# 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 targets residential pollution by restricting local housing construction. We document both direct effects and leakage in polluters, but no leakage in pollution: in treated locations, nutrient pollution and water quality improve modestly, while housing completions fall, and prices increase. We find strong evidence of leakage in polluters: housing completions increase nearby. However, the absence of any accompanying leakage in pollution casts doubt on the link between housing construction and nutrient pollution. Instead, tying housing construction to reductions in nutrient levels creates strong incentives to reduce pollution through other means – likely violating the polluter pays 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 targets nutrient pollution in water bodies by restricting 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, 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 rollout of Nutrient Neutrality policy across English localities since 2017. We find that treated localities experience moderate improvements in nutrient pollution and water quality: total nitrogen decreases, whereas total phosphorus does not change significantly; water quality improves in terms of biochemical oxygen demand, but not dissolved oxygen. 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 uptake in nutrient pollution. This casts

[1] Nutrient 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).

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

[3] See 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.

doubt on the mechanism at the heart of the policy: that residential wastewater from new houses would contribute meaningfully to nutrient pollution in local water bodies.

An alternative interpretation of the policy's mechanism is that it introduces strong incentives for local authorities to *somehow* address nutrient pollution, either by forcing local developers to over-offset, or by resorting to other, unspecified means beyond housing. The threat of banning housing unless new construction is offset appears to reduce nutrient pollution in total nitrogen by 13.5%, although these improvements in water quality come at a steep economic cost of depressing new residential construction by 19% and an increase in local and regional house prices of at least 2.4%, with the latter also extending to untreated neighbours.

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. Our findings are in line with Nutrient Neutrality introducing strong incentives for local councils to address nutrient pollution due to the threat of housing bans, without providing a clear mechanism how such improvements could be achieved.[4] In particular, the policy falls short of establishing a clear link between major emitters of nutrients and efforts to mitigate their pollution, violating the polluter pays principle – which can help explain the strong opposition to the policy and its political economy repercussions.[5,6] Therefore, our findings call for a more structured approach to combat nutrient pollution, e.g., via more hands-on guidance, or market-based instruments, e.g., via cap-and-trade of pollution permits.

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

[4]The Royal Institute of British Architects provides a suggestive list of how projects could achieve Nutrient Neutrality, including: compensatory offsite wetlands, agricultural run-off interceptor sites, upgrading of wastewater treatment plants, or sustainable urban drainage systems (RIBA, 2022).

[5]Recent 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.

[6]See the 'gilets jaunes' in France (Boyer et al., 2020) and EU farmer protests (Finger et al., 2024).

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 $CO_2$. 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.[7]

[7]A report commissioned by the Home Builders Federation, estimates that only 0.29% of average

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 from such a policy in predominantly rural areas covered by Nutrient Neutrality.

The remainder of this paper is organized as follows. Section 2 provides context and details on the Nutrient Neutrality policy. In Section 3 we discuss the data and the empirical strategy. The results from the direct effects of the policy are introduced in Section 4 and the results on leakage in Section 5. Section 6 offers concluding remarks.

## 2 Setting

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,

nutrient pollution can be attributed to new housing developments (Brookbanks, 2023).

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.[8] Across advanced economies, the three main contributors to nutrient pollution in water bodies are agriculture, especially fertilizer run-off, industrial waste water and residential waste water.

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 as it targets new residents and their associated waste water 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' 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 by investments in local wetland restoration or equivalent projects (Natural England, 2022a), such that the new developments become 'neutral' in terms of nutrient pollution. Thus, the policy gives affected LPAs the implicit choice to either restrict the number of new houses to be approved to zero, or to fully neutralise extra nutrient inflow to water bodies from approved housing with costly investments in extra nutrient outflow (e.g., waste water treatment plants) or conversion (e.g., wetland restoration).

Natural England assigned LPAs to fall under Nutrient Neutrality guidance in a staggered fashion, starting in 2017, reaching 74 LPAs by 2024. Currently 19% of LPAs 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 Q2 of 2017 with six additional WBCs 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 WBCs in 2022 (see Appendix Table A1 for a

[8]In 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.

[9]A 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.

detailed overview of treatment timing and cumulative coverage).

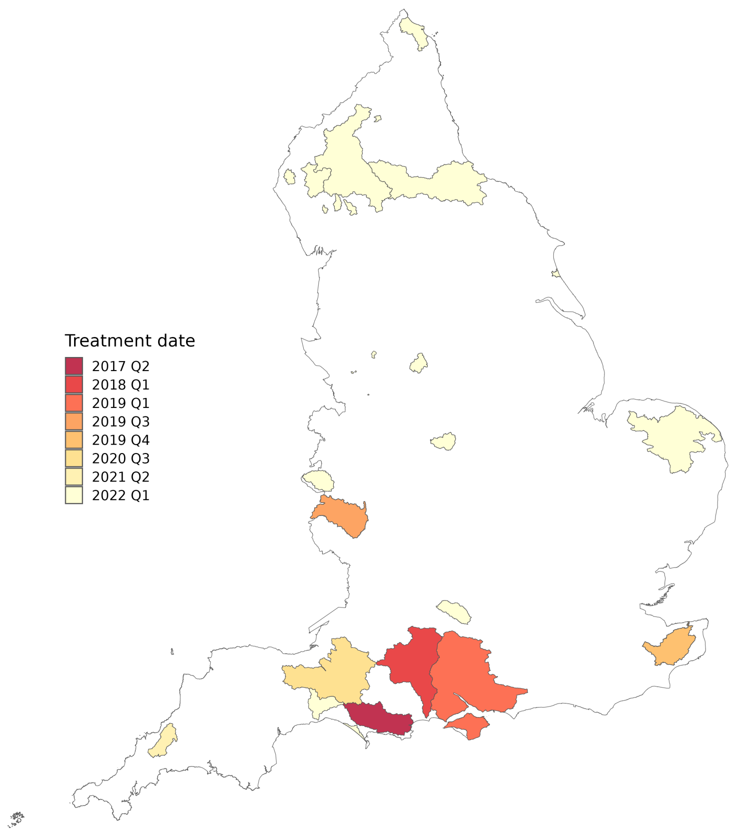


Figure 1: Nutrient Neutrality treatment status by water body catchment area

*This figure displays the issuance of Nutrient Neutrality guidance by Natural England across space and over time (see Appendix Table A1 for further details).*

## 3 Data and estimation

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 four 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 from Natural England (see Appendix Table A1 for details). The treatment areas correspond to water body catchment areas (WBCs) that 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.[10] 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. Our unit of observation is defined at the WBC-period level.

The second 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 and of pollutants not directly targeted by the policy, such as dissolved oxygen, biochemical oxygen demand, nitrate, phosphate, orthophosphate, pH and chlorophyll. For our main results we use the mean reading across samples within a WBC-half year, 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-half year level. Since samples are not taken every half year in every WBC but at irregular intervals this is an unbalanced panel. During the initial outbreak of the Covid pandemic (i.e., Q2 and Q3 of 2020) no samples were taken at all, so these quarters are implicitly dropped from the sample.

Third, we use a more standard dataset for the UK housing market, namely the British Land registry data on prices paid from the universe of residential housing transactions in the UK. Based on these transactions and the methodology developed by Ahlfeldt et al. (2023), we calculate quarterly house price indices for all water body catchment areas in England.

Fourth, we obtain data on finished housing constructions from newly issued Energy

[10] Although 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.

Performance Certificates and aggregate those to the WBC-quarter level.

Combining these four sources, we create a novel dataset that allows us to track the effects of the policy on both local environmental outcomes and the housing market. We drop London from our sample as there are no treated areas within the Greater London area and no treated areas with a similar level of urbanization. Furthermore, the London housing market is likely to be driven by a number of other factors, such as geopolitics and international financial markets, that are different to the rest of the country (Badarinza & Ramadorai, 2018). We restrict our estimation sample to only periods for which data from at least two treated locations is available to avoid our results being driven by idiosyncratic shocks to any single location. To econometrically account for both the staggered nature of the roll-out and the expected dynamic treatment effects that may take time to materialise, or even accumulate with the duration of treatment, we employ the dynamic, doubly-robust difference-in-differences estimator developed by De Chaisemartin and d'Haultfoeuille (2024).

## 4 Direct effects

To estimate the direct effects of the policy on the housing market and targeted pollutants in treated locations, we estimate the following equation:

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

where $y_{ct}$ are the outcomes variables of interests in water body catchment area $c$ and period $t$: housing completions, local house price index, phosphorus levels and nitrogen levels. $\gamma_t$ and $\gamma_c$ represent period and WBC fixed effects, respectively. Standard errors are clustered at the WBC level. For housing completions we shift the start of the treatment period by two years, in order to account for the fact that the policy only affects new planning applications, and that it takes on average two years to proceed from planning application to completion. The results are displayed in Figure 2. We find mixed results on targeted pollutants: while nitrogen decreases by 0.57 mg/l, phosphorus slightly increases by 0.037 mg/l (even so marginally insignificantly).[11]

[11] We provide further results on different components of nitrogen and phosphorus in Appendix Table A5. In line with the overall decrease in nitrogen, nitrate and ammonia fall, although the changes are not statistically significant. The phosphorus components total phosphate and orthophosphate both increase significantly in treated areas.

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, and highlight the importance of biochemical feedback processes in water bodies that challenge effective policy design. In the housing market, we find economically 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 m$^2$, which is equivalent to a 2% increase in the median WBC. This increase is gradual, but starts shortly after the implementation of the policy. 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 effect of the policy.[12]

Figure 3 provides an overview of the dynamic effects of nutrient neutrality on different measures of water quality not directly targeted by the policy in treated locations. While there are no significant effects on water quality as measured by dissolved oxygen, the observed significant decrease in biochemical oxygen demand – even though there seems to be some mean reversion – is consistent with an overall improvement of water quality. We further find a statistically significant reduction in pH that is likely related to reduced nutrient input. The overall increase in water quality and reduction in pH are also in line with a decrease in chlorophyll concentration suggesting a decrease in algal bloom, although not statistically significant.

