based on Equation 2.

of the four proxies for water quality, the trajectories of biochemical oxygen demand and chlorophyll in particular highlight potential improvements in water quality that we are under-powered to detect.¹⁵

Overall, our analysis finds modest effects of Nutrient Neutrality policy on environmental outcomes, accompanied by stark treatment effects on housing outcomes. However, given the highly unbalanced nature of water quality monitoring data in England over our sample period, point estimates often indicate qualitative improvements in pollution and water quality components, but effects are imprecisely estimated. Re-

¹⁵Such a positive interpretation is supported by findings of some significant water quality improvements in terms of BOD and chlorophyll across sub-samples (see Appendix Tables A.15 and A.17), as well as significant decreases in maximum (instead of mean) chlorophyll readings (see Appendix Figure A.13), suggesting decreases in algal bloom and organic matter in treated locations.

assuringly, our event study graphs highlight that across various outcomes variables, we fail to detect any systematic violations of our parallel trends assumption. In fact, pre-treatment estimates are often centred around zero, whereas post-treatment estimates deviate systematically away from zero in one direction for nitrogen, house completions, prices, and tentatively, biochemical oxygen demand, chlorophyll and nitrate. Given the substantial noise in the raw data and the imbalanced nature of the panel, we perform a rich set of robustness tests to increase confidence in our results.

4.2 Robustness

We provide a rich set of robustness tests for our main results below. Table 2 provides our four main outcomes (nitrogen, phosphorus, housing completion, house price) across four different estimation samples and one alternative specification.

First, Panel B in Table 2 provides robustness to dropping coastal locations that could be subject to differential economic and biochemical conditions, which does not materially alter any result compared to the main sample reproduced in Panel A.

Second, Panel C in Table 2 performs our main estimation on only rural locations. Since our treated locations are more rural than the average control WBC even after excluding London (see Table 1, Panel A), we show that our results also hold when restricting the sample to only rural locations. This becomes particularly relevant as the time horizon of our study significantly overlaps with the Covid-19 pandemic. One of the key implications from the pandemic is a shift of housing demand towards more rural areas, which would suggest that housing demand increased relatively more in treated (more rural) locations than in control locations. Such a differential demand shock would attenuate the negative effect on housing completions we document, rendering our main estimates conservative. For house prices, however, a rural-biased demand shock could spuriously inflate the estimated price increase in treated areas, since our estimate may conflate a pandemic-driven reallocation of demand towards rural locations with a contraction in supply induced by Nutrient Neutrality. Our subsample analyses directly address this concern. When we restrict the sample to rural areas only, treated and control WBCs are balanced on pre-treatment housing market characteristics (Table 1, Panel B), satisfying a much stronger identifying assumption than required for our dynamic difference-in-differences analysis, but ensuring that any aggregate shift in rural housing demand affects both groups symmetrically. Results are qualitatively unchanged, although the nitrogen result loses significance.

Table 2: Robustness of main results to sample restrictions and specifications

	Nitrogen	Phosphorus	Housing Completion	House Price
	mg/l	mg/l	# of houses	£/m ²
<i>Panel A: Main sample and specification</i>				
Nutrient Neutrality	-0.79** (0.37)	-0.01 (0.05)	-1.59*** (0.31)	61.06*** (12.70)
N. Obs	15646	19491	185816	185816
<i>Panel B: Only non-coastal locations</i>				
Nutrient Neutrality	-0.79** (0.39)	-0.01 (0.05)	-1.83*** (0.51)	61.06*** (9.61)
N. Obs	15646	19491	185816	185816
<i>Panel C: Only rural locations</i>				
Nutrient Neutrality	-0.42 (0.37)	-0.00 (0.03)	-1.39** (0.68)	49.86*** (15.55)
N. Obs	10414	12882	127736	127736
<i>Panel D: Only Special Protection Area control locations</i>				
Nutrient Neutrality	-1.08** (0.47)	-0.06 (0.04)	-2.26*** (0.78)	80.81*** (16.15)
N. Obs	5965	6989	57430	57430
<i>Panel E: Only Special Protection Area locations</i>				
Nutrient Neutrality	-1.23*** (0.35)	-0.07 (0.05)	-3.61*** (1.11)	109.44*** (14.65)
N. Obs	3923	4677	41004	41004
<i>Panel F: Two-way fixed effects specification</i>				
Nutrient Neutrality	-0.15 (0.12)	0.01 (0.01)	-1.78*** (0.46)	78.84** (34.92)
R ²	0.83	0.68	0.61	0.96
N. WBCs	1076	1402	4058	4058
N. Quarters	44	44	46	46
N. Obs	15646	19491	185816	185816

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT/LATE of Nutrient Neutrality treatment on nitrogen, phosphate, house completion and house price at the Water Body Catchment (WBC) area across various sample restrictions and specifications. Quarterly water data (nitrogen, phosphorus) sourced from the UK Water Quality Archive; housing completions measured as the number of completed builds in each quarter, derived from Energy Performance Certificates for new buildings; quarterly house prices sourced from the LSE REEF Index, measured as price per square meter. Panel A reproduces the ATT of Nutrient Neutrality treatment on main results at the Water Body Catchment (WBC) area using quarterly data. Panel B restricts the former to only non-coastal WBCs. Panel C restricts the sample to only non-urban WBCs. Panel D restricts the sample to only control group WBCs that intersect with a Special Protection Area (SPA). Panel E restricts the sample to only WBCs that intersect with a SPA in both treatment and control. Panel F provides the LATE of Nutrient Neutrality treatment on main outcomes using a two-way fixed effects specification. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. All standard errors clustered at the WMC-level.

Third, to make treatment and control areas even more like-for-like than by restricting to only rural locations, we also estimate our main specification only for control group WBCs contained in special protected areas (Panel D in Table 2).

Fourth, and directly related, Panel E in Table 2 restricts both treatment and control groups to WBCs that contain special protected areas.¹⁶

Restricting the control group (Panel D) or the both treatment and control groups (Panel E) to WBCs that contain special protected areas narrows the comparison to locations that share the ecological characteristics that motivated Nutrient Neutrality designations, further reducing scope for unobserved differences in amenity appeal or land use composition to confound our estimates. The fact that our results are qualitatively and quantitatively robust, and actually of substantially larger magnitude and more precisely estimated despite the much smaller sample (approximately half of the rural-only sample) is reassuring. It also suggests that differential exposure to the pandemic-era reallocation of demand does not appear to be driving our findings.

Finally, Panel F in Table 2 reports results from estimating a standard two-way fixed effects regression (i.e., Equation 1): results are again qualitatively unchanged, and quantitatively comparable for house completion and price, whereas the treatment effect on nitrogen is depressed and not significant at conventional levels (p-value .22). As previously discussed, the staggered fashion of treatment across multiple periods should be expected to bias two-way fixed effects estimates. In fact, nitrogen, housing completion and price all seem to be biased towards zero, with the most unbalanced sample (nitrogen) producing the starkest difference to our doubly-robust dynamic difference-in-differences estimate.

Overall, our results are remarkable stable: effects remain qualitatively unchanged and quantitatively very close to our main results across samples and specifications.

To avoid selective reporting of environmental outcomes and sampling metrics, we produce four event study graphs each for the ten environmental outcomes in the Online Appendix. This includes the mean, median, minimum and maximum of sample readings for each of nitrogen, phosphorus, nitrate, ammonia, nitrite, orthophosphate, dissolved oxygen, biochemical oxygen demand, pH value and chlorophyll-a (see Appendix Figures A.4-A.13). Results qualitatively and quantitatively confirm the main

¹⁶Nutrient Neutrality guidance was issued to special protected areas in unfavourable condition, but treatment assignment frequently includes non-protected adjacent WBCs that are hydrologically connected.

results derived from the quarterly mean reading of a given pollution measure.

For full transparency on the combination of sample restrictions and various outcome variables, Appendix Tables [A.6-A.17](#) produce results equivalent to the sample restrictions in [Table 2](#) for all outcome variables separately, and further includes robustness exercises to exclude neighbouring WBCs from the control group to prevent potential stable unit treatment value assumption (SUTVA) violations from driving our main result ([Appendix Tables A.6-A.17](#), columns 6-8).¹⁷

While there is no evidence of pre-trends in our main outcomes, there are still signs of seasonality (particularly for phosphorus) that can be detected in our event study graphs, despite including time (quarter) fixed effects (see [Figure 2](#), top right). These artefacts in the data likely originate from different seasonal environmental dynamics across different locations in England. To make sure that such artefacts do not drive our results, we show that our main results are robust to aggregating our data to the semi-annual and annual frequency. [Appendix Table A.3](#) provides results for our main outcomes across quarterly, semi-annual and annual frequencies, whereas [Appendix Tables A.4](#) and [A.5](#) show the same for sub-pollutant and water quality outcomes, respectively.¹⁸ All main results are confirmed, although the reduction in ammonia and the increase in orthophosphate become significant at semi-annual frequency ([Appendix Table A.4](#), Panel B).

To defuse concerns about potential compositional changes driving our housing market results, we also provide additional evidence on housing constructions by type. If developers change the composition of houses that they build (or their floor space) in response to the policy, our estimated reduction in housing construction is prone to misinterpretation. To test for any changes in the composition of houses supplied, we re-estimate our baseline specification with housing completions by type as outcomes. [Table 3](#) provides results for the level (Panel A) and share (Panel B) of detached, semi-detached and terraced houses, as well as the overarching categories of houses and flats. The lack of statistically significant or economically meaningful effects on shares of completions suggests that developers do not adjust the type of newly constructed housing. Regarding construction levels, the decline in construction affects houses much more than flats ([Panel A](#), columns 5 and 6), as would be expected given the

¹⁷In results not shown, we also confirm that partially excluding or fully including the second half of 2023, for which only partial water quality data is available does not materially affect results.

¹⁸Respective event study graphs at annual frequency are provided in [Appendix Figures A.14-A.16](#)

Table 3: Doubly-robust dynamic difference-in-differences: House completion by type

<i>Panel A: House Completion (#) by Type</i>						
	#	#	#	#	#	#
Nutrient Neutrality	-1.83*** (0.51)	-0.42 (0.31)	-0.80*** (0.31)	-0.63 (0.40)	-1.22* (0.74)	-0.62 (1.01)
House Type	Any	Detached	Semi-det.	Terraced	House	Flat
Mean Dep. Var.	9.62	3.74	2.49	2.74	6.79	2.83
N. WBCs	4058	4058	4058	4058	4058	4058
N. Quarters	46	46	46	46	46	46
N. Obs	185816	185816	185816	185816	185816	185816
<i>Panel B: House Completion (%) by Type</i>						
	#	#	#	#	#	#
Nutrient Neutrality	0.02 (0.02)	-0.01 (0.02)	-0.01 (0.02)	-0.01 (0.02)	0.00 (0.06)	-0.00 (0.04)
House Type		Detached	Semi-det.	Terraced	House	Flat
Mean Dep. Var.		0.59	0.22	0.19	0.87	0.13
N. WBCs		3688	3688	3688	3689	3689
N. Quarters		46	46	46	46	46
N. Obs		88787	88787	88787	90554	90554

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Panel A shows the ATT of Nutrient Neutrality treatment on house completion by house type in levels at the Water Body Catchment (WBC) area. Panel B shows the ATT of Nutrient Neutrality treatment on house completion by house type in shares at the Water Body Catchment (WBC) area. House types derived from EPCs issued for new completed buildings. Detached, semi-detached and terraced house types are mutually exclusive. House and flat status are likewise mutually exclusive. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. Standard errors clustered at the WMC-level.

prevailing low density of housing in treated locations.

We also estimate the effect of the policy on total floor space constructed, as well as average and median floorspace per newly constructed property. As Table 4 shows, and in line with the decrease in properties constructed, we find a significant decline of newly provided floorspace of around 180 m² following the introduction of the policy. There is some evidence to suggest that average floor space of properties constructed increases (columns 3-4), but this effect is not statistically significant at conventional levels. At 15 m², it is also economically too small to offset the overall effect on total floor area (column 2). However, it is interesting to note that the results paint

Table 4: Doubly-robust dynamic difference-in-differences: House floor area

	Completion	Floor Area		
	Total #	Total sqm	Mean sqm	Median sqm
Nutrient Neutrality	-1.83*** (0.51)	-180.29*** (54.61)	15.89 (9.96)	15.04 (11.14)
Mean Dep. Var.	9.62	912.60	132.29	126.03
N. WBCs	4058	4058	3689	3689
N. Quarters	46	46	46	46
N. Obs	185816	185816	90554	90554

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on house completions at the Water Body Catchment (WBC) area. Housing builds measured as the number of completed builds in each quarter, measured by the EPCs for new buildings issued. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. Floor area in square metres derived from the EPCs issued for new buildings. Standard errors clustered at the WMC-level.

a coherent picture: the average treated WBC loses 1.83 house completions, with an average new house size (mean total new floor area of 912 m² divided by mean completions of 9.6 buildings) of 94.86 m², we cannot reject that the total decrease in floor area is exactly equal to the mechanical effect of building 1.83 houses less.¹⁹

Finally, given hypothetical concerns about hydrological spillovers of treatment into neighbouring water body catchments, we test robustness of our main results to varying the level at which standard errors are clustered. Our main results retain statistical significance at conventional levels when clustered at the next larger-than-treatment unit of water catchment and at next, smaller-than-treatment level. Even when clustering at the smallest unit, the water body catchment area, results retain significance, although standard errors are smallest, by far, when clustering at the smaller-than-treatment level of water operational catchment areas.²⁰

¹⁹Note that any disproportionate decline in total floor area could either be driven by developers strategically changing property sizes, or by smaller developments being disproportionately driven out of treated locations, e.g., because the extra cost from offsets constitutes a larger share of the cost of housing construction. In either case, we fail to find evidence supporting such a mechanism.

²⁰It is also important to note that standard errors across housing and environmental outcomes react differently with respect to the level of clustering. Results are available upon request.

4.3 Leakage

Nutrient Neutrality increases the cost of building new residential properties in treated locations. This gives neighbouring but untreated locations a cost advantage and generates an economic incentive for developers to move construction across the policy boundary. To estimate the leakage affect across locations for both polluters and pollution we re-estimate Equation 2 replacing originally treated locations with their direct neighbours. Neighbours are defined as untreated WBCs that fall within a set radius of a given treated WBC. We vary this radius and present results for neighbours that are located within five, ten and twenty kilometres. This placebo treatment specification, where neighbours are now considered treated (and originally treated WBCs deleted from the sample), can be estimated across a wide array of environmental and economic outcome variables. However, since Nutrient Neutrality explicitly targeted housing, and nitrogen appears to be the only pollutant that improves in treatment locations, it seems natural to investigate the spatial displacement of, in particular, housing construction and nitrogen pollution to neighbouring (untreated) locations.

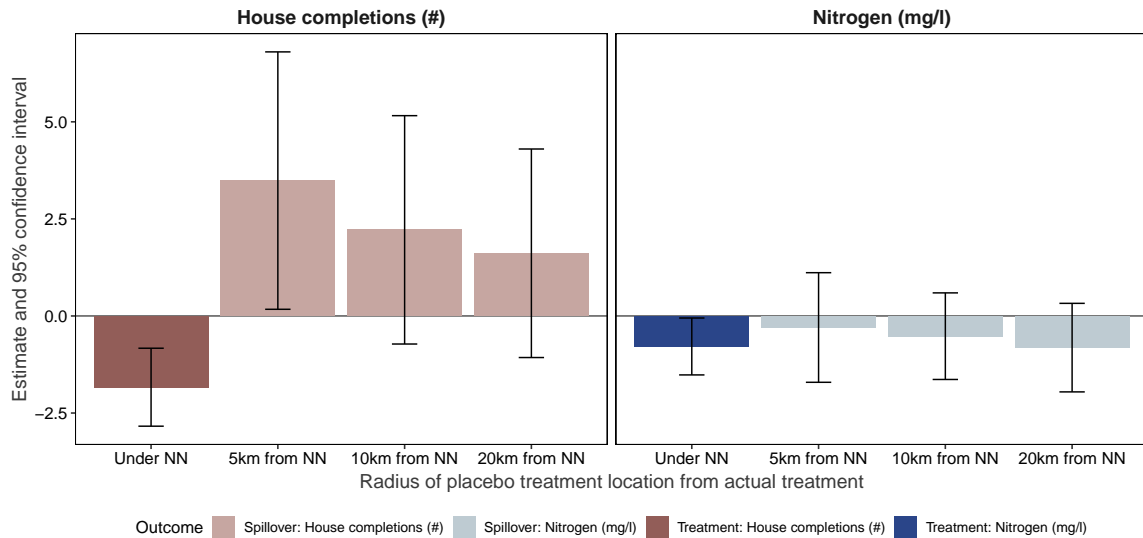


Figure 4: Spillovers of Nutrient Neutrality (NN) treatment to neighbouring locations

This figure displays the average treatment effect on the treated on house completions and mean nitrogen readings based on Equation 2. Different bars indicate different locations defined as treatment (from left to right): WBC affected by the policy, WBCs within a 5 km radius of treated locations, WBCs within a 10km radius of treated locations, and WBCs within 20 km of a treated location, where the latter three exclude the treated WBCs from the sample.

When studying the spatial displacement of polluters we find that housing com-

pletions in neighbouring untreated WBCs increase up to a radius of five kilometre distance around the treated WBCs (see Figure 4).²¹ Quantitatively, we cannot reject a one-for-one displacement of housing construction from locations treated by the policy to adjacent, neighbouring WBCs. This finding suggests that the policy failed to reduce the overall amount of local housing construction. Curiously, despite their increase in housing construction, neighbouring locations do not experience any increases in nitrogen, as the right hand side of Figure 4 shows. Put differently, while the supposed polluter, residential houses and their wastewater, gets displaced, we cannot detect any analogous displacement of nutrient pollution to these locations. If a reduction in housing completions were to decrease nitrogen levels (as documented in Figure 2) in a causal fashion one would expect an increase in nitrogen pollution from the increase in housing completions in neighbouring locations. The evident lack of such a pollution response in untreated neighbouring locations provides evidence that observed decreases in nitrogen (in treated locations) may in fact not be driven by reductions in housing completions.

5 Mechanism

The results in Section 4.3 cast doubt on a causal link from reduced housing construction to lower nitrogen pollution. If the policy’s intended mechanism (restricting new residential development to curb wastewater-related nutrient emissions) was operating, we would expect the displacement of housing to neighbouring locations to be accompanied by an increase in nitrogen pollution in these locations. The absence of such a pollution response suggests that the observed nitrogen reductions in treated areas are driven by factors beyond the mere reduction in the number of houses being built. Instead, in this section we explore two potential mechanisms that can rationalise the estimated effects of Nutrient Neutrality policy: the implementation of offset programs by Local Planning Authorities (LPAs), and the role of (future) wastewater treatment plant (WWTP) improvements.

²¹While Figure 4 displays the aggregate dynamic ATT for neighbours within three different radii from treated WBCs, Appendix Figures A.1 and A.2 display the corresponding event studies for the five kilometre radius, highlighting that there are no relevant pre-trends in the outcomes when estimating these placebo treatment effects for untreated neighbours.

5.1 Offset schemes

To shed light on the role of offset schemes and programs, we leverage heterogeneity in how local planning authorities (LPAs) implement Nutrient Neutrality guidance. This information has not been previously compiled in a systematic fashion. Hence, codifying each treated LPA’s response to the policy in terms of their implementation of offset schemes represents a novel contribution of our paper. As discussed in Section 2, Natural England provided very limited guidance on how developers could make new residential construction nutrient-neutral. LPAs responded to this absence of guidance in different ways: some LPAs established their own off-site offset schemes, some facilitated private nutrient credit trading platforms, and others provided no support at all. These differences generate meaningful variation across locations in the cost and feasibility of continued housing construction under the policy. We exploit this variation in LPAs’ responses to the policy for heterogeneity analysis of our main results below.

Intuitively, developers face the highest cost and barriers to making their developments nutrient-neutral in locations without any offset programs: in order to continue constructing new residential buildings, they need to independently identify suitable instruments to compensate for or reduce their construction project’s nutrient emissions. This could, for example, involve finding and negotiating with a willing landowner to convert some of their land, or acquiring and converting land themselves.²² Therefore, the largest contraction in housing construction would be expected in exactly the locations without offset schemes being offered. However, if nitrogen reductions are indeed driven by offset activities rather than by reductions in house construction itself, we would also expect the most limited environmental improvements precisely where no offset scheme exists.

To test for this potential mechanism, we re-estimate our main dynamic difference-in-differences specification (Equation 2) separately by locations’ offset scheme status. Table 5 reports results for housing completions and nitrogen levels. While column 1 reproduces our earlier main results on housing completion (Panel A) and nitrogen (Panel B) for reference, column 2 restricts the sample to only those treated WBCs for which the responsible LPA operates any offset scheme (‘Any’). Column 3 in turn restricts the sample to only those treated WBCs for which the responsible LPA did not

²²Initial reactions from the building industry provided suggestions for costly pollution abatement including on-site investments to neutralise nutrient emissions, such as septic tanks.

Table 5: Nutrient offset schemes in doubly-robust dynamic diff-in-diff: House completion vs N

<i>Panel A: House Completion</i>					
	#	#	#	#	#
Nutrient Neutrality	-1.59*** (0.31)	-1.74*** (0.58)	-3.06** (1.26)	-1.36** (0.54)	-2.71** (1.24)
Offset Scheme	–	Any	None	Credit	Offsite
Mean Dep. Var.	9.62	9.86	9.74	10.00	9.98
N. WBCs	4058	3890	3673	3745	3532
N. Periods	46	46	46	46	46
N. Obs	185816	178517	168541	171934	162403
<i>Panel B: Nitrogen</i>					
	mg/l	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	-0.79** (0.37)	-0.63* (0.37)	-1.24 (1.14)	-0.53* (0.29)	-1.34*** (0.27)
Offset Scheme	–	Any	None	Credit	Offsite
Mean Dep. Var.	4.05	4.16	3.84	4.09	3.95
N. WBCs	1076	1028	966	984	933
N. Periods	44	44	44	44	44
N. Obs	15646	14753	13397	13846	12751

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Panel A shows the ATT of Nutrient Neutrality treatment on house completions at the Water Body Catchment (WBC) area. Housing completions measured as the number of completed builds in each quarter, measured by the Energy Performance Certificates for new buildings issued. Panel B shows the ATT of Nutrient Neutrality treatment on nitrogen at the Water Body Catchment (WBC) area. Semi-annual water data sourced from the UK Water Quality Archive. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. Standard errors clustered at the WMC-level.

implement offset schemes ('None'). Columns 4 and 5 then split the sample with any offset scheme from column 2 further into those with a credit offset scheme ('Credit') and those with an offsite offset scheme ('Offsite').

Two patterns stand out from this heterogeneity analysis: first, locations without any offset program experience the largest decline in housing completions (Panel A, column 3), yet show no significant reduction in nitrogen pollution (Panel B, column 3). Second, locations with credit-based or off-site offset schemes experience significant nitrogen reductions (Panel B, columns 4 and 5), with off-site schemes showing the

largest effect. These are precisely the locations where local authorities and developers actively invest in nutrient mitigation measures to enable continued construction. That nitrogen falls most where offset activity is greatest, rather than where construction falls most, provides further evidence that offset investments, and not reductions in housing, drive the observed environmental improvements.

Taken together, these results point to an alternative interpretation of the policy’s mechanism. Rather than reducing pollution by restricting its supposed source (residential wastewater), Nutrient Neutrality appears to improve water pollution by creating strong incentives for local authorities and developers to invest in nutrient mitigation. The threat of *de facto* construction bans motivates costly abatement activities that go beyond neutralising the marginal nutrient burden of new housing – effectively over-offsetting expected emissions. While this achieves genuine environmental benefits, it does so at the cost of violating the polluter pays principle: housing developers and future residents bear the burden of reducing pollution that appears predominantly attributable to agriculture.

What drives LPAs to adopt different offset strategies? Table 6 presents pre-treatment characteristics of treated locations by offset scheme implementation. In Panel A we show that locations with any form of offset scheme are significantly larger in terms of housing completions, total floor area, and are more urban than those without. This pattern is consistent with selection into offset schemes driven by local state capacity and market size. Accordingly, in Panel B we highlight that smaller LPAs with limited administrative resources and thin local housing markets are less likely to establish formal offset credit programs, as the fixed costs of designing and managing such schemes could not be justified by the volume of development at stake. In contrast, the largest and more urbanised treated LPAs appear to have both the institutional capacity and the market depth to support nutrient credit trading platforms, which require sufficient numbers of buyers (developers) and sellers (landowners willing to convert land use) to function effectively. Finally, in Panel C we confirm that council-run offsite schemes occupy a middle ground, requiring less market thickness but greater direct LPA involvement in sourcing and verifying offset measures. These differences in LPA characteristics suggest that the availability of offset schemes may reflect underlying variation in local state capacity across treated locations. This highlights the importance of designing environmental policies, such as Nutrient Neutrality, in ways so that they can actually be implemented effectively at the local level.