In the Online Appendix we provide additional robustness tests for these results. For all environmental outcomes we show results for the semi-annual median, minimum and maximum levels of each environmental outcome. Results qualitatively and quantitatively confirm the main results derived from the semi-annual mean reading of a given pollution measure (see Appendix Figures A2-A9). We also show that for all outcomes, the main results are robust to excluding coastal WBCs that could be subject to differential economic and biochemical conditions (see Appendix Tables A8-A15, column 2 in comparison to the main results reproduced in column 1). Results are likewise robust to excluding treatment locations' neighbours from the staggered roll-out, addressing concerns around potential stable unit treatment value assumption

[12]Observational studies link water quality to house prices (Moore et al., 2020; Mamun et al., 2023). Such a hyperlocal, 'lakeside' amenity effect of water quality improvements is unlikely to drive our catchment area-wide effects on house prices that even extend to neighbouring areas.

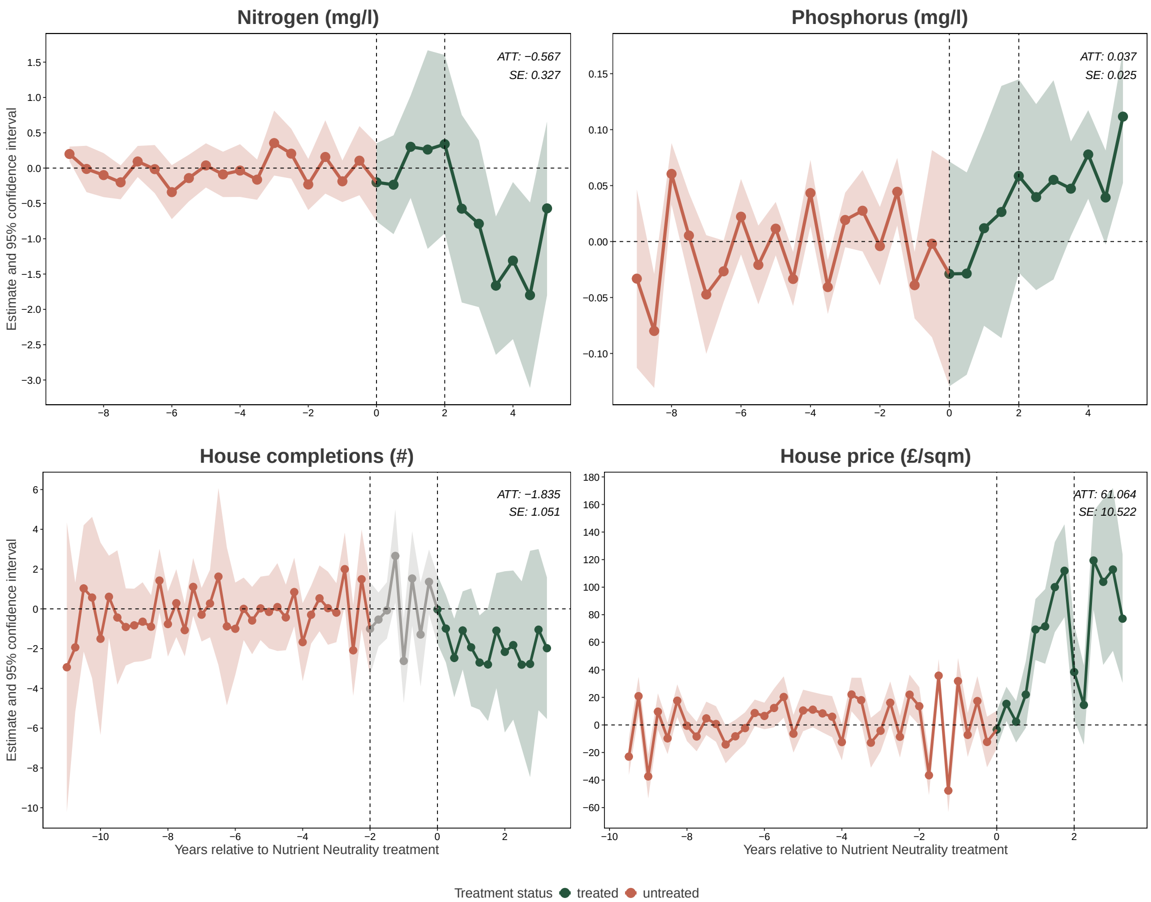


Figure 2: Event studies of main outcomes on Nutrient Neutrality treatment

*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 1.*

(SUTVA) violations, but results are remarkably stable for agnostic choices of distance buffers around treatment locations (see Appendix Tables A8-A15, columns 3-5).[13]

[13] In results not shown, we 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.

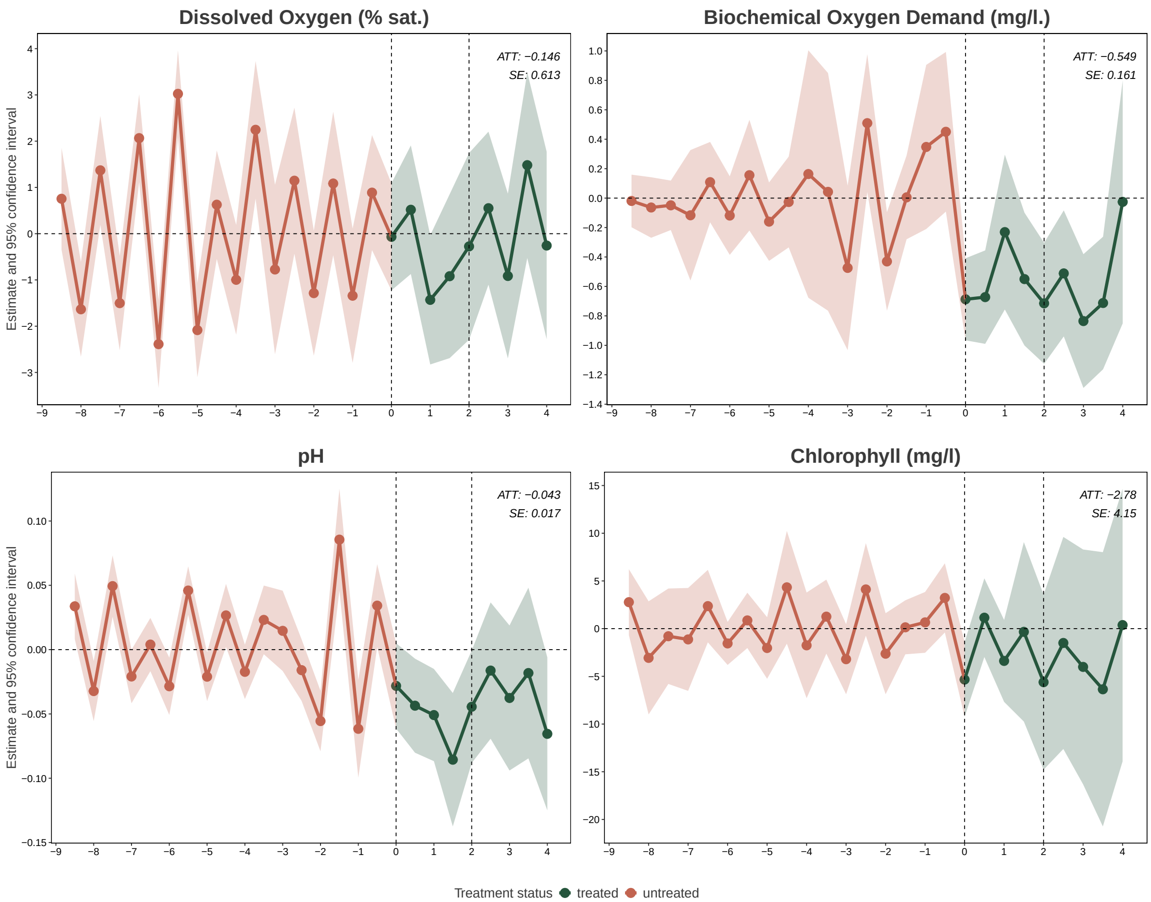


Figure 3: Event studies of water quality outcomes on Nutrient Neutrality treatment

*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 1.*

## 5 Leakage

To estimate the leakage affect across locations for both polluters and pollution we re-estimate Equation 1 replacing originally treated locations with their neighbours. This equation 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 targeted pollutant to improve in treatment locations, it seems natural to study and compare spatial displacement of housing construction as well as nitrogen pollution to neighbouring (untreated) locations.

When studying the spatial displacement of polluters we find that housing completions in neighbouring locations increase in neighbouring untreated WBCs in a radius up to 5km and up to 10km around treated WBCs (see Figure 4). 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 – in other words, while the supposed polluter, residential housing and their wastewater, gets displaced, we cannot detect an analogous displacement of 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 not be driven by reductions in housing completions.

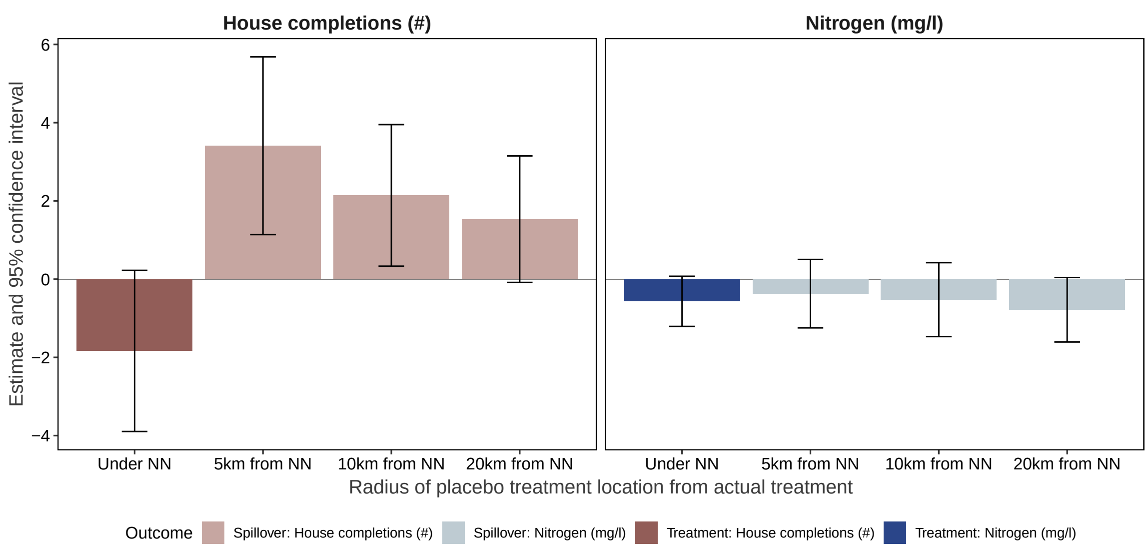


Figure 4: Spillovers of Nutrient Neutrality (NN) treatment to neighbouring locations

*This figure displays the average treatment effect on the treated on house completions and mean nitrogen readings based on Equation 1. 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.*

Our results suggest that new residential housing construction may only be a minor contributor to nutrient pollution such that restricting housing construction should only have minor effects on nutrient pollution levels – and so should investments into offsetting its implied nutrient pollution. Beyond this ineffective targeting, by design

Nutrient Neutrality can only prevent nutrient pollution from increasing, but cannot reduce already existing nutrient pollution.