Table 6: Housing market characteristics across locations with different offset schemes

<i>Panel A: Any offset vs. no offset ($N_{\text{off}} = 381, N_{\text{no}} = 164$)</i>					
	Offset	No offset	Difference	SE	<i>p</i> -value
Completions (quarterly mean)	7.22	2.87	4.35	1.02	0.000
Completions: houses	4.96	2.00	2.96	0.63	0.000
Completions: flats	2.26	0.87	1.40	0.51	0.007
Completions: detached	2.17	0.83	1.34	0.26	0.000
Completions: semi-detached	1.52	0.58	0.94	0.21	0.000
Completions: terraced	2.41	1.00	1.41	0.39	0.000
Total floor area (sqm)	657	271	386	85.20	0.000
Price per sqm (GBP)	2,287	2,366	-79.28	62.75	0.207
Urban share	0.24	0.11	0.13	0.03	0.000
<i>Panel B: Credit only vs. no offset ($N_{\text{credit}} = 236, N_{\text{no}} = 164$)</i>					
	Credit	No offset	Difference	SE	<i>p</i> -value
Completions (quarterly mean)	8.25	2.87	5.38	1.31	0.000
Completions: houses	5.48	2.00	3.48	0.78	0.000
Completions: flats	2.77	0.87	1.90	0.71	0.008
Completions: detached	2.42	0.83	1.60	0.33	0.000
Completions: semi-detached	1.75	0.58	1.18	0.27	0.000
Completions: terraced	2.75	1.00	1.74	0.52	0.001
Total floor area (sqm)	739	271	468	107	0.000
Price per sqm (GBP)	2,194	2,366	-172	71.30	0.017
Urban share	0.29	0.11	0.17	0.03	0.000
<i>Panel C: Offsite only vs. no offset ($N_{\text{offsite}} = 23, N_{\text{no}} = 164$)</i>					
	Offsite	No offset	Difference	SE	<i>p</i> -value
Completions (quarterly mean)	6.02	2.87	3.15	2.96	0.299
Completions: houses	2.96	2.00	0.96	1.26	0.454
Completions: flats	3.05	0.87	2.19	1.77	0.230
Completions: detached	2.15	0.83	1.32	1.02	0.206
Completions: semi-detached	1.02	0.58	0.45	0.53	0.406
Completions: terraced	1.74	1.00	0.73	0.86	0.403
Total floor area (sqm)	597	271	326	304	0.294
Price per sqm (GBP)	2,834	2,366	468	77.80	0.000
Urban share	0.17	0.11	0.06	0.07	0.414

Notes: Sample restricted to treated WBCs only. Pre-treatment WBC-level means (before 2017 Q2). Difference = Offset – No offset. *p*-values from Welch’s *t*-test. Panel A compares all treated WBCs with any offset scheme against those without. Panels B and C decompose by offset type: credit-based schemes only (B) and offsite mitigation only (C).

5.2 Wastewater treatment plant improvements

As discussed in Section 2, as part of the on-going efforts to achieve water quality improvements in designated sites, the UK government mandated all wastewater treatment plants (WWTP) that interact with designated sites under Nutrient Neutrality guidance to upgrade their nutrient removal efficiency by 2030. While none of these improvements have been successfully implemented during our sample period, we would not expect these future WWTP upgrades to have any discernible environmental effects. However, the anticipated improvements in nutrient discharge from WWTPs into water bodies reduce the amount of nutrients that developers need to offset over the lifetime of their housing developments, and should have an effect on contemporaneous housing construction already. To test these predictions, we run our baseline ATT specification separately for treated locations with and without wastewater treatment plant upgrade potential, where among treated WBCs, upgrade potential is defined as an indicator if the relevant LPA announced a future WWTP upgrade or not. Table 7 shows the results of this heterogeneity analysis.

Table 7: Wastewater treatment plant upgrade potential in doubly-robust dynamic diff-in-diff: House completion vs N

	House Completion			Nitrogen		
	#	#	#	mg/l	mg/l	mg/l
Nutrient Neutrality	-1.59*** (0.31)	-1.75*** (0.60)	-3.07** (1.26)	-0.79** (0.37)	-0.25 (0.62)	-1.19 (0.77)
WWTP Potential	–	Yes	No	–	Yes	No
Mean Dep. Var.	9.62	9.68	9.93	4.05	4.09	3.91
N. WBCs	4058	3887	3678	1076	980	1018
N. Periods	46	46	46	44	44	44
N. Obs	185816	178388	168756	15646	13932	14325

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on house completions at the Water Body Catchment (WBC) area. Housing completions measured as the number of completed builds in each quarter, measured by the Energy Performance Certificates for new buildings issued. Quarterly water data sourced from the UK Water Quality Archive. “WWTP Potential” denotes WBCs for which the Local Planning Authority (LPA) announced future wastewater treatment plant (WWTP) upgrades. Future WWTP upgrades enable LPAs to lower present offset requirements for new residential nutrient pollution. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. Standard errors clustered at the WMC-level.

In line with the predicted reduction in necessary offset requirements per housing unit due to future WWTP upgrades, we can confirm that housing completions decrease much more in locations that do not have WWTP improvement plans in place, and decrease less in locations with such WWTP improvement plans. Given these differential changes in construction, it is *a priori* ambiguous whether one should expect total offset of nutrient pollution to increase relatively (i.e., nutrient pollution to decrease by more) in locations with potential WWTP improvements or in locations without. The former, locations experience relatively more housing construction, but less offset per unit constructed, whereas the latter experience relatively less housing construction, but more offset per unit constructed. Empirically, we cannot find any statistically significant improvements in nitrogen pollution in either sub-group among the treated locations, although noisy estimates hint at potentially larger nitrogen improvements in treated locations without WWTP upgrade potential.

We leave a more thorough analysis of the interaction between wastewater treatment plant upgrades, local nutrient pollution and the housing market for future work, especially once the first plant upgrades should have been realised across water body catchment areas in England around 2030.

6 Conclusion

Restoring valuable natural capital such as clean water is costly and involves inherent trade-offs. We study a recent environmental policy designed to improve water quality in England, called Nutrient Neutrality, that takes a novel approach by regulating residential housing construction rather than directly targeting the dominant sources of nutrient pollution. We show that the policy reduces nitrogen pollution by 19.5%, but these environmental gains come at substantial economic cost: housing completions fall by 17.7% in treated areas and house prices increase by 2.3%. The incomplete spatial coverage of the regulation gives rise to significant leakage in polluters: housing completions are displaced almost one-for-one to neighbouring untreated locations. Crucially, however, we fail to detect any accompanying leakage in pollution: nitrogen in neighbouring untreated locations remains unaffected. This asymmetry between leakage in polluters and the absence of leakage in pollution casts doubt on the core premise of the policy's design: that restricting residential development can meaningfully curb nutrient pollution.

Our analysis of the policy’s mechanism reveals what actually drives the observed environmental improvements. Leveraging heterogeneity in how local planning authorities respond to the policy, we show that nitrogen reductions are concentrated in locations where authorities established offset schemes that channel investment into mitigation measures such as wetland creation and agricultural land conversion. In contrast, locations where no offset scheme is established experience the largest declines in housing construction, but no significant improvement in nitrogen pollution. This pattern demonstrates that the policy’s environmental benefits arise not from restricting housing construction itself, but from the offset investments that the threat of construction bans incentivises. The availability of offset schemes, in turn, reflects local state capacity and market size: smaller, more rural authorities lack the administrative resources to design and manage such schemes, while larger authorities have the institutional capacity and market depth to support nutrient credit markets.

Our findings have several implications for the design of environmental offset policies. First, the effectiveness of such policies depends critically on the availability of well-functioning offset mechanisms. Second, leaving offset scheme design entirely to local discretion, without structured, central guidance, generates large disparities in policy outcomes driven by differences in local capacity rather than differences in environmental need. Third, Nutrient Neutrality policy violates the polluter pays principle: housing developers and future residents bear the cost of reducing nutrient pollution that is overwhelmingly attributable to agriculture, which likely contributes to the significant public opposition to the policy.

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Online Appendix (not for publication)

A.I Additional tables

Table A.1: Rollout of nutrient neutrality policy across designated sites

Water body catchment area	Date	% NN covered	% England covered
Poole Harbour SPA/Ramsar	2017 Q2	0.05	0.01
River Avon SAC	2018 Q1	0.15	0.02
The Solent	2019 Q1	0.34	0.05
River Wye SAC	2019 Q3	0.39	0.05
Stodmarsh SAC/SPA/Ramsar	2019 Q4	0.39	0.05
Somerset Levels & Moors Ramsar	2020 Q3	0.51	0.07
River Camel SAC	2021 Q2	0.52	0.07
Chesil & the Fleet SAC/Ramsar/SPA	2022 Q1	0.53	0.07
Esthwaite Water Ramsar	2022 Q1	0.53	0.07
Hornsea Mere SPA	2022 Q1	0.53	0.07
Lindisfarne SPA/Ramsar	2022 Q1	0.54	0.07
Oak Mere SAC	2022 Q1	0.55	0.07
Peak District Dales SAC	2022 Q1	0.55	0.07
River Axe SAC	2022 Q1	0.57	0.07
River Clun SAC	2022 Q1	0.59	0.08
River Derwent & Bassenthwaite SAC	2022 Q1	0.61	0.08
River Eden SAC	2022 Q1	0.74	0.10
River Kent SAC	2022 Q1	0.75	0.10
River Lambourn SAC	2022 Q1	0.76	0.10
River Mease SAC	2022 Q1	0.77	0.10
Roman Walls Loughs SAC	2022 Q1	0.77	0.10
Rostherne Mere Ramsar	2022 Q1	0.77	0.10
Teesmouth & Cleveland SPA/Ramsar	2022 Q1	0.89	0.12
The Broads SAC	2022 Q1	1.00	0.13
W. Midlands Mosses SAC (Abbotts)	2022 Q1	1.00	0.13
W. Midlands Mosses SAC (Wynbunbury)	2022 Q1	1.00	0.13

Table A.2: Pollution levels across treated and control locations

	Treated	Control	Difference	SE	<i>p</i> -value
<i>Panel A: Full sample</i> ($N_{\text{treat}} = 549$, $N_{\text{ctrl}} = 3564$)					
Nitrogen (mg/l)	4.08	3.47	0.61	0.37	0.099
Phosphorus (mg/l)	0.12	0.24	-0.12	0.02	0.000
Dissolved oxygen (mg/l)	93.66	91.46	2.20	0.40	0.000
BOD (mg/l)	1.66	1.99	-0.33	0.07	0.000
pH	7.91	7.87	0.05	0.01	0.000
Chlorophyll ($\mu\text{g/l}$)	10.50	11.95	-1.46	1.31	0.267
<i>Panel B: Rural only</i> ($N_{\text{treat}} = 417$, $N_{\text{ctrl}} = 2376$)					
Nitrogen (mg/l)	3.97	3.23	0.73	0.43	0.094
Phosphorus (mg/l)	0.10	0.21	-0.10	0.02	0.000
Dissolved oxygen (mg/l)	94.31	92.32	1.99	0.46	0.000
BOD (mg/l)	1.69	1.87	-0.19	0.09	0.049
pH	7.92	7.87	0.05	0.01	0.000
Chlorophyll ($\mu\text{g/l}$)	10.97	12.84	-1.87	1.79	0.298
<i>Panel C: SPA only</i> ($N_{\text{treat}} = 549$, $N_{\text{ctrl}} = 727$)					
Nitrogen (mg/l)	4.08	2.53	1.55	0.43	0.000
Phosphorus (mg/l)	0.12	0.14	-0.02	0.02	0.305
Dissolved oxygen (mg/l)	93.66	92.00	1.66	0.56	0.003
BOD (mg/l)	1.66	1.95	-0.29	0.10	0.004
pH	7.91	7.82	0.10	0.02	0.000
Chlorophyll ($\mu\text{g/l}$)	10.50	14.85	-4.35	2.10	0.039

Notes: Pre-treatment WBC-level means (2010 Q1 – 2017 Q1). Difference = Treated – Control. *p*-values from Welch’s *t*-test. Panel A includes all WBCs. Panel B restricts to rural WBCs (urban share $\leq 50\%$). Panel C compares all treated WBCs against untreated WBCs that contain a Special Protection Area (SPA).

Table A.3: Doubly-robust dynamic diff-in-diff: Main results across panel frequencies

<i>Panel A: Quarterly</i>				
	Nitrogen	Phosphorus	Housing Completion	House Price
	mg/l	mg/l	# of houses	£/m ²
Nutrient Neutrality	-0.79** (0.37)	-0.01 (0.05)	-1.59*** (0.31)	61.06*** (12.70)
N. Periods	44	44	46	46
N. Obs	15646	19491	185816	185816
<i>Panel B: Semi-annual</i>				
Nutrient Neutrality	-0.71** (0.30)	0.03 (0.04)	-2.74*** (0.87)	54.33*** (11.77)
N. Periods	23	23	23	23
N. Obs	8310	10507	92766	92766
<i>Panel C: Annual</i>				
Nutrient Neutrality	-0.75* (0.38)	0.01 (0.03)	-5.83*** (2.03)	48.40*** (14.29)
Mean Dep. Var.	4.12	0.17	38.29	2699.49
N. WBCs	1083	1406	4058	4058
N. Periods	12	12	12	12
N. Obs	4762	6006	48412	48412

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on nitrogen, phosphate, house completion and house price at the Water Body Catchment (WBC) area across data aggregated at different temporal frequencies. All data are originally available at quarterly level: quarterly water data sourced from the UK Water Quality Archive; housing completions measured as the number of completed builds in each quarter, measured by the Energy Performance Certificates for new buildings issued; quarterly house prices sourced from the LSE REEF Index, measured as price per square meter. Panel A shows the ATT of Nutrient Neutrality treatment on main results at the Water Body Catchment (WBC) area using quarterly data. Panel B shows the same when data aggregated to semi-annual level. Panel C shows the same when data aggregated to annual level. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. Standard errors clustered at the WMC-level.

Table A.4: Doubly-robust dynamic diff-in-diff: Other nutrients across panel frequencies

<i>Panel A: Quarterly</i>				
	Nitrate	Ammonia	Nitrite	Orthophosphate
	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	0.34 (0.50)	-0.01 (0.02)	-0.00 (0.00)	0.04 (0.04)
N. Periods	44	44	44	44
N. Obs	99271	100224	100724	98144
<i>Panel B: Semi-annual</i>				
Nutrient Neutrality	-0.04 (0.35)	-0.03* (0.01)	-0.00 (0.00)	0.05* (0.03)
N. Periods	23	23	23	23
N. Obs	54064	54565	54765	53484
<i>Panel C: Annual</i>				
Nutrient Neutrality	0.10 (0.39)	-0.01 (0.01)	-0.00 (0.00)	0.02 (0.02)
Mean Dep. Var.	5.05	0.13	0.03	0.20
N. WBCs	3678	3686	3684	3679
N. Periods	12	12	12	12
N. Obs	30244	30525	30597	30004

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on nitrate, ammonia, nitrite and orthophosphate at the Water Body Catchment (WBC) area across data aggregated at different temporal frequencies. All data are originally available at quarterly level: quarterly water data sourced from the UK Water Quality Archive; housing completions measured as the number of completed builds in each quarter, measured by the Energy Performance Certificates for new buildings issued; quarterly house prices sourced from the LSE REEF Index, measured as price per square meter. Panel A shows the ATT of Nutrient Neutrality treatment on other nutrient pollution results at the Water Body Catchment (WBC) area using quarterly data. Panel B shows the same when data aggregated to semi-annual level. Panel C shows the same when data aggregated to annual level. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. Standard errors clustered at the WMC-level.

Table A.5: Doubly-robust dynamic diff-in-diff: Water quality across panel frequencies

<i>Panel A: Quarterly</i>				
	Dissolved Oxy.	Bioch. Oxy. Demand	pH	Chlorophyll
	% sat.	mg/l	pH scale	mg/l
Nutrient Neutrality	1.34 (1.54)	-0.46 (0.79)	-0.01 (0.03)	-4.11 (3.08)
N. Periods	45	44	45	45
N. Obs	102010	17012	104806	20012
<i>Panel B: Semi-annual</i>				
Nutrient Neutrality	-0.17 (1.43)	-0.54 (0.44)	-0.04 (0.03)	-2.74 (2.92)
N. Periods	23	23	23	23
N. Obs	55706	10304	56889	10763
<i>Panel C: Annual</i>				
Nutrient Neutrality	-0.15 (0.92)	-0.02 (0.39)	-0.02 (0.04)	-1.73 (1.95)
Mean Dep. Var.	92.02	2.04	7.88	9.98
N. WBCs	3776	1879	3759	934
N. Periods	12	12	12	12
N. Obs	31158	6262	31690	6031

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on dissolved oxygen, biochemical oxygen demand, pH value and chlorophyll-a at the Water Body Catchment (WBC) area across data aggregated at different temporal frequencies. All water quality data are originally available at quarterly level, sourced from the UK Water Quality Archive. Panel A shows the ATT of Nutrient Neutrality treatment on water quality results at the Water Body Catchment (WBC) area using quarterly data. Panel B shows the same when data aggregated to semi-annual level. Panel C shows the same when data aggregated to annual level. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. Standard errors clustered at the WMC-level.

Table A.6: Doubly-robust dynamic difference-in-differences: House completion

	House Completion							
	#	#	#	#	#	#	#	#
Nutrient Neutrality	-1.83*** (0.51)	-1.83*** (0.51)	-1.39** (0.68)	-2.26*** (0.78)	-3.61*** (1.11)	-1.62*** (0.52)	-1.84*** (0.52)	-1.86*** (0.59)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	9.62	9.62	2.96	8.82	9.88	10.23	10.39	10.20
N. WBCs	4058	4058	2792	1267	897	3375	3039	2419
N. Quarters	46	46	46	46	46	46	46	46
N. Obs	185816	185816	127736	57430	41004	154398	138942	110422

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on house completions at the Water Body Catchment (WBC) area. Housing builds measured as the number of completed builds in each quarter, measured by the EPCs for new buildings issued. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.7: Doubly-robust dynamic difference-in-differences: House price

	House Price							
	£/m ²	£/m ²	£/m ²	£/m ²	£/m ²	£/m ²	£/m ²	£/m ²
Nutrient Neutrality	61.06*** (12.70)	61.06*** (9.61)	49.86*** (15.55)	80.81*** (16.15)	109.44*** (14.65)	63.21*** (10.07)	63.07*** (9.72)	66.76*** (10.45)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	2666.59	2666.59	2708.14	2602.26	2583.89	2665.78	2671.67	2692.44
N. WBCs	4058	4058	2792	1267	897	3375	3039	2419
N. Quarters	46	46	46	46	46	46	46	46
N. Obs	185816	185816	127736	57430	41004	154398	138942	110422

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on house prices at the Water Body Catchment (WBC) area. House prices sourced from the LSE REEF Index, measured as price per square meter. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.8: Doubly-robust dynamic difference-in-differences: Nitrogen

	Nitrogen							
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	-0.79** (0.37)	-0.79** (0.39)	-0.42 (0.37)	-1.08** (0.47)	-1.23*** (0.35)	-0.86** (0.38)	-0.88** (0.40)	-1.01** (0.43)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	4.05	4.05	3.92	3.74	3.23	4.27	4.35	4.47
N. WBCs	1076	1076	723	321	210	871	793	635
N. Quarters	44	44	44	44	44	44	44	44
N. Obs	15646	15646	10414	5965	3923	12593	11477	9284

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.9: Doubly-robust dynamic difference-in-differences: Phosphorus

	Phosphorus							
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	-0.01 (0.05)	-0.01 (0.05)	-0.00 (0.03)	-0.06 (0.04)	-0.07 (0.05)	-0.01 (0.04)	-0.02 (0.04)	-0.02 (0.04)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	0.18	0.18	0.15	0.12	0.13	0.19	0.19	0.19
N. WBCs	1402	1402	984	441	308	1128	1009	811
N. Quarters	44	44	44	44	44	44	44	44
N. Obs	19491	19491	12882	6989	4677	15684	14150	11444

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.10: Doubly-robust dynamic difference-in-differences: Nitrate

	Nitrate							
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	0.34 (0.50)	0.34 (0.42)	0.33 (0.55)	0.07 (0.56)	0.02 (0.50)	0.37 (0.40)	0.37 (0.37)	0.37 (0.39)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	5.01	5.02	4.81	4.06	3.84	5.18	5.25	5.37
N. WBCs	3677	3672	2561	1063	718	3063	2753	2199
N. Quarters	44	44	44	44	44	44	44	44
N. Obs	99271	99168	67322	29061	19262	82600	74379	59627

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.11: Doubly-robust dynamic difference-in-differences: Ammonia

	Ammonia							
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	-0.01 (0.02)	-0.01 (0.01)	-0.01 (0.01)	-0.03 (0.13)	-0.04 (0.08)	-0.02 (0.01)	-0.02 (0.01)	-0.02 (0.01)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	0.13	0.13	0.10	0.12	0.13	0.13	0.13	0.13
N. WBCs	3685	3679	2560	1070	724	3071	2762	2208
N. Quarters	44	44	44	44	44	44	44	44
N. Obs	100224	100113	67896	29151	19333	83375	75112	60272

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.12: Doubly-robust dynamic difference-in-differences: Nitrite

	Nitrite							
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.01)	-0.01 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	0.04	0.04	0.03	0.03	0.03	0.04	0.04	0.04
N. WBCs	3683	3677	2562	1067	722	3069	2758	2203
N. Quarters	44	44	44	44	44	44	44	44
N. Obs	100724	100613	68310	29376	19512	83745	75381	60441

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.13: Doubly-robust dynamic difference-in-differences: Orthophosphate

	Orthophosphate							
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	0.04 (0.04)	0.04 (0.04)	0.02 (0.04)	0.00 (0.07)	0.02 (0.05)	0.05 (0.04)	0.05 (0.04)	0.05 (0.04)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	0.21	0.21	0.19	0.15	0.15	0.22	0.22	0.22
N. WBCs	3678	3673	2558	1065	720	3064	2756	2202
N. Quarters	44	44	44	44	44	44	44	44
N. Obs	98144	98041	66585	28813	19052	81656	73588	59050

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.14: Doubly-robust dynamic difference-in-differences: Dissolved Oxygen

	Dissolved Oxygen							
	% sat.	% sat.	% sat.	% sat.	% sat.	% sat.	% sat.	% sat.
Nutrient Neutrality	1.34 (1.54)	1.38 (1.59)	1.60 (1.43)	1.14 (1.07)	-0.09 (1.43)	1.19 (1.41)	1.24 (1.42)	0.98 (1.25)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	91.87	91.85	92.53	93.21	92.62	91.68	91.68	91.91
N. WBCs	3775	3745	2582	1142	797	3144	2831	2265
N. Quarters	45	45	45	45	45	45	45	45
N. Obs	102010	101591	67905	31133	21341	84821	76526	61443

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.15: Doubly-robust dynamic difference-in-differences: Biochemical Oxygen Demand

	Biochemical Oxygen Demand							
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	-0.46 (0.79)	-0.46 (0.81)	0.02 (1.42)	-0.56* (0.33)	0.49* (0.28)	-0.41 (0.74)	-0.38 (0.68)	-0.22 (0.63)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	2.04	2.04	1.89	1.93	2.07	2.05	2.06	2.03
N. WBCs	1784	1783	1102	466	307	1506	1368	1100
N. Quarters	44	44	44	44	44	44	44	44
N. Obs	17012	17011	9049	4281	3053	14481	13226	10496

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.16: Doubly-robust dynamic difference-in-differences: pH

	pH							
	pH	pH	pH	pH	pH	pH	pH	pH
Nutrient Neutrality	-0.01 (0.03)	-0.01 (0.03)	-0.01 (0.04)	-0.02 (0.03)	-0.05* (0.03)	-0.01 (0.03)	-0.01 (0.03)	-0.01 (0.03)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	7.88	7.88	7.88	7.88	7.85	7.88	7.88	7.89
N. WBCs	3758	3735	2578	1125	779	3131	2818	2252
N. Quarters	45	45	45	45	45	45	45	45
N. Obs	104806	104619	70326	31124	21044	87022	78390	62850

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.17: Doubly-robust dynamic difference-in-differences: Chlorophyll

	Chlorophyll							
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	-4.11 (3.08)	-4.15 (3.00)	-3.88 (3.27)	-3.46 (2.11)	3.01* (1.63)	-4.48* (2.71)	-4.50* (2.66)	-4.09 (2.52)
No Coastal		✓						
No Urban			✓					
SPAs only (Control)				✓				
SPAs only					✓			
Neighbour Exclusion						5km	10km	20km
Mean Dep. Var.	10.45	10.51	10.54	9.87	10.26	10.50	10.40	10.36
N. WBCs	932	914	499	338	246	775	706	577
N. Quarters	45	45	44	45	45	45	45	45
N. Obs	20012	19832	10705	7788	5834	16449	14981	12230

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on water quality at the Water Body Catchment (WBC) area. Water data sourced from the UK Water Quality Archive. All samples exclude Q3/Q4 2023 and London. “No Coastal” excludes all coastal WBCs from sample. “No Urban” excludes all urban WBCs from sample. “SPAs only (Control)” excludes any control WBCs from sample that do not intersect with a Special Protection Area (SPA). “SPAs only” excludes any WBCs from sample that do not intersect with a SPA. “Neighbour Exclusion” removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WMC-level.

Table A.18: Spillovers in doubly-robust dynamic diff-in-diff: House completion vs N

	House Completion				Nitrogen			
	#	#	#	#	mg/l	mg/l	mg/l	mg/l
Nutrient Neutrality	-1.59*** (0.31)	3.49** (1.69)	2.22 (1.50)	1.61 (1.37)	-0.79** (0.37)	-0.30 (0.76)	-0.52 (0.53)	-0.82 (0.53)
Placebo Radius	-	5km	10km	20km	-	5km	10km	20km
Mean Dep. Var.	9.62	10.00	10.00	10.00	4.05	3.94	3.94	3.94
N. WBCs	4058	3509	3509	3509	1076	922	922	922
N. Periods	46	46	46	46	44	44	44	44
N. Obs	185816	161414	161414	161414	15646	12611	12611	12611

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on house completions and nitrogen at the Water Body Catchment (WBC) area. Housing completions measured as the number of completed builds in each quarter, measured by the Energy Performance Certificates for new buildings issued. Quarterly water data sourced from the UK Water Quality Archive. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023 and London. "Placebo Radius" reassigns treatment status to the WBCs neighbouring treated WBCs (and removes actually treated ones), where the radius of being a "neighbour" varies.