Against this background, how could Nutrient Neutrality have achieved the observed significant reduction in nitrogen pollution? Given the scarcity of policy guidance on how to offset nutrient pollution, local authorities might have enforced 'offsetting' measures on developers that overshot the offsetting amount of pollution, hence reducing nitrogen beyond the additional emissions of new housing construction. In addition, the policy creates strong incentives for local authorities to decrease the amount of targeted pollutants in water bodies to exit Nutrient Neutrality treatment, since withholding planning applications for construction directly affects locations' tax income, likely creating dissatisfaction among constituents. Anecdotal evidence suggests that the decline in nitrogen could be caused by a decrease in untreated sewage effluent and improved wastewater treatment, which is usually less effective at phosphorus removal and hence consistent with the observed non-decline in phosphorus pollution. The cost of the reduction in nutrient pollution is therefore either born by developers or by the local taxpayer, while the largest polluter (agriculture) remains unaffected by the policy. Such a violation of the polluter pays principle (as established in the 1990 Environmental Protection Act, UK (1990)) highlights an inherent design flaw of the policy, likely undermining its public support (Oh & Gramig, 2025).

Finally, the large and significant increases of (ortho-)phosphate in treated locations following Nutrient Neutrality could point to underlying changes in pollution emissions by its largest local source: agricultural land use. One hypothetical effect may be that the relative expansion of residential housing in untreated locations (i.e., displacement) reduces relative agricultural activity in untreated locations at the expense of treated locations, leading to a potentially large (relative) increase in nutrients in treated locations, undermining the rationale of combatting nutrient pollution.[14]

## 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. We show that the policy's approach to

[14]Similarly, the less significant changes in total phosphorus levels in water could be driven by the sediment-bound, slow-moving phosphorus commonly found in water bodies.

combat nutrient pollution through regulating the housing market is costly in terms of depressed housing completions and increased house prices, although it attains modest environmental benefits in terms of nitrogen pollution and water quality. The incomplete nature of the regulation, which only targets locations that are non-compliant in water pollution levels gives rise to spatial displacement: we find strong evidence of leakage in polluters, with an almost one-for-one displacement of housing completions to neighbouring, untreated locations. However, we fail to detect any accompanying leakage in nutrient pollution, which casts doubt on the core mechanism at the heart of the policy's design, that restricting residential development can curb nutrient pollution. Instead, it appears that the environmental benefits of the policy arose from over-offsetting expected pollution burdens by housing developers, or some other means of adjustment by local authorities. In either case, the policy violates the polluter pays principle since housing developers and future residents are paying an implicit tax to reduce nutrient pollution that is mostly not of their making, highlighting the need to realign pollution cause and remedy in future policy design.

## References


Ahlfeldt, G. M., Heblich, S., & Seidel, T. (2023). Micro-geographic property price and rent indices. *Regional Science and Urban Economics*, *98*, 103836.

Badarinza, C., & Ramadorai, T. (2018). Home away from home? Foreign demand and London house prices. *Journal of Financial Economics*, *130*(3), 532–555.

Becker, R., & Henderson, J. (2000). Effects of air quality regulations on polluting industries. *Journal of Political Economy*, *108*(2), 379–421.

Bou Sleiman, L. (2025). Displacing congestion: Evidence from Paris. *NUS mimeo*.

Boyer, P. C., Delemotte, T., Gauthier, G., Rollet, V., & Schmutz, B. (2020). Les déterminants de la mobilisation des gilets jaunes. *Revue économique*, *71*(1), 109–138.

Brookbanks. (2023). The extent to which housebuilding contributes to nutrient pollution across watercourses in England. https://www.hbf.co.uk/documents/13061/Brookbanks_-_Research_Report_Nov_2023.pdf

Burt, T., Howden, N., Worrall, F., Whelan, M., & Bieroza, M. (2011). Nitrate in United Kingdom rivers: Policy and its outcomes since 1970. *Environmental Science & Technology*, *45*(1), 175–181.

Bushnell, J. B., & Mansur, E. T. (2011). Vertical targeting and leakage in carbon policy. *American Economic Review*, *101*(3), 263–267.

Chen, C.-T., Lade, G. E., Crespi, J., & Keiser, D. A. (2024). Sized-based regulation and environmental quality: Evidence from the US livestock industry. *Center for Agricultural and Rural Development Working Paper*, (24-WP 657).

Cohen, A., & Keiser, D. A. (2017). The Effectiveness of Incomplete and Overlapping Pollution Regulation: Evidence from Bans on Phosphate in Automatic Dishwasher Detergent. *SSRN Scholarly Paper*, (2905906). https://doi.org/10.2139/ssrn.2905906

Currie, J., & Walker, R. (2019). What do economists have to say about the Clean Air Act 50 years after the establishment of the Environmental Protection Agency? *Journal of Economic Perspectives*, *33*(4), 3–26.

De Chaisemartin, C., & d'Haultfoeuille, X. (2024). Difference-in-differences estimators of intertemporal treatment effects. *Review of Economics and Statistics*, 1–45.

Del Rossi, G., Hoque, M. M., Ji, Y., & Kling, C. L. (2023). The Economics of Nutrient Pollution from Agriculture. *Annual Review of Resource Economics*, *15*(1), 105–130.

Environment Agency. (2024a). State of the water environment indicator b3: Supporting evidence pack may 2024. *Government bulletin*.

Environment Agency. (2024b). Indicative catchment statistics for nutrient pollution: Protected areas with diffuse water pollution plans or nutrient neutrality advice. *Government bulletin*.

Environmental Protection Agency. (2025). Nutrients research. *https://www.epa.gov/water-research/nutrients-research*.

European Commission. (2022). Nutrients: Commission seeks views on better management. *https://environment.ec.europa.eu/news/nutrients-commission-seeks-views-better-management-2022-06-03_en*.

Financial Times. (2023a). UK to scrap rules protecting waterways to boost housebuilding. Retrieved July 15, 2025, from https://www.ft.com/content/4569fa08-670a-4807-b5e2-9a5aeb007cb0

Financial Times. (2023b). Rishi Sunak defeated in House of Lords over rules on river pollution. Retrieved July 15, 2025, from https://www.ft.com/content/5558364c-e40c-42e9-bbf4-837b1f57a4d1

Financial Times. (2024). UK ministers set to change environmental rules to boost housebuilding. Retrieved July 15, 2025, from https://www.ft.com/content/e34aaaf8-451f-4210-9d77-0d479e9de219

Financial Times. (2025). Planning approvals for new homes in England drop to 13-year low. Retrieved July 15, 2025, from https://www.ft.com/content/41e2122c-3612-4362-8071-c0c59a4f59db

Finger, R., Fabry, A., Kammer, M., Candel, J., Dalhaus, T., & Meemken, E. M. (2024). Farmer protests in Europe 2023–2024. *EuroChoices*, *23*(3), 59–63.

Fowlie, M. L. (2009). Incomplete environmental regulation, imperfect competition, and emissions leakage. *American Economic Journal: Economic Policy*, *1*(2), 72–112.

Garnache, C., Swinton, S. M., Herriges, J. A., Lupi, F., & Stevenson, R. J. (2016). Solving the phosphorus pollution puzzle: Synthesis and directions for future research. *American Journal of Agricultural Economics*, *98*(5), 1334–1359.

Henderson, J. V. (1996). Effects of air quality regulation. *The American Economic Review*, *86*(4), 789–813.

Hilber, C. A. L., & Vermeulen, W. (2015). The impact of supply constraints on house prices in England. *The Economic Journal*, *126*(591), 358–405.

Jacobson, S. (2014). Temporal spillovers in land conservation. *Journal of Economic Behavior and Organization*, *107*, 366–379.

Jun, M.-J. (2004). The effects of Portland's urban growth boundary on urban development patterns and commuting. *Urban Studies*, *41*(7), 1333–1348.

Keiser, D. A. (2020). Policy brief – the effectiveness of phosphate bans in the United States. *Review of Environmental Economics and Policy*, *14*(2).

Keiser, D. A., & Shapiro, J. S. (2019). Consequences of the Clean Water Act and the Demand for Water Quality. *The Quarterly Journal of Economics*, *134*(1), 349–396.

Koster, H. R. A. (2023). The welfare effects of greenbelt policy: Evidence from england. *The Economic Journal*, *134*(657), 363–401.

Liu, P., Wang, Y., & Zhang, W. (2023). The influence of the environmental quality incentives program on local water quality. *American Journal of Agricultural Economics*, *105*(1), 27–51.

Mamun, S., Castillo-Castillo, A., Swedberg, K., Zhang, J., Boyle, K. J., Cardoso, D., Kling, C. L., Nolte, C., Papenfus, M., Phaneuf, D., & Polasky, S. (2023).

Valuing water quality in the United States using a national dataset on property values. *Proceedings of the National Academy of Sciences of the United States of America*, *120*(15).

Moore, M. R., Doubek, J. P., Xu, H., & Cardinale, B. J. (2020). Hedonic price estimates of lake water quality: Valued attribute, instrumental variables, and ecological-economic benefits. *Ecological Economics*, *176*, 106692.

Natural England. (2022a). Advice for development proposals with the potential to affect water quality resulting in adverse nutrient impactso. *Letter*.

Natural England. (2022b). New scheme to protect our waterways from pollution and enable home building set to launch. *Natural England Blog*.

Oh, S., & Gramig, B. M. (2025). Pay the polluter or polluter pays? A preliminary assessment of public preferences for water quality policy. *Ecological Economics*, *233*, 108608.

Parliament of the United Kingdom. (1990). Environmental Protection Act. https://www.legislation.gov.uk/ukpga/1990/43/contents

Paudel, J., & Crago, C. L. (2020). Environmental externalities from agriculture: Evidence from water quality in the United States. *American Journal of Agricultural Economics*, *103*(1), 185–210.