A.II Additional figures

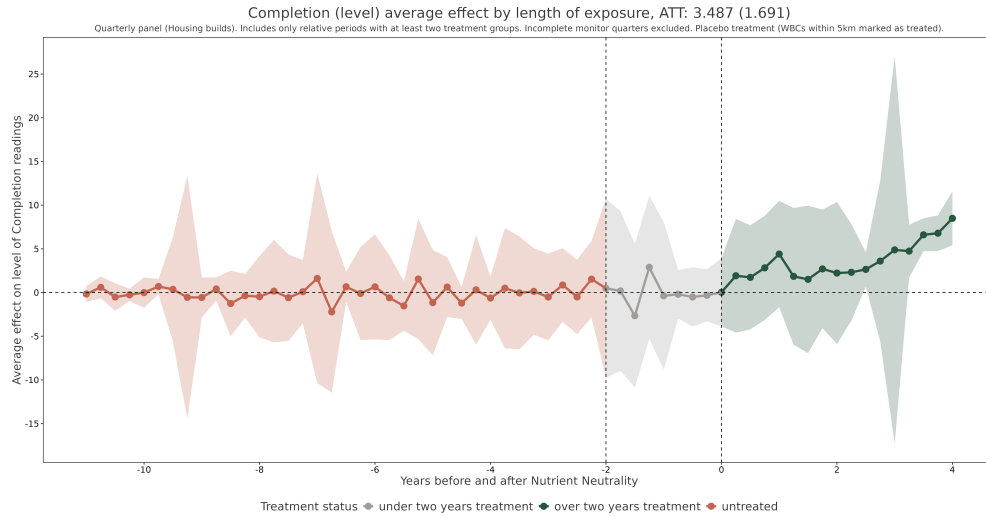


Figure A.1: Event study of housing completions in 5km neighbours of locations under Nutrient Neutrality treatment

This figure displays average treatment effects on the treated of issuance of 'Nutrient Neutrality' guidance on housing completions in WBCs within 5 km of the actually treated locations based Equation 2.

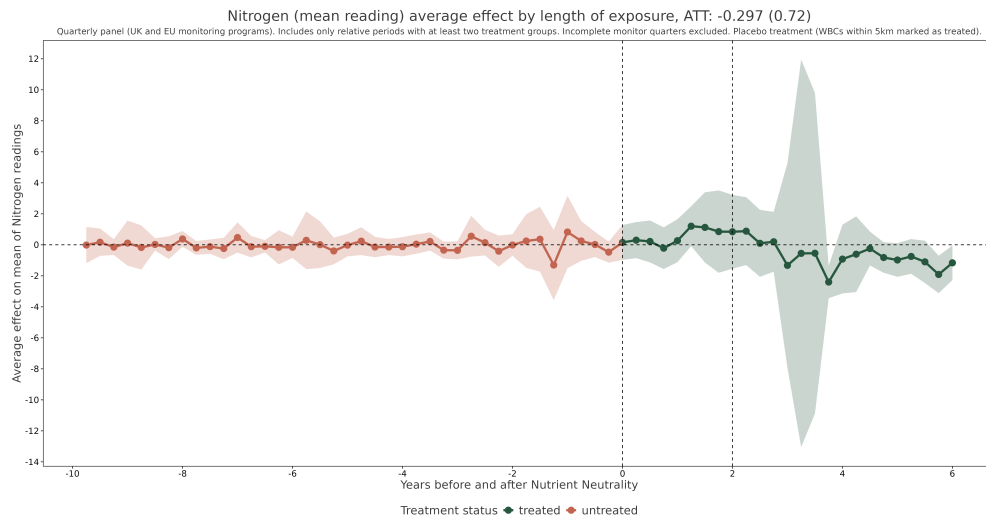


Figure A.2: Event study of nitrogen in 5km neighbours of locations under Nutrient Neutrality treatment

This figure displays average treatment effects on the treated of issuance of 'Nutrient Neutrality' guidance on nitrogen pollution in WBCs within 5 km of the actually treated locations based Equation 2.

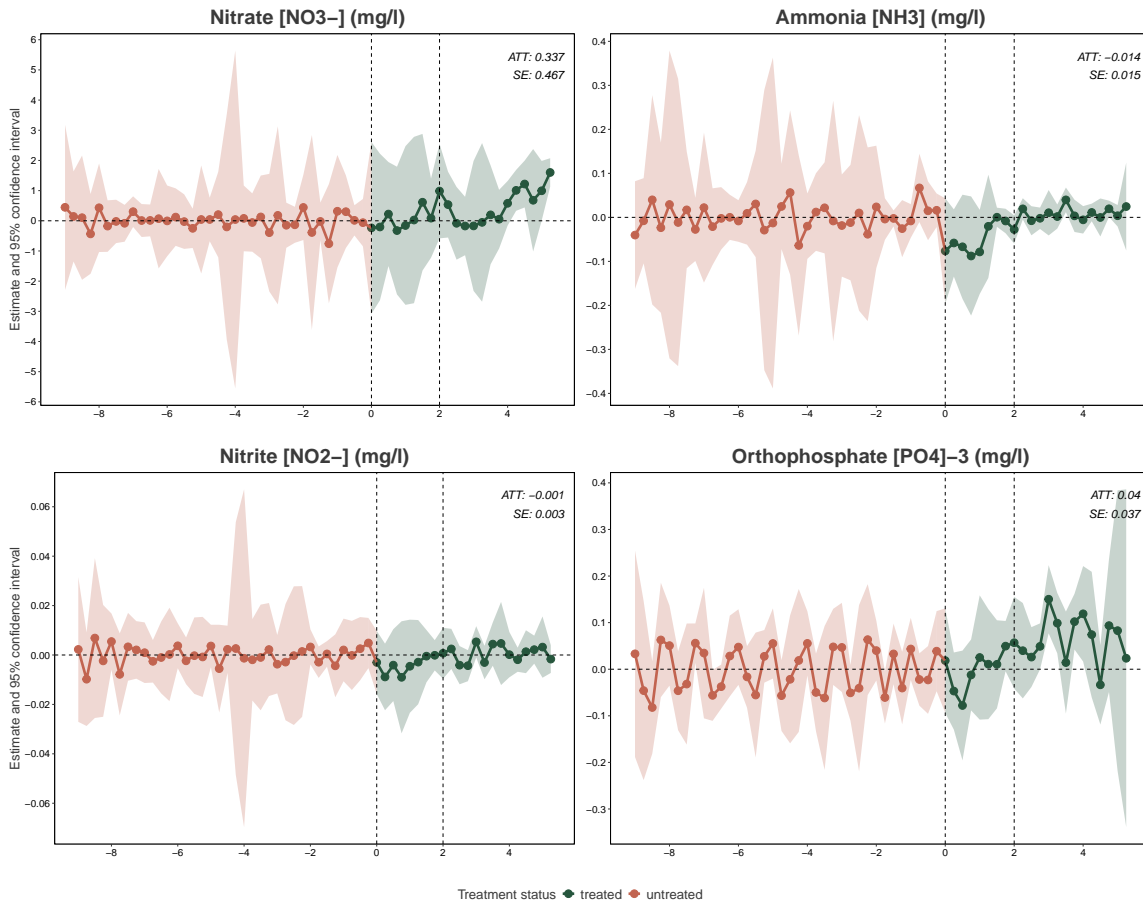


Figure A.3: Event studies of sub-pollutant outcomes on Nutrient Neutrality treatment

This figure displays average treatment effects on the treated of issuance of 'Nutrient Neutrality' guidance on mean levels of nitrate, ammonia, phosphate and orthophosphate based on Equation 2.

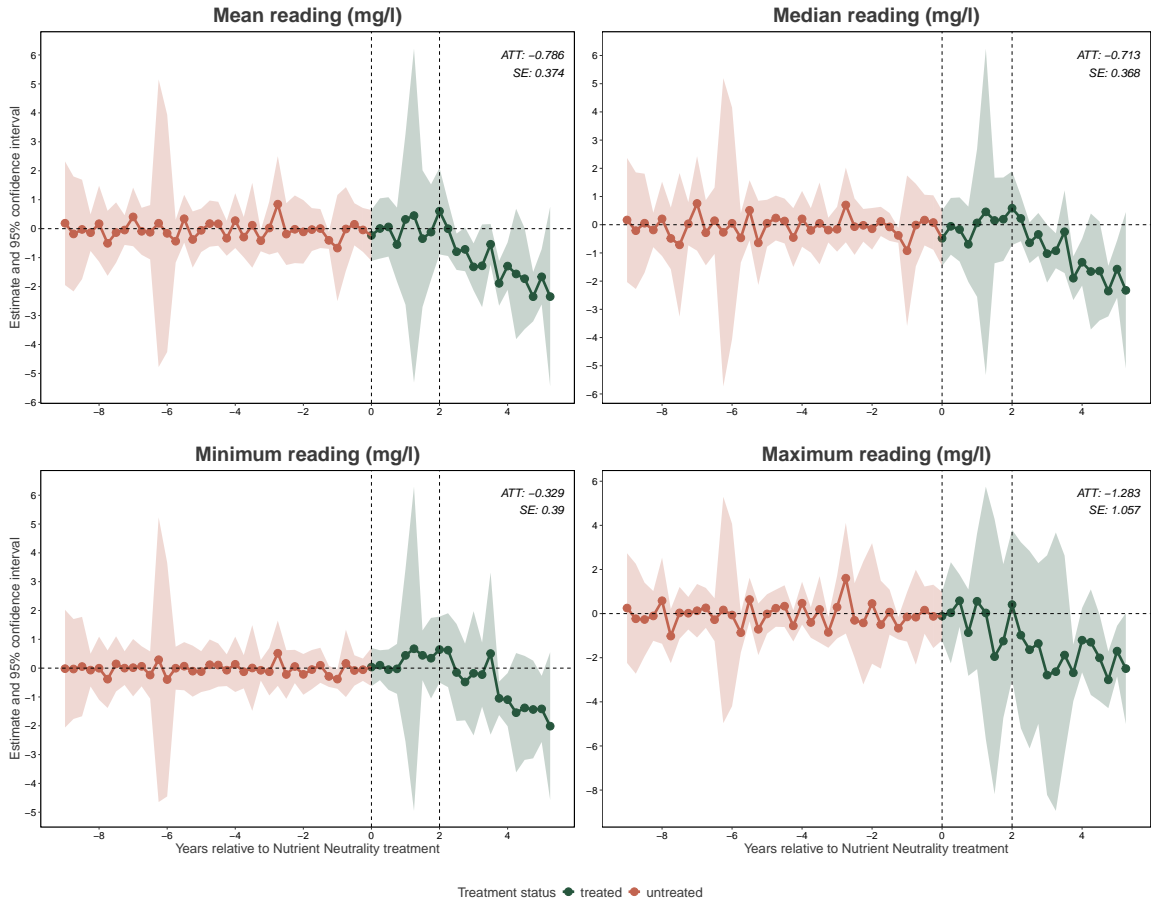


Figure A.4: Event studies of nitrogen measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of nitrogen per half-year, based on Equation 2.

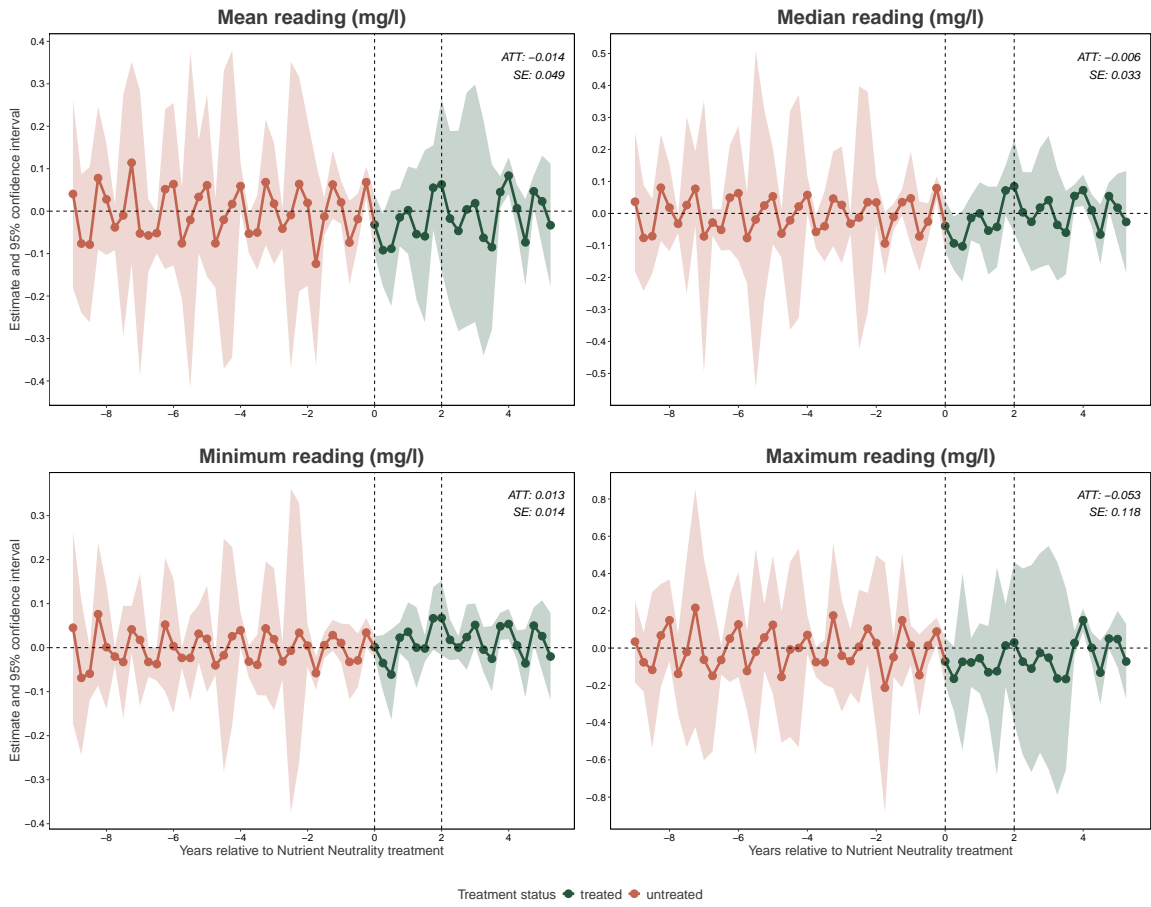


Figure A.5: Event studies of phosphorus measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of phosphorus per half-year, based on Equation 2.

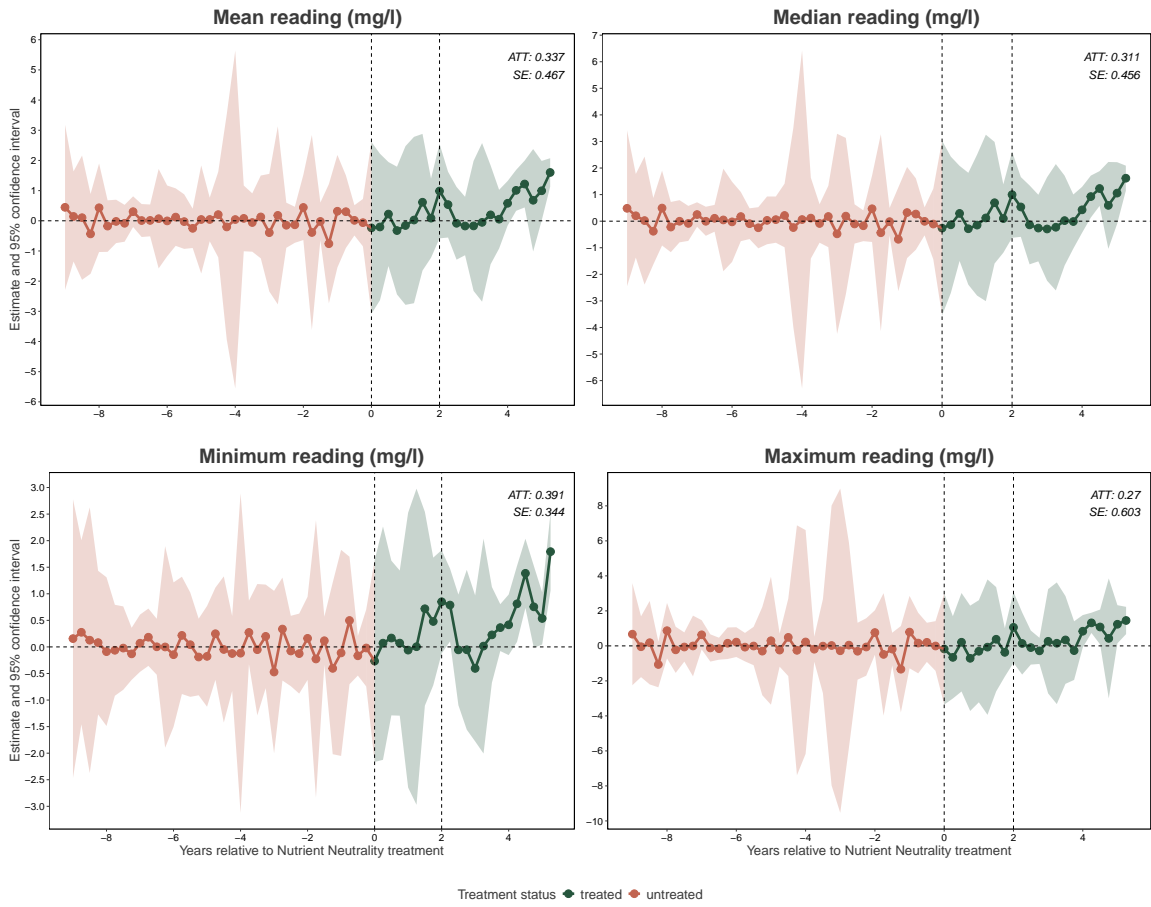


Figure A.6: Event studies of nitrate measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of nitrate per half-year, based on Equation 2.

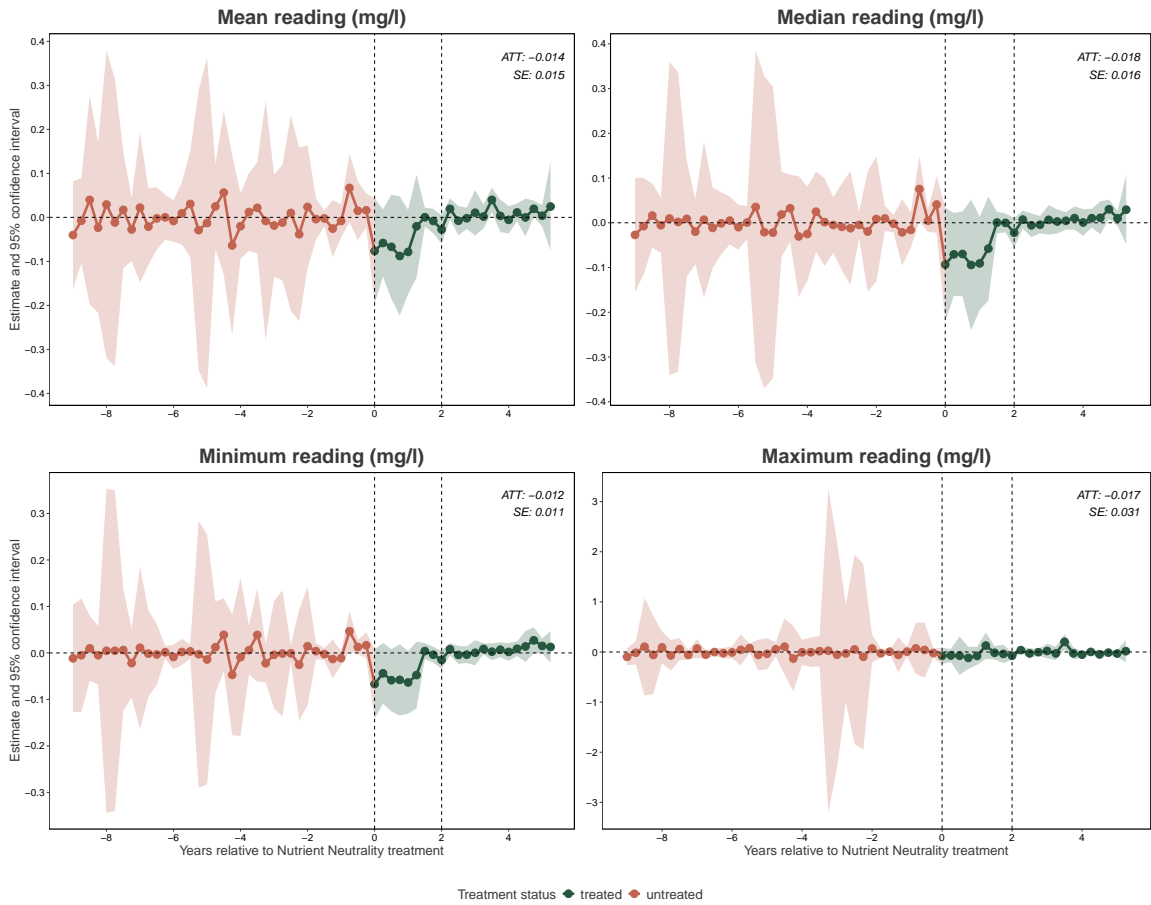


Figure A.7: Event studies of ammonia measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of ammonia per half-year, based on Equation 2.

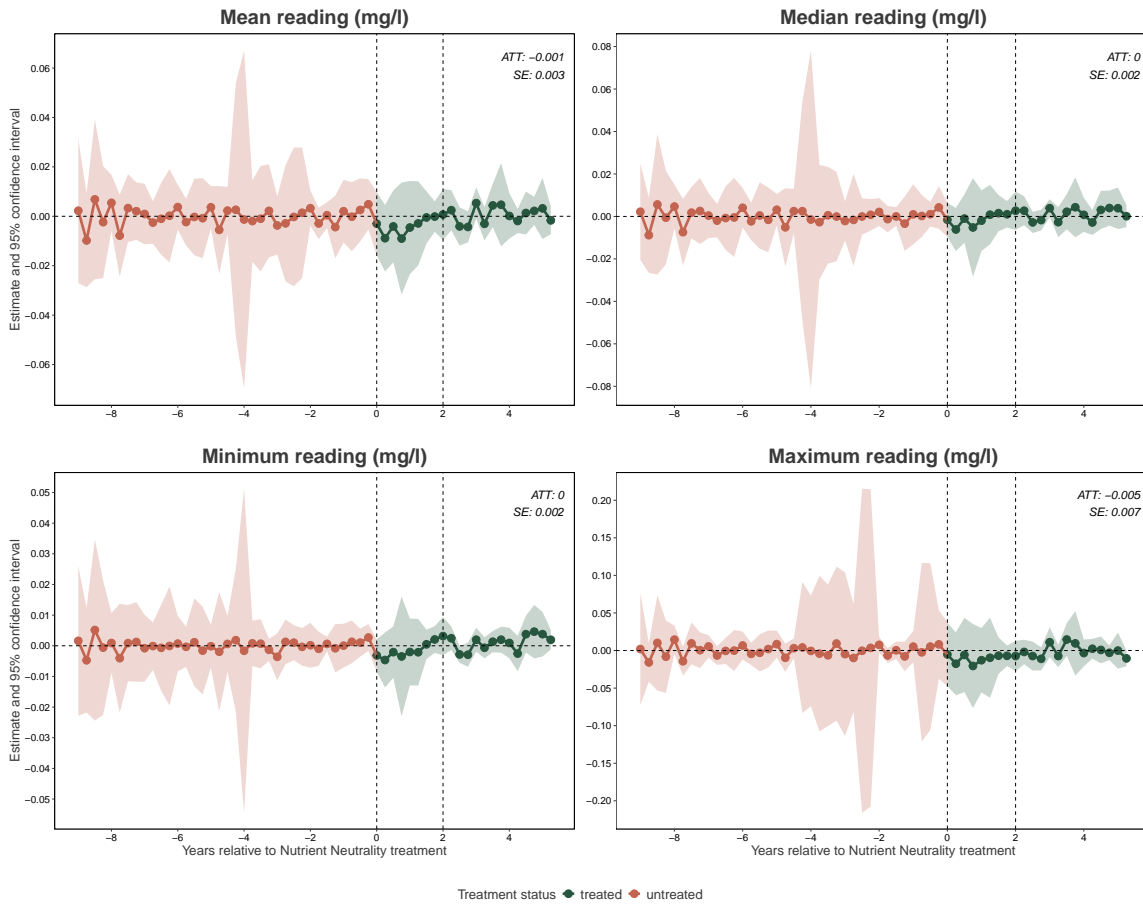


Figure A.8: Event studies of nitrite measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of nitrite per half-year, based on Equation 2.

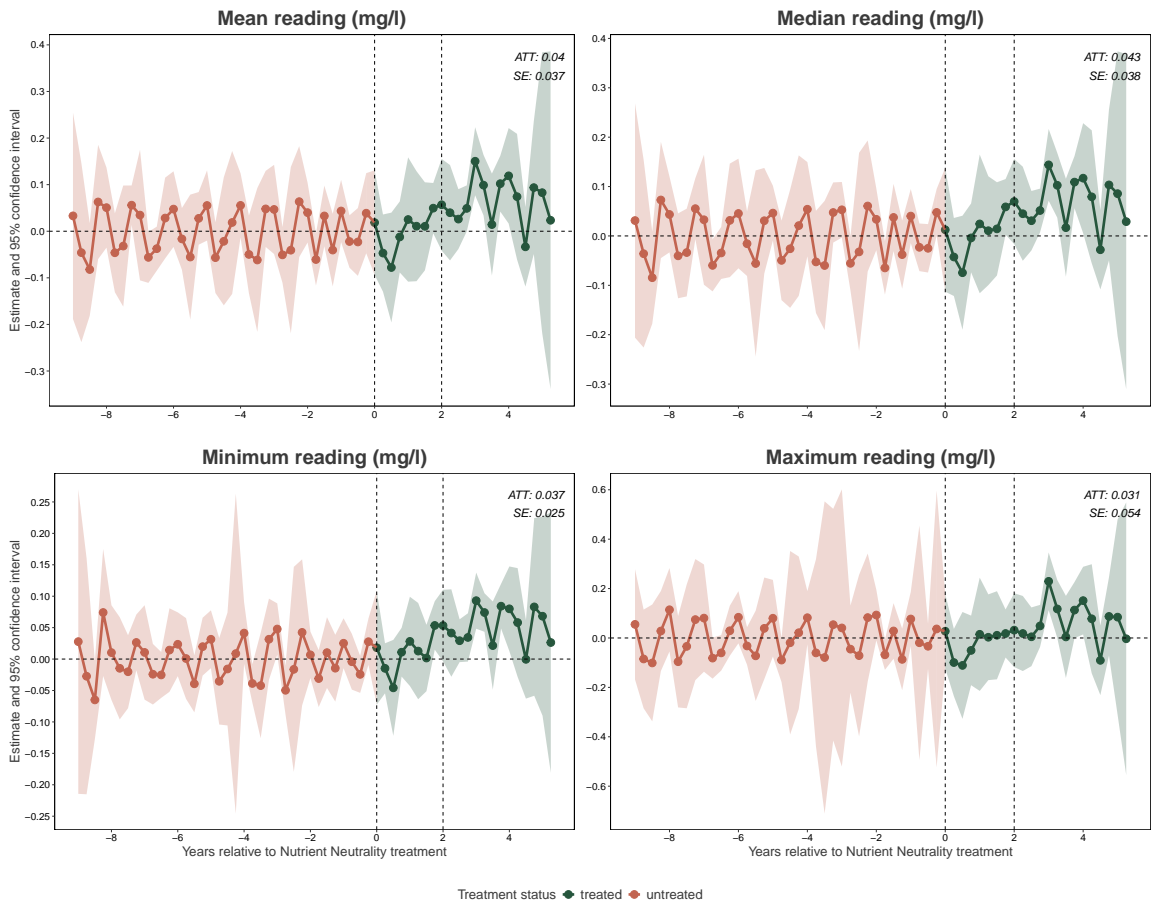


Figure A.9: Event studies of orthophosphate measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of orthophosphate per half-year, based on Equation 2.