Raff, Z., & Meyer, A. (2021). CAFOs and surface water quality: Evidence from Wisconsin. *American Journal of Agricultural Economics*, *104*(1), 161–189.

Royal Institute of British Architects. (2022). What is ‘nutrient neutrality’ and why is it stalling thousands of projects? Retrieved July 15, 2025, from https://www.architecture.com/knowledge-and-resources/knowledge-landing-page/what-is-nutrient-neutrality-and-why-is-it-stalling-thousands-of-projects

Segerson, K., & Walker, D. (2002). Nutrient pollution: An economic perspective. *Estuaries*, *25*(4b), 797–808.

Skidmore, M., Andarge, T., & Foltz, J. (2023). Effectiveness of local regulations on nonpoint source pollution: Evidence from Wisconsin dairy farms. *American Journal of Agricultural Economics*, *105*(1), 1333–1364.

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., De Vries, W., De Wit, C. A., et al. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223), 1259855.

Walker, W. R. (2011). Environmental regulation and labor reallocation: Evidence from the Clean Air Act. *American Economic Review*, *101*(3), 442–47.

Whelan, M. J., Linstead, C., Worrall, F., Ormerod, S. J., Durance, I., Johnson, A. C., Johnson, D., Owen, M., Wiik, E., Howden, N. J. K., Burt, T. P., Boxall, A., Brown, C. D., Oliver, D. M., & Tickner, D. (2022). Is water quality in British rivers better than at any time since the end of the Industrial Revolution? *Science of The Total Environment*, *843*, 157014.

Wolff, H. (2014). Keep your clunker in the suburb: Low-emission zones and adoption of green vehicles. *The Economic Journal*, *124*(578), F481–F512.

Wolff, H., & Perry, L. (2010). Policy monitor: Trends in clean air legislation in Europe: Particulate matter and low emission zones. *Review of Environmental Economics and Policy*, *4*(2), 293–308.

Zhai, M., & Wolff, H. (2021). Air pollution and urban road transport: Evidence from the world's largest low-emission zone in London. *Environmental Economics and Policy Studies*, *23*, 721–748.

# Online Appendix (not for publication)

## A.I Additional tables

Table A1: 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 A2: Doubly-robust dynamic diff-in-diff: Main outcomes of Nutrient Neutrality

| | Nitrogen | Phosphorus | Housing Completion | House Price |
|---|---|---|---|---|
| | mg/l | mg/l | # of houses | £/$m^2$ |
| ATT | $-0.57^{*}$ | 0.04 | $-1.83^{*}$ | $61.06^{***}$ |
| | (0.31) | (0.02) | (1.05) | (10.52) |
| Mean Dep. Var. | 4.22 | 0.18 | 9.62 | 2666.59 |
| N. WBCs | 1100 | 1428 | 4058 | 4058 |
| N. Groups | 8 | 8 | 7 | 7 |
| N. Periods | 23 | 23 | 46 | 46 |
| N. Obs | 8605 | 10880 | 185816 | 185816 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on nitrogen, phosphate, house completion and house price at the Water Body Catchment (WBC) area. Semi-annual water data sourced from the UK Water Quality Archive. Housing builds measured as the number of completed builds in each quarter, measured by the Energy Performance Certificates for new buildings issued. 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. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A3: Spillovers in doubly-robust dynamic diff-in-diff: House completion vs N

| | House Completion | | | | Nitrogen | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| ATT | $-1.83^{*}$ | $3.41^{***}$ | $2.14^{**}$ | $1.53^{*}$ | $-0.57^{*}$ | $-0.37$ | $-0.52$ | $-0.78^{*}$ |
| | (1.05) | (1.16) | (0.92) | (0.83) | (0.31) | (0.45) | (0.48) | (0.42) |
| Placebo Radius | – | 5km | 10km | 20km | – | 5km | 10km | 20km |
| Mean Dep. Var. | 9.62 | 9.62 | 9.62 | 9.62 | 4.22 | 4.15 | 4.15 | 4.15 |
| N. WBCs | 4058 | 4058 | 4058 | 4058 | 1100 | 946 | 946 | 946 |
| N. Groups | 7 | 7 | 7 | 7 | 8 | 8 | 8 | 8 |
| N. Periods | 46 | 46 | 46 | 46 | 23 | 23 | 23 | 23 |
| N. Obs | 185816 | 185816 | 185816 | 185816 | 8605 | 7015 | 7015 | 7015 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on house completions and nitrogen at the Water Body Catchment (WBC) area. Housing builds measured as the number of completed builds in each quarter, measured by the Energy Performance Certificates for new buildings issued. 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. "Placebo Radius" reassigns treatment status to the WBCs neighbouring treated WBCs (and removes actually treated ones), where the radius of being a "neighbour" varies.

Table A4: Doubly-robust dynamic diff-in-diff: Water quality outcomes

| | Dissolved Oxy. | Bioch. Oxy. Demand | pH | Chlorophyll-A |
|---|---|---|---|---|
| | % sat. | mg/l | pH scale | mg/l |
| ATT | $-0.15$ | $-0.55^{***}$ | $-0.04^{**}$ | $-2.78$ |
| | (0.59) | (0.17) | (0.02) | (3.97) |
| Mean Dep. Var. | 91.84 | 2.05 | 7.88 | 10.32 |
| N. WBCs | 3831 | 1808 | 3814 | 954 |
| N. Groups | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 |
| N. Obs | 56719 | 10504 | 57909 | 11079 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. 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 WBC-level.

Table A5: Doubly-robust dynamic diff-in-diff: Other nutrient pollution outcomes

| | Nitrate | Ammonia | Phosphate | Orthophosphate |
|---|---|---|---|---|
| | mg/l | mg/l | mg/l | mg/l |
| ATT | $-0.01$ | $-0.03$ | $0.11^{***}$ | $0.05^{***}$ |
| | (0.30) | (0.02) | (0.04) | (0.02) |
| Mean Dep. Var. | 5.06 | 0.13 | 0.15 | 0.21 |
| N. WBCs | 3732 | 3741 | 333 | 3733 |
| N. Groups | 8 | 8 | 7 | 8 |
| N. Periods | 23 | 23 | 23 | 23 |
| N. Obs | 55073 | 55574 | 2562 | 54490 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. Table shows the ATT of Nutrient Neutrality treatment on nitrate, ammonia, phosphate and orthophosphate 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 WBC-level.

Table A6: Doubly-robust dynamic difference-in-differences: House Completion

| | House Completion | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | $-1.83^{*}$ | $-1.83^{*}$ | $-1.62$ | $-1.84$ | $-1.86^{*}$ |
| | (1.05) | (1.06) | (1.13) | (1.13) | (1.04) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 9.62 | 9.62 | 10.23 | 10.39 | 10.20 |
| N. WBCs | 4058 | 4058 | 3375 | 3039 | 2419 |
| N. Groups | 7 | 7 | 7 | 7 | 7 |
| N. Quarters | 46 | 46 | 46 | 46 | 46 |
| N. Obs | 185816 | 185816 | 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. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A7: Doubly-robust dynamic difference-in-differences: House Price

| | House Price | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | $61.06^{***}$ | $61.06^{***}$ | $63.21^{***}$ | $63.07^{***}$ | $66.76^{***}$ |
| | (10.52) | (9.61) | (10.07) | (9.72) | (10.45) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 2666.59 | 2666.59 | 2665.78 | 2671.67 | 2692.44 |
| N. WBCs | 4058 | 4058 | 3375 | 3039 | 2419 |
| N. Groups | 7 | 7 | 7 | 7 | 7 |
| N. Quarters | 46 | 46 | 46 | 46 | 46 |
| N. Obs | 185816 | 185816 | 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. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A8: Doubly-robust dynamic difference-in-differences: Nitrogen

| | Nitrogen | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | $-0.57^{*}$ | $-0.57^{*}$ | $-0.64^{*}$ | $-0.64^{*}$ | $-0.73^{*}$ |
| | (0.33) | (0.31) | (0.37) | (0.35) | (0.39) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 4.22 | 4.22 | 4.46 | 4.56 | 4.72 |
| N. WBCs | 1100 | 1100 | 895 | 817 | 659 |
| N. Groups | 8 | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 8605 | 8605 | 6987 | 6394 | 5227 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A9: Doubly-robust dynamic difference-in-differences: Nitrate

| | Nitrate | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | −0.01 | −0.01 | 0.02 | 0.01 | −0.01 |
| | (0.30) | (0.29) | (0.32) | (0.28) | (0.32) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 5.06 | 5.07 | 5.24 | 5.31 | 5.44 |
| N. WBCs | 3732 | 3727 | 3118 | 2808 | 2254 |
| N. Groups | 8 | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 55073 | 55013 | 46012 | 41542 | 33496 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A10: Doubly-robust dynamic difference-in-differences: Ammonia

| | Ammonia | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | −0.03 | −0.03 | −0.03 | −0.03 | −0.03 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 0.13 | 0.13 | 0.13 | 0.14 | 0.13 |
| N. WBCs | 3741 | 3735 | 3127 | 2818 | 2264 |
| N. Groups | 8 | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 55574 | 55510 | 46417 | 41920 | 33825 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A11: Doubly-robust dynamic difference-in-differences: Phosphorus

| | Phosphorus | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | 0.04 | 0.04 | 0.05* | 0.04 | 0.04 |
| | (0.02) | (0.03) | (0.02) | (0.03) | (0.03) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 0.18 | 0.18 | 0.20 | 0.20 | 0.20 |
| N. WBCs | 1428 | 1428 | 1154 | 1035 | 837 |
| N. Groups | 8 | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 10880 | 10880 | 8826 | 7990 | 6533 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A12: Doubly-robust dynamic difference-in-differences: Phosphate

| | Phosphate | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | 0.11** | 0.11** | 0.13** | 0.15** | 0.14* |
| | (0.05) | (0.05) | (0.06) | (0.06) | (0.07) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 0.15 | 0.15 | 0.16 | 0.17 | 0.15 |
| N. WBCs | 333 | 333 | 265 | 243 | 200 |
| N. Groups | 7 | 7 | 7 | 7 | 7 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 2562 | 2562 | 2106 | 1931 | 1659 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A13: Doubly-robust dynamic difference-in-differences: Orthophosphate

| | Orthophosphate | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | 0.05*** | 0.05*** | 0.06*** | 0.06*** | 0.07*** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 0.21 | 0.21 | 0.22 | 0.22 | 0.23 |
| N. WBCs | 3733 | 3728 | 3119 | 2811 | 2257 |
| N. Groups | 8 | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 54490 | 54430 | 45513 | 41116 | 33183 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A14: Doubly-robust dynamic difference-in-differences: Dissolved Oxygen