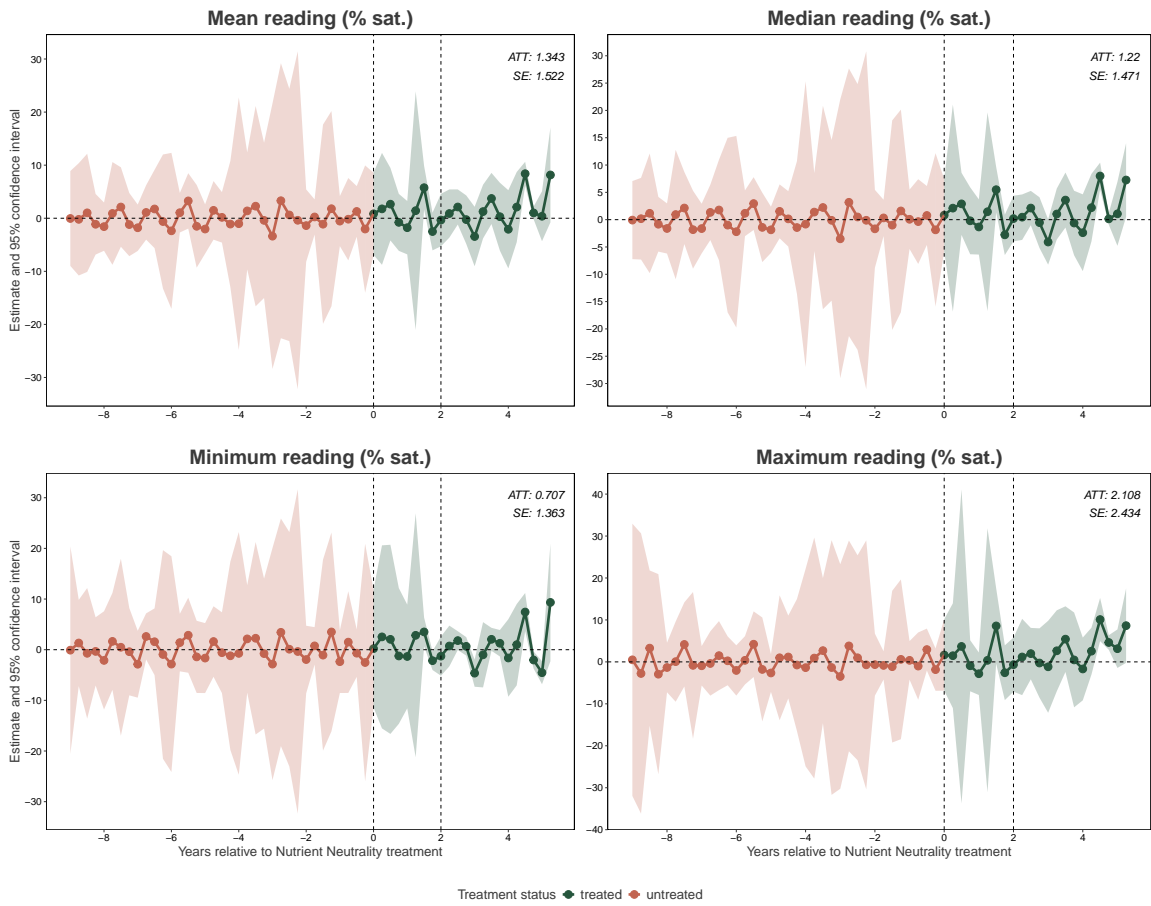


Figure A.10: Event studies of dissolved oxygen measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of dissolved oxygen per half-year, based on Equation 2.

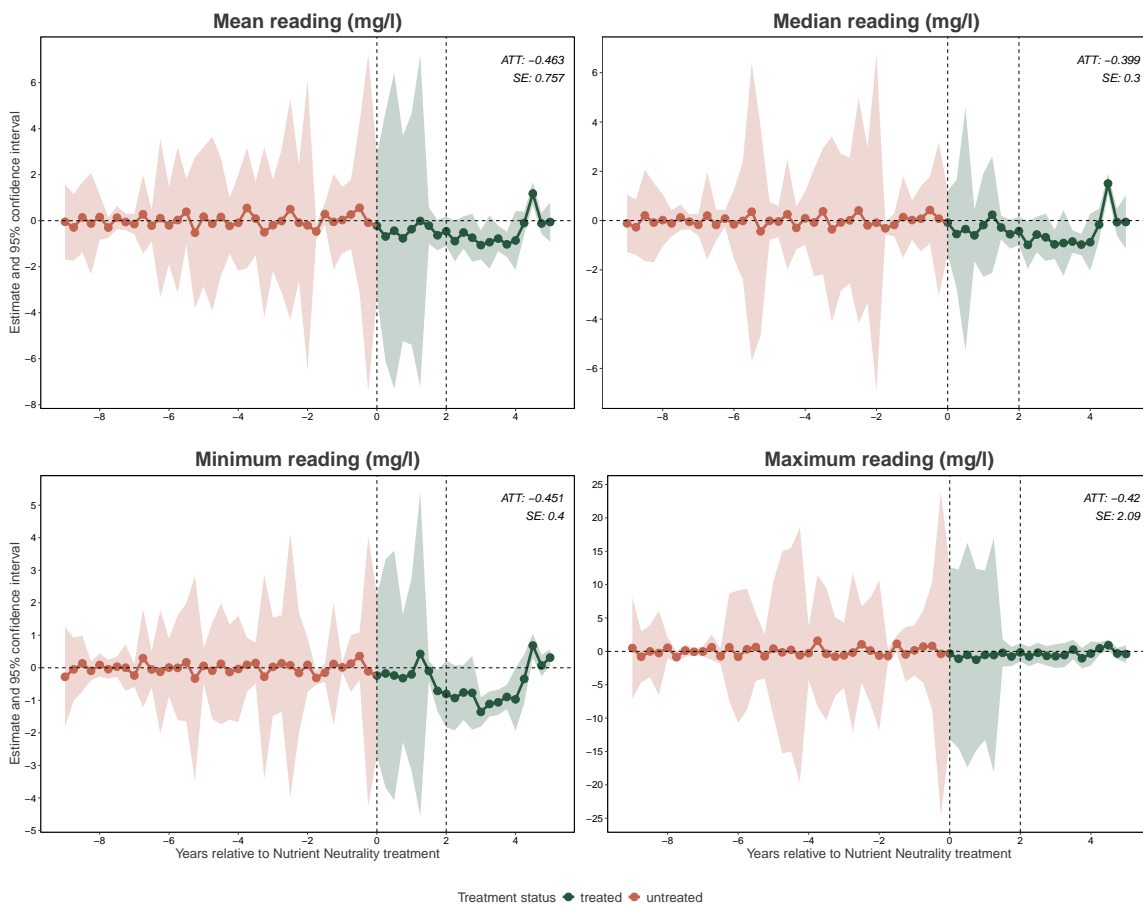


Figure A.11: Event studies of biochemical oxygen demand measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of biochemical oxygen demand per half-year, based on Equation 2.

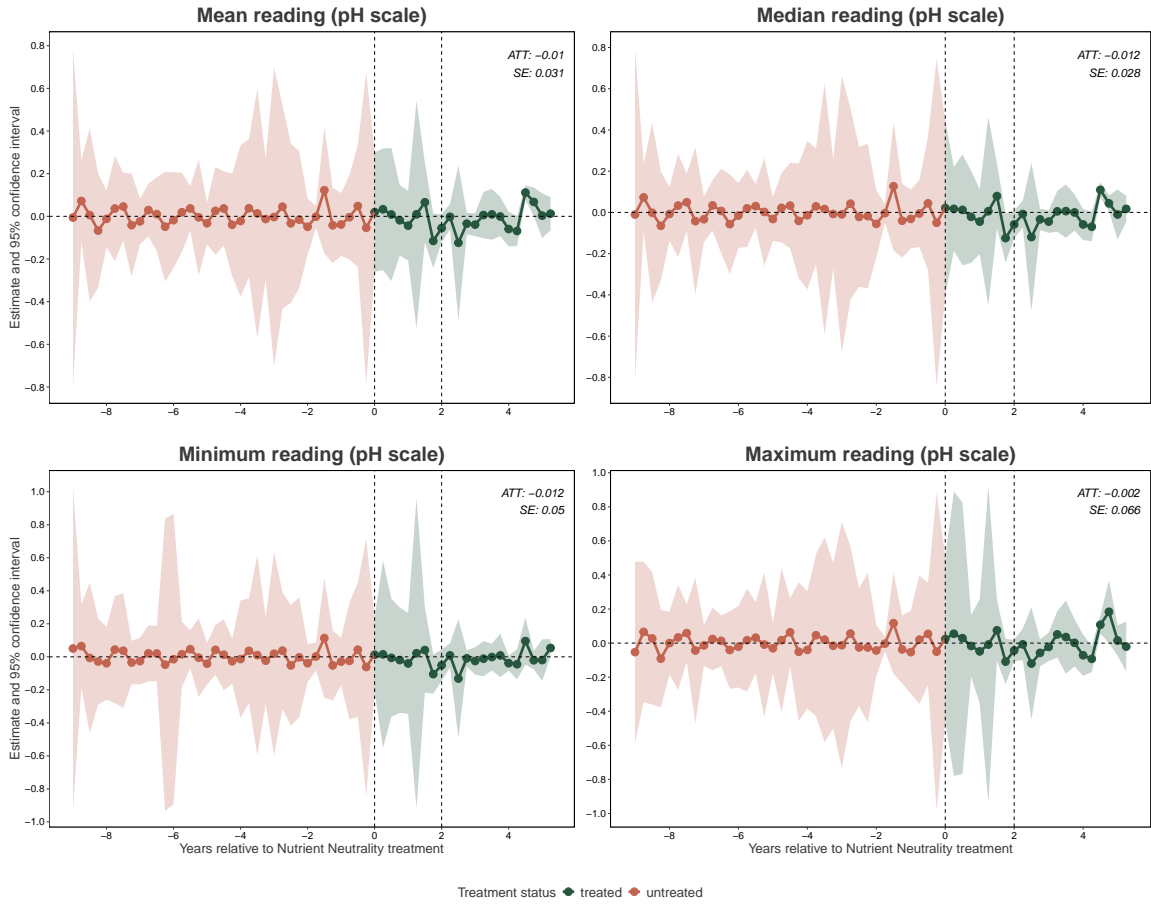


Figure A.12: Event studies of pH measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of pH value per half-year, based on Equation 2.