| | Dissolved Oxygen | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | −0.15 | −0.12 | −0.35 | −0.29 | −0.56 |
| | (0.61) | (0.57) | (0.60) | (0.62) | (0.63) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 91.84 | 91.83 | 91.62 | 91.61 | 91.78 |
| N. WBCs | 3831 | 3801 | 3200 | 2887 | 2321 |
| N. Groups | 8 | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 56719 | 56475 | 47352 | 42825 | 34585 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A15: Doubly-robust dynamic difference-in-differences: Biochemical Oxygen Demand

| | Biochemical Oxygen Demand | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | $-0.55^{***}$ | $-0.55^{***}$ | $-0.50^{***}$ | $-0.45^{**}$ | $-0.32$ |
| | (0.16) | (0.17) | (0.18) | (0.20) | (0.27) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 2.05 | 2.05 | 2.06 | 2.07 | 2.04 |
| N. WBCs | 1808 | 1807 | 1530 | 1392 | 1124 |
| N. Groups | 8 | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 10504 | 10503 | 8943 | 8176 | 6530 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A16: Doubly-robust dynamic difference-in-differences: pH

| | pH | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | $-0.04^{**}$ | $-0.04^{**}$ | $-0.05^{***}$ | $-0.05^{***}$ | $-0.05^{***}$ |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 7.88 | 7.88 | 7.89 | 7.89 | 7.89 |
| N. WBCs | 3814 | 3791 | 3187 | 2874 | 2308 |
| N. Groups | 8 | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 57909 | 57796 | 48280 | 43597 | 35157 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

Table A17: Doubly-robust dynamic difference-in-differences: Chlorophyll

| | Chlorophyll | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| ATT | −2.78 | −2.80 | −2.80 | −2.93 | −3.00 |
| | (4.15) | (4.34) | (4.12) | (4.38) | (4.18) |
| No Coastal | | ✓ | | | |
| Neighbour Exclusion Radius | | | 5km | 10km | 20km |
| Mean Dep. Var. | 10.32 | 10.38 | 10.38 | 10.32 | 10.32 |
| N. WBCs | 954 | 936 | 797 | 728 | 599 |
| N. Groups | 8 | 8 | 8 | 8 | 8 |
| N. Periods | 23 | 23 | 23 | 23 | 23 |
| N. Obs | 11079 | 10972 | 9166 | 8368 | 6887 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. 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. Minimum of two treatment groups in sample. All samples exclude Q3/Q4 2023. "No Coastal" excludes all coastal WBCs from sample. "Neighbour Exclusion Radius" removes WBCs that neighbour treated WBCs within the given radius around treated WBCs. Standard errors clustered at the WBC-level.

## A.II Additional figures

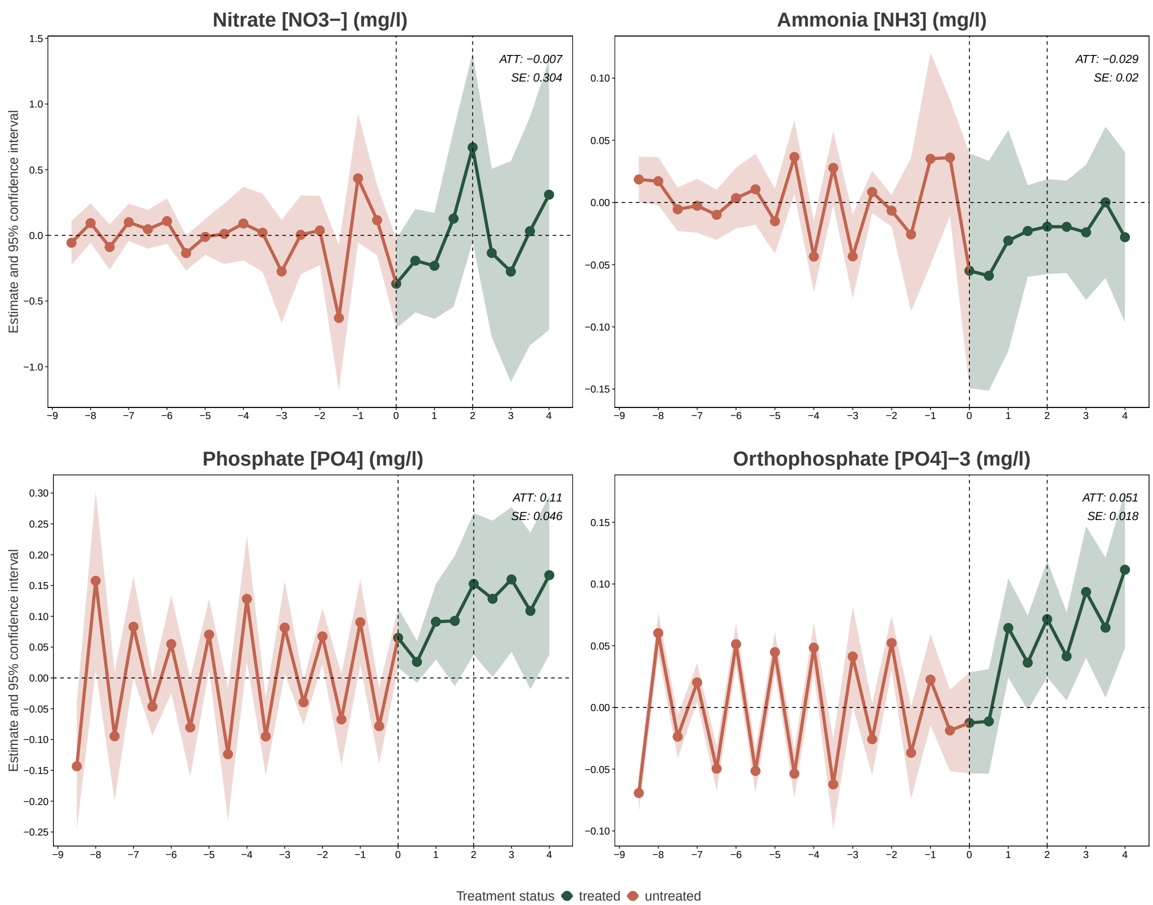


Figure A1: Event studies of sub-pollutant outcomes on Nutrient Neutrality treatment

*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 1.*

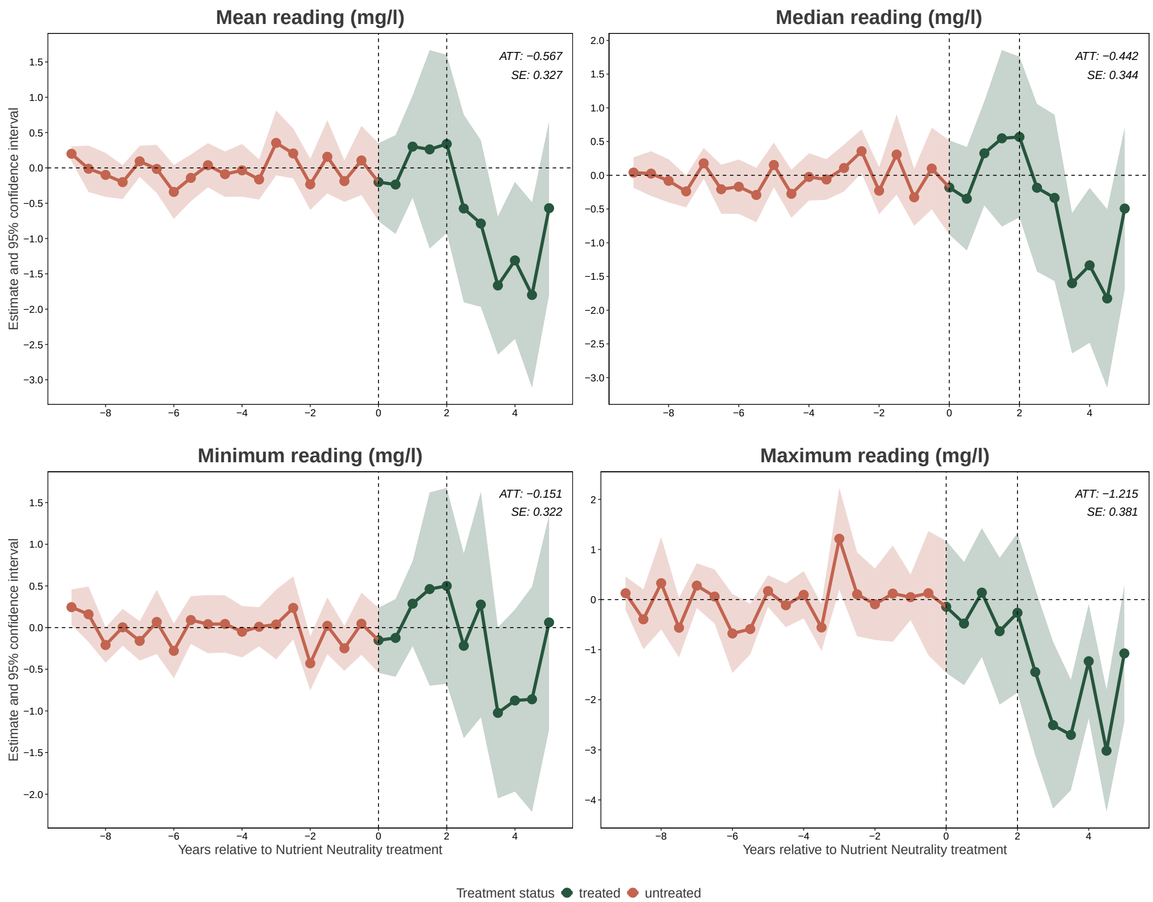


Figure A2: Event studies of nitrogen measures on Nutrient Neutrality treatment

*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 1.*

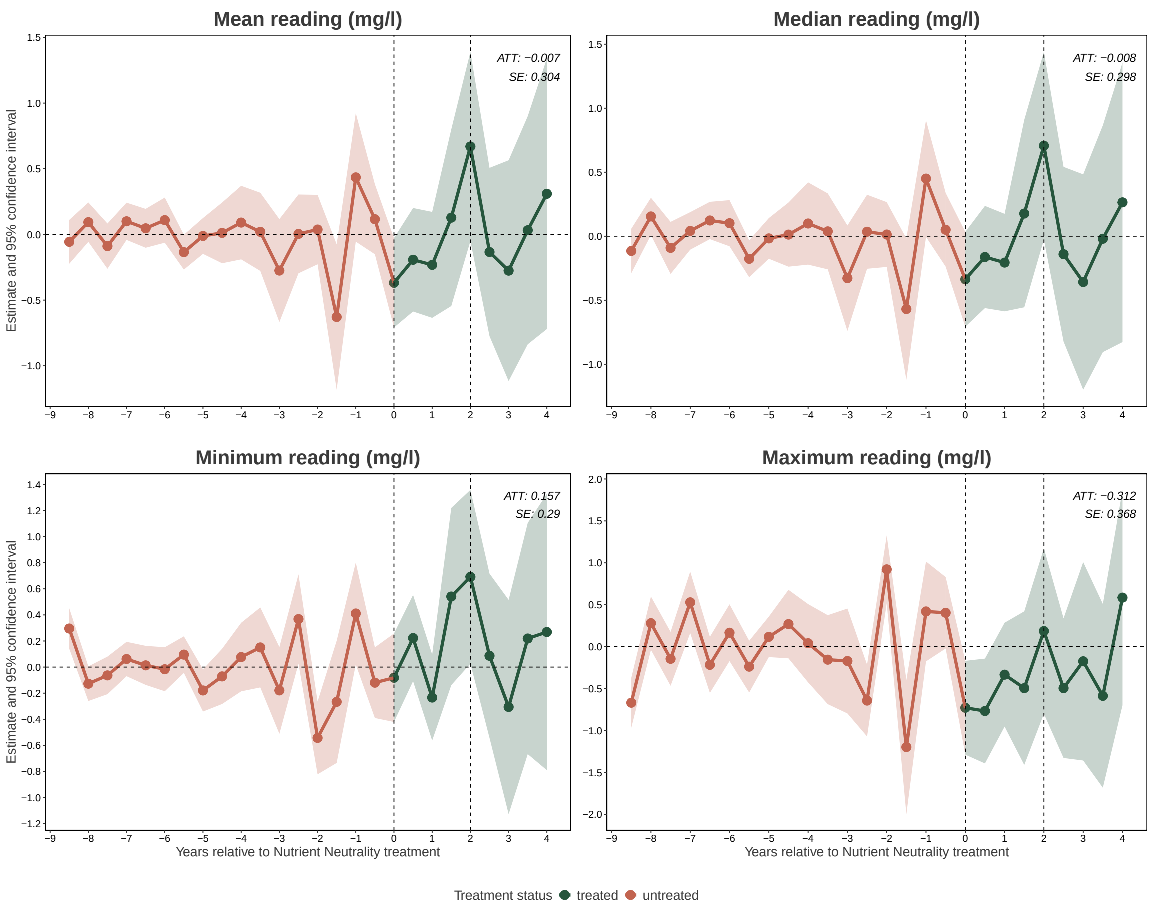


Figure A3: Event studies of nitrate measures on Nutrient Neutrality treatment

*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 1.*

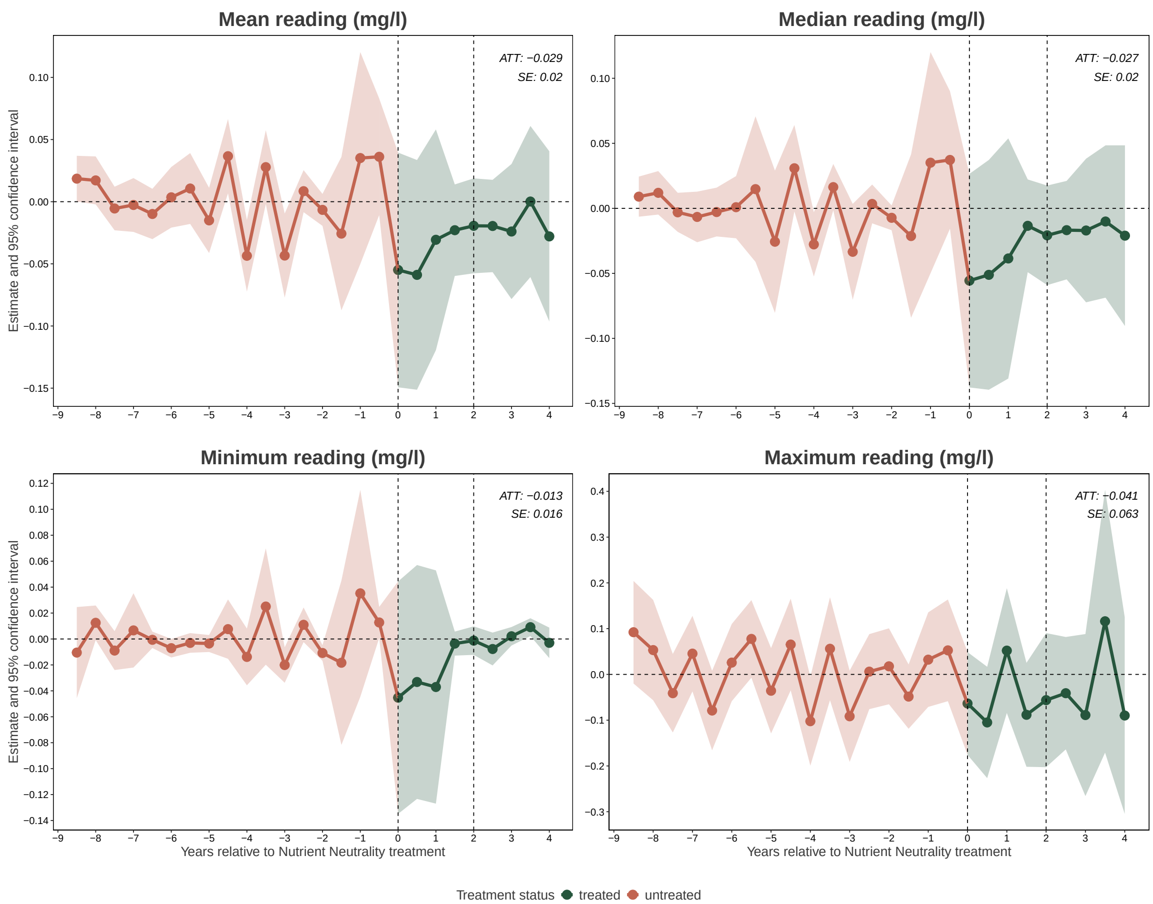


Figure A4: Event studies of ammonia measures on Nutrient Neutrality treatment

*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 1.*

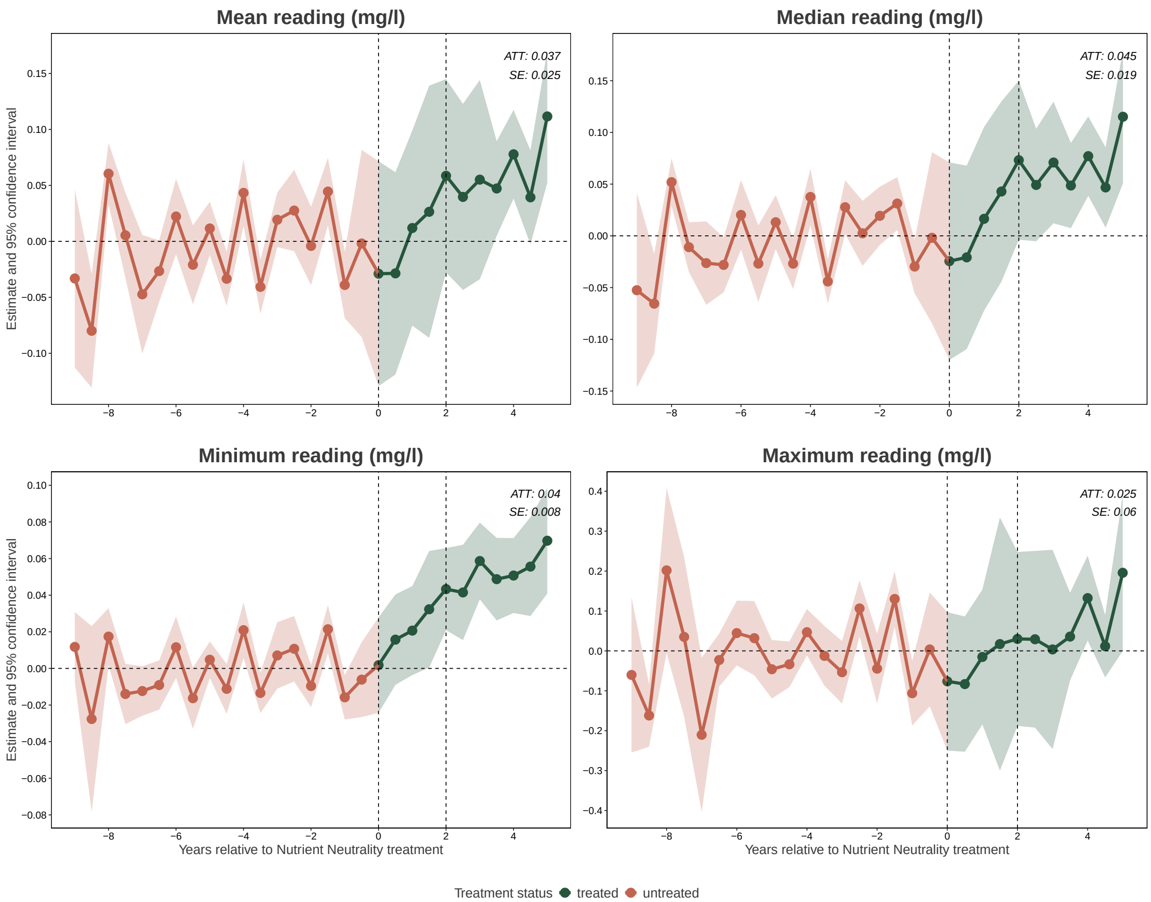