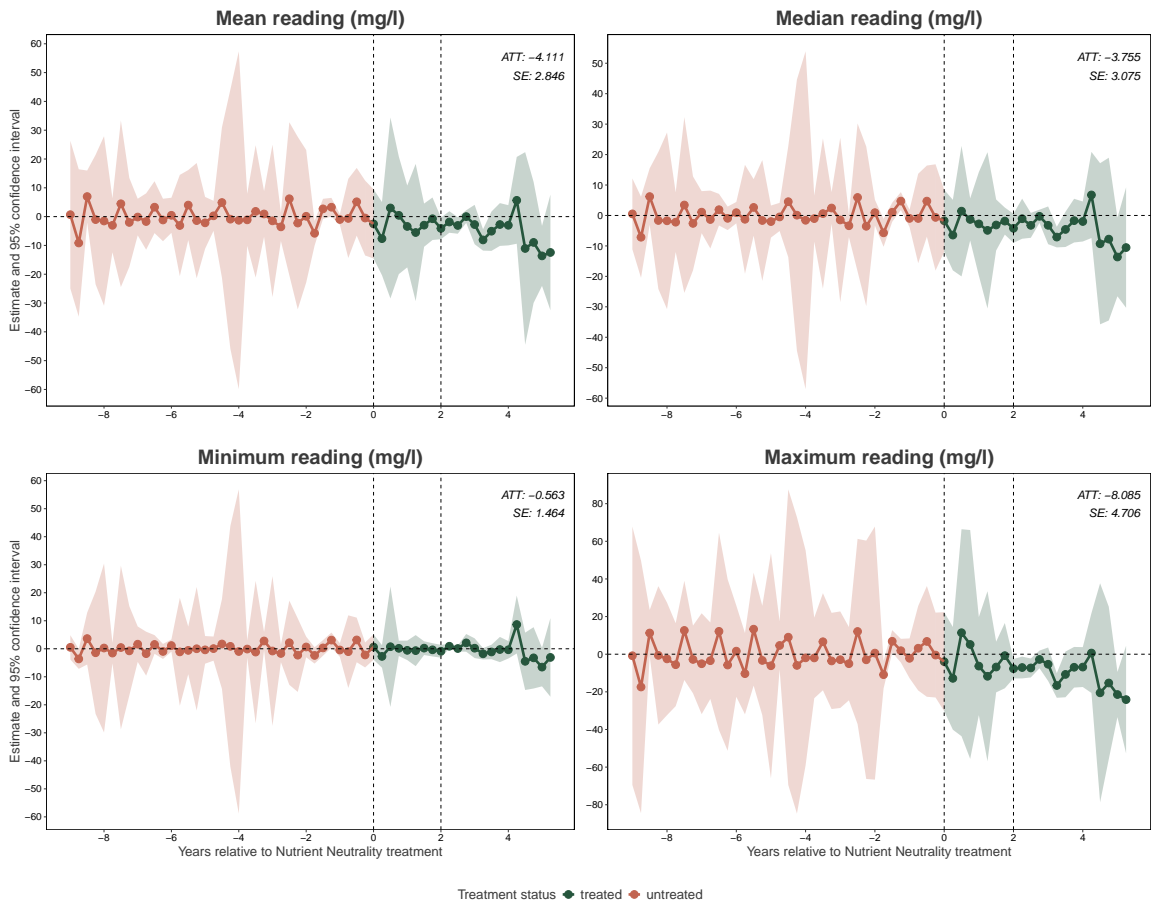


Figure A.13: Event studies of chlorophyll-a measures on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of the issuance of 'Nutrient Neutrality' guidance on the the mean, median, minimum and maximum level of chlorophyll-a per half-year, based on Equation 2.

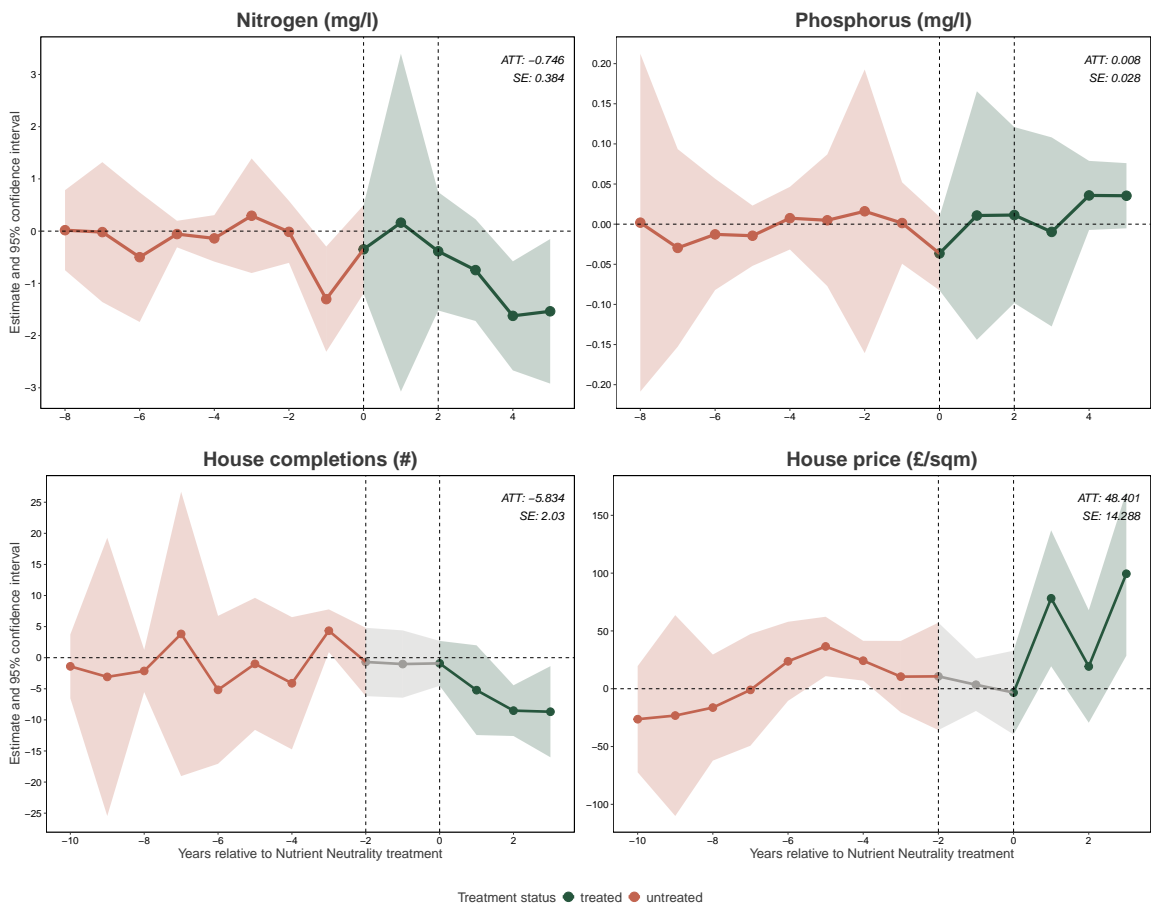


Figure A.14: Event studies at annual frequency of main outcomes on Nutrient Neutrality treatment

This figure displays the average treatment effect on the treated of issuance of 'Nutrient Neutrality' guidance on mean level of nitrogen, mean level of phosphorus, number of housing completions and house prices based on Equation 2, with data aggregated to annual level.

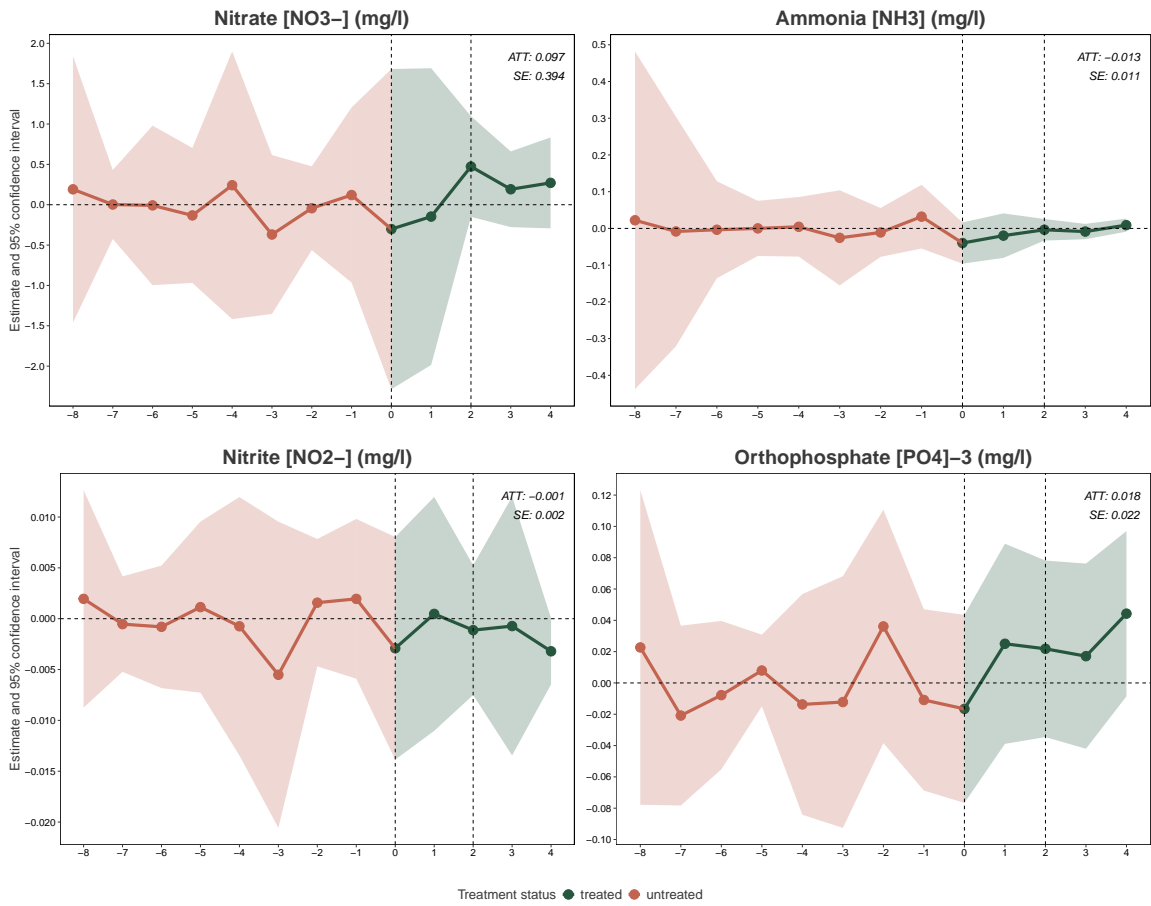


Figure A.15: Event studies at annual frequency of sub-pollutant outcomes on Nutrient Neutrality treatment

This figure displays average treatment effects on the treated of issuance of 'Nutrient Neutrality' guidance on mean levels of nitrate, ammonia, phosphate and orthophosphate based on Equation 2, with data aggregated to annual level.

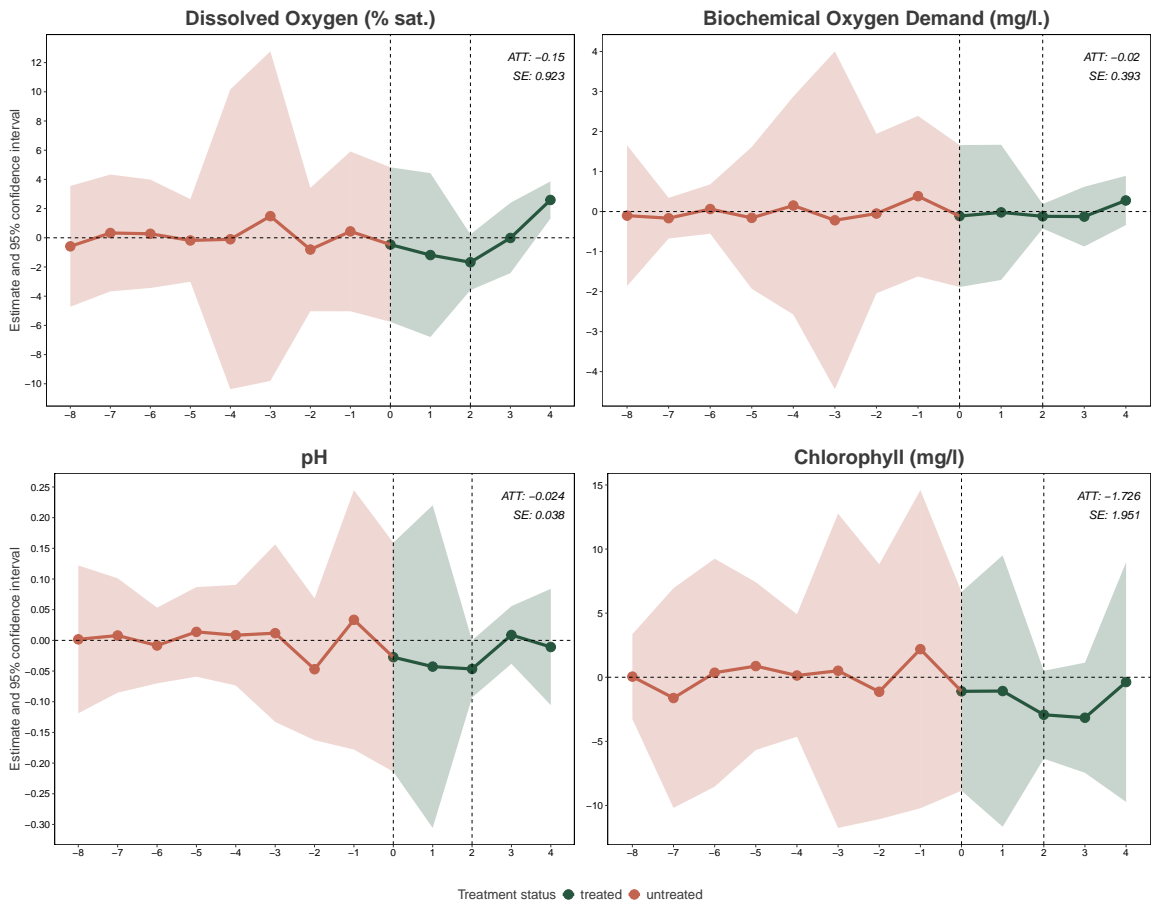


Figure A.16: Event studies at annual frequency of water quality outcomes on Nutrient Neutrality treatment

This figure displays average treatment effects on the treated of issuance of 'Nutrient Neutrality' guidance on mean levels of dissolved oxygen, BOD, pH and chlorophyll based on Equation 2, with data aggregated to annual level.