Figure A5: Event studies of phosphorus measures on Nutrient Neutrality treatment

*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 1.*

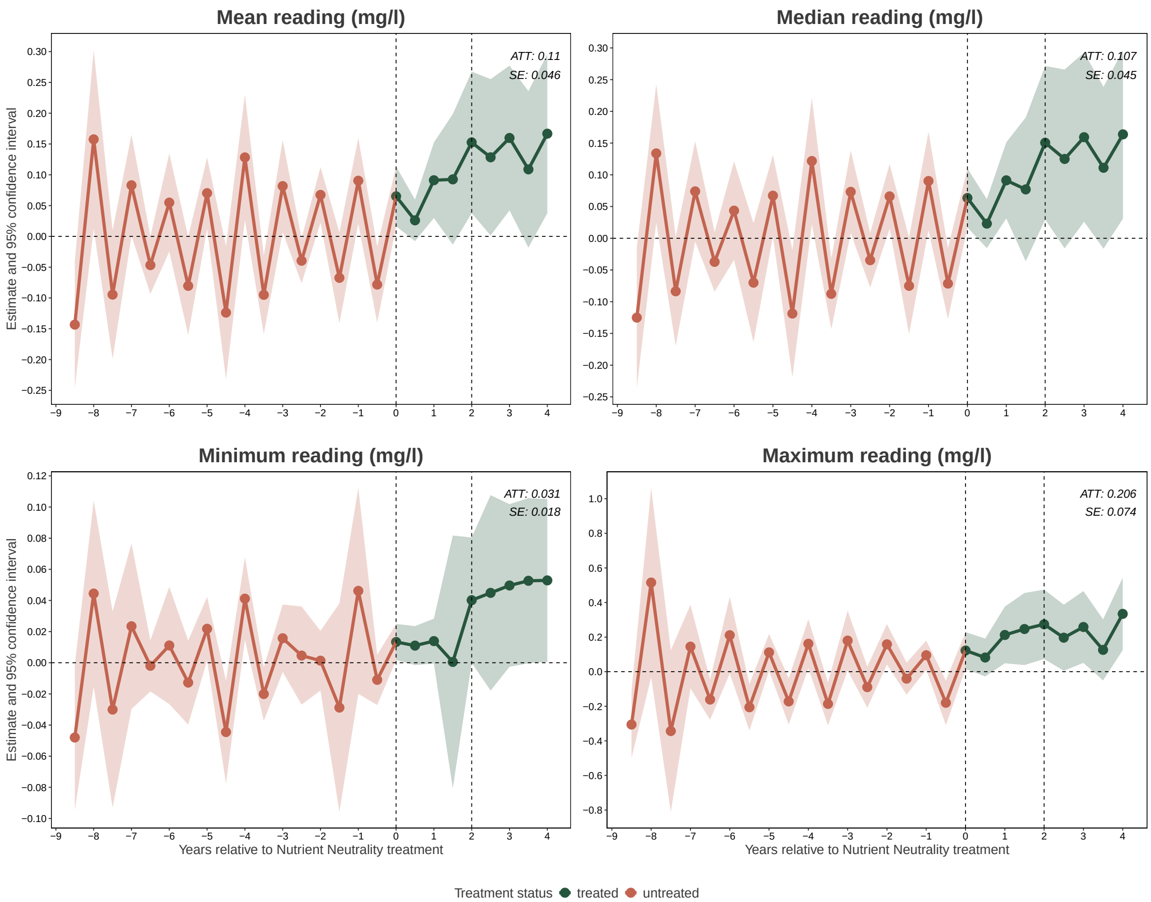


Figure A6: Event studies of phosphate measures on Nutrient Neutrality treatment

*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 phosphate per half-year, based on Equation 1.*

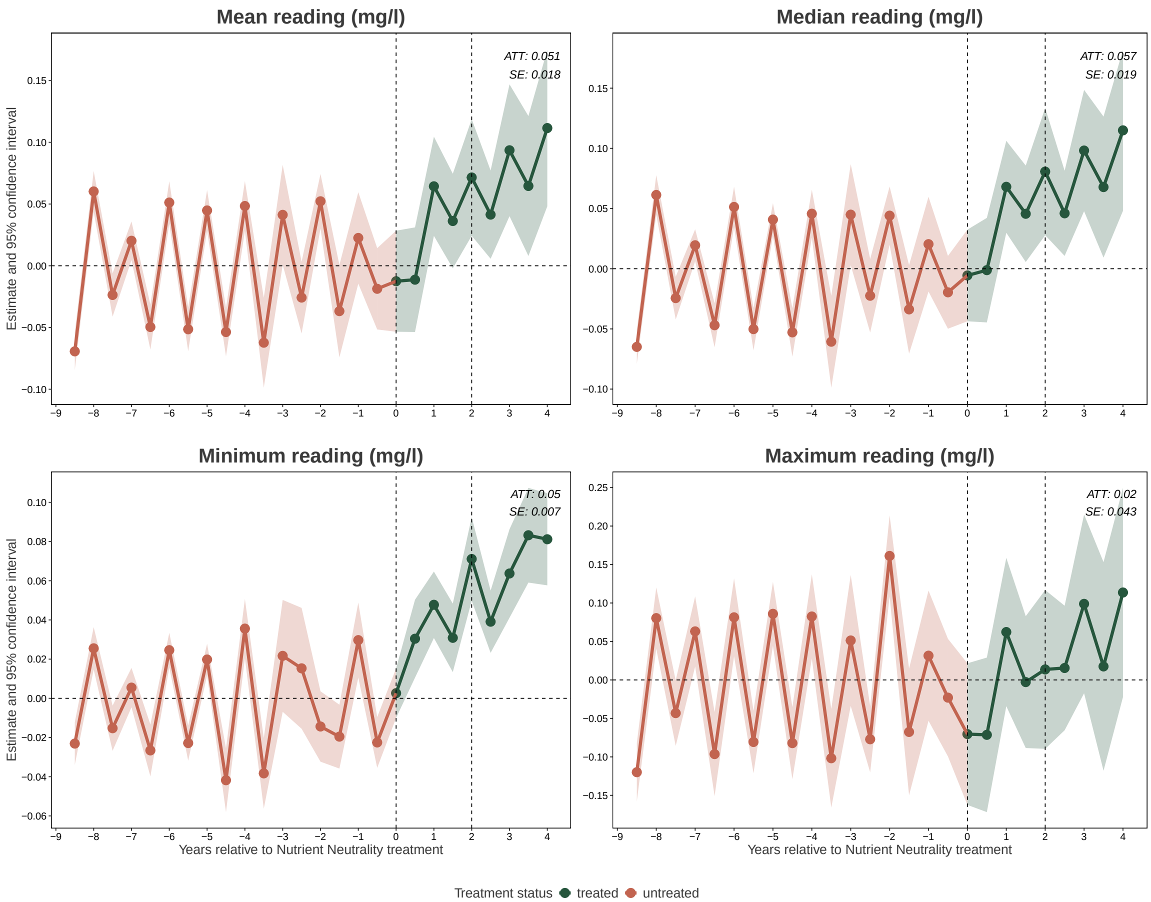


Figure A7: Event studies of orthophosphate measures on Nutrient Neutrality treatment

*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 1.*

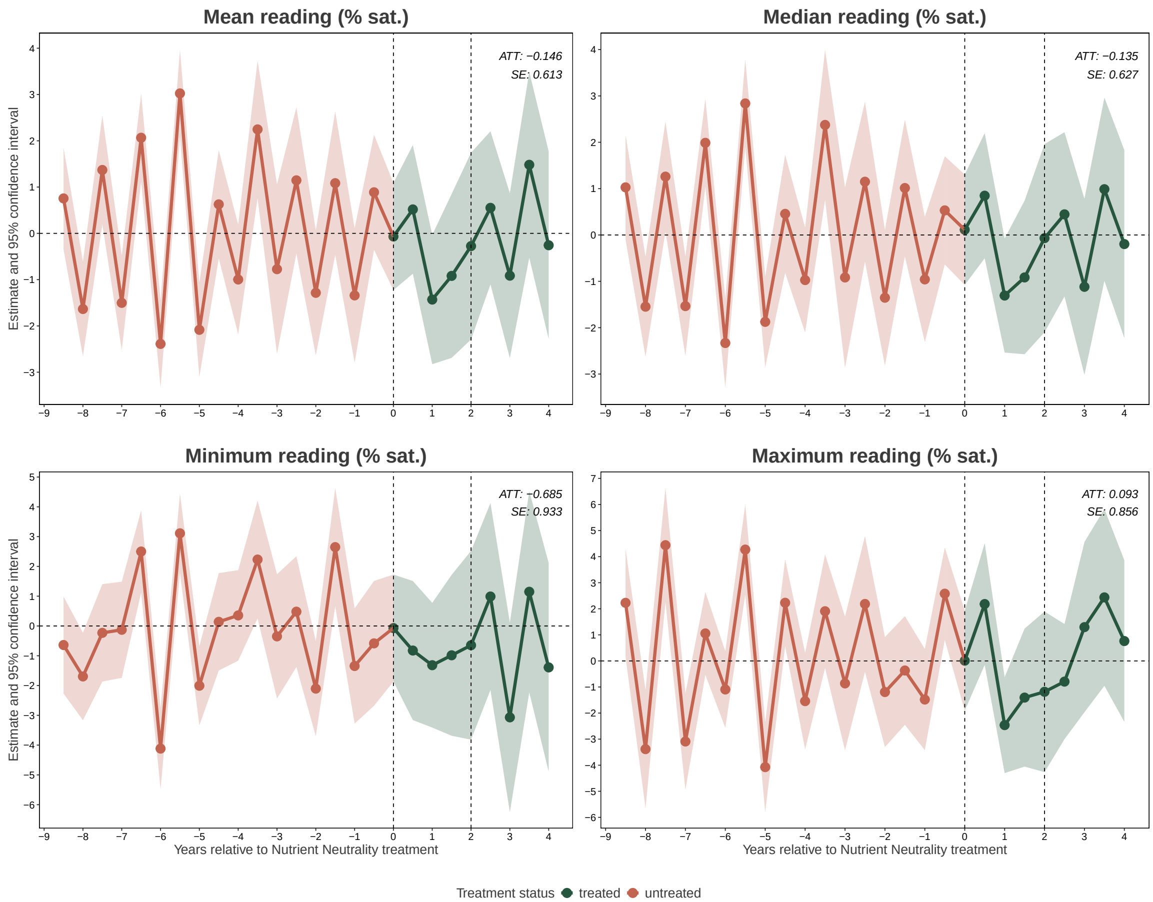


Figure A8: Event studies of dissolved oxygen measures on Nutrient Neutrality treatment

*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 1.*

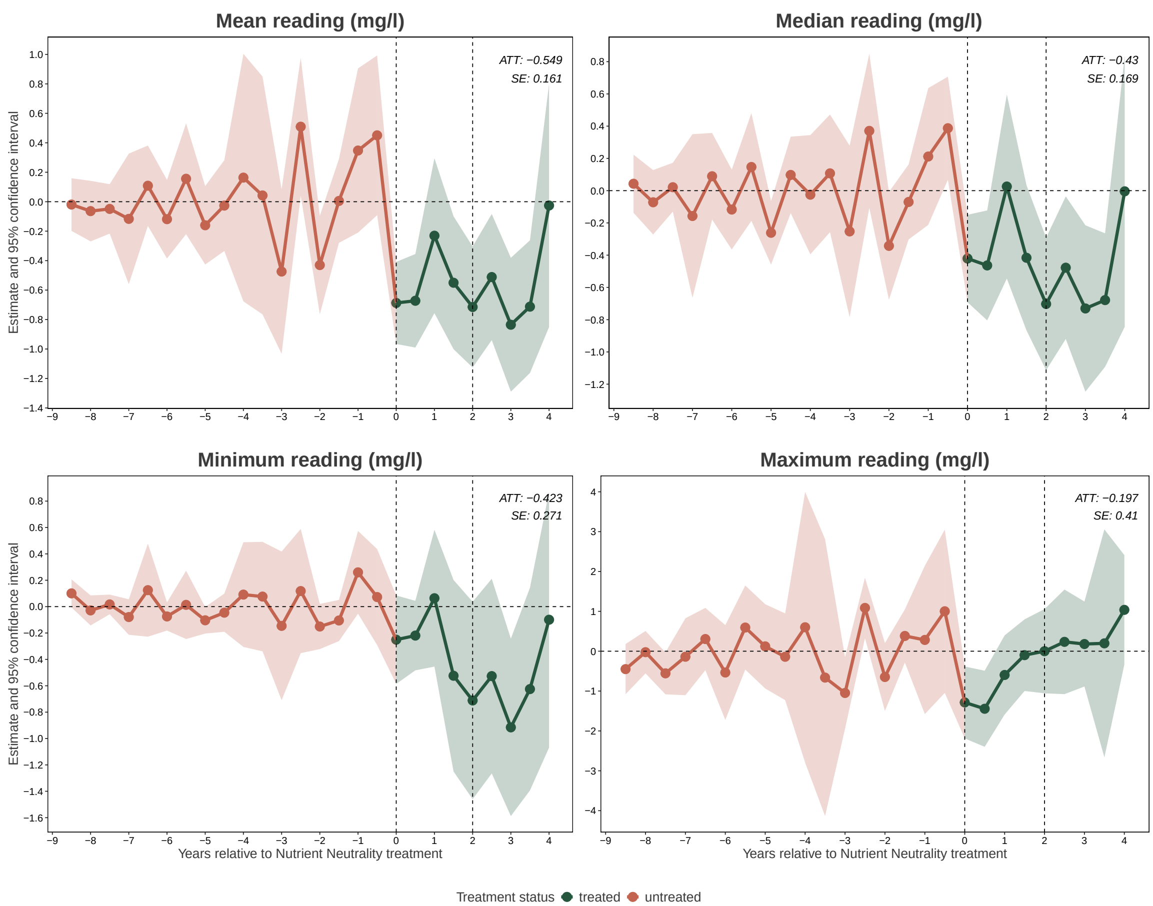


Figure A9: Event studies of biochemical oxygen demand measures on Nutrient Neutrality treatment

*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 1.*

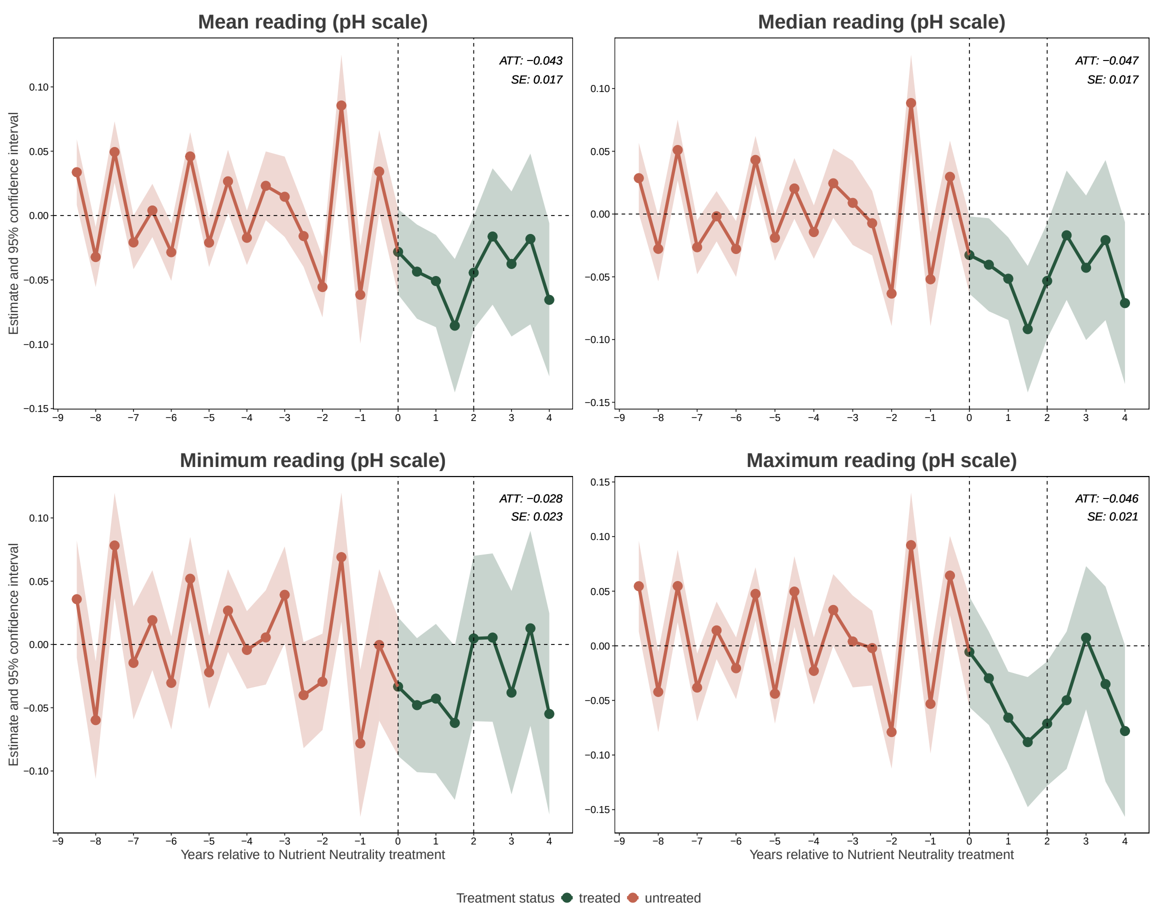


Figure A10: Event studies of pH measures on Nutrient Neutrality treatment

*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 1.*

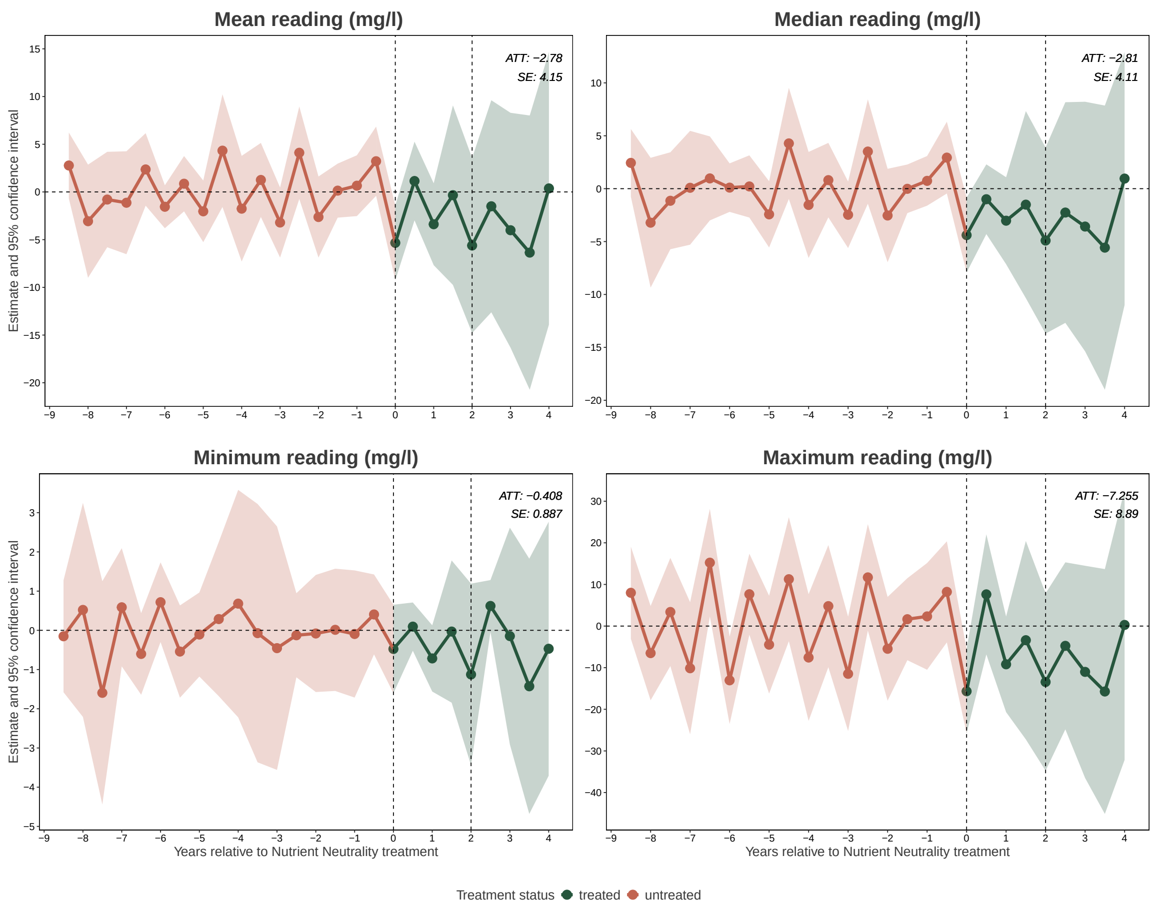


Figure A11: Event studies of chlorophyll-a measures on Nutrient Neutrality treatment

*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 1.*