nature portfolio

Peer Review File

The Potential of Carbon Markets to Accelerate Green Infrastructure Based Water Quality Trading

Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality

11th Dec 23

Dear Professor Thomas,

Your manuscript titled "Greening America's Rivers: The Potential of Climate Financing for Nature-Based Water Quality Improvement" has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We hope you will find the reviewers' comments useful as you decide how to proceed. Should additional work allow you to

• address these criticisms (that is, either to incorporate the suggestions or provide a compelling argument why the point made by the reviewer is not valid or relevant to the editorial threshold as outlined below)

AND
• meet our editorial thresholds as outlined below,

then we would be happy to look at a revised manuscript.

In the following, we list our minimum requirements for publication.

*** Present novel and firmly supported insights into the cost and environmental benefits of the green technologies and gray infrastructure alternatives to improve water quality in the United States.

*** Clarify the framing and scope of your study and provide a detailed explanation of the comparison of traditional technologies and green infrastructure options.

*** Communicate the limitations and uncertainties in your research and discuss your findings in the broader context.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
[link redacted]
** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to receive your revised paper within six weeks; please let us know if you aren't able to

submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Martina Grecequet, PhD
Associate Editor,
Communications Earth & Environment
@CommsEarth

EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

Editorial Policy: Policy requirements (Download the link to your computer as a PDF.)

Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist:
Communications Earth & Environment formatting checklist

and also in our style and formatting guide Communications Earth & Environment formatting guide .

*** DATA: Communications Earth & Environment endorses the principles of the Enabling FAIR data project (http://www.copdess.org/enabling-fair-data-project/). We ask authors to make the data that support their conclusions available in permanent, publically accessible data repositories. (Please contact the editor if you are unable to make your data available).

All Communications Earth & Environment manuscripts must include a section titled "Data Availability" at the end of the Methods section or main text (if no Methods). More information on this policy, is available at http://www.nature.com/authors/policies/data/data-availability-statements-data-citations.pdf.

In particular, the Data availability statement should include:
- Unique identifiers (such as DOIs and hyperlinks for datasets in public repositories)
- Accession codes where appropriate
- If applicable, a statement regarding data available with restrictions
- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at http://www.nature.com/sdata/policies/repositories.

If a community resource is unavailable, data can be submitted to generalist repositories such as figshare or Dryad Digital Repository. Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section.

Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The authors acknowledge that freshwater quality in the United States is impaired by non-point source pollution from sources largely unregulated, but then imply that wastewater treatment facilities, as point-source river discharges which are regulated, have to construct ”gray infrastructure” requiring significant capital and operational costs as well as embodied emissions from materials and indirect emissions from energy use, as the only means to improve river water quality.
While it is true that the EPA would consider non-point sources of nutrients when setting discharge consents for WWTWs, this does not mean that the expectation is for them to address river water quality other than reducing their own nutrient discharges. They employ ”gray infrastructure” to reduce the pollution they cause, which should be reduced to a little as possible independent of how much receiving water bodies can cope with based on other non-point pollution sources.
NBSs can be employed by wastewater treatment facilities to reduce the nutrient load of their discharges (i.e. in stages such as effluent polishing) but as complementary to their treatment processes and not as a substitute. Still this is not what the authors are talking about, as by green infrastructure they do not seem to refer to actions to be taken by WWTWs but solutions such as riparian, floodplain, and wetlands restoration; regenerative agricultural practices; improved forestry management; and other efforts to reduce non-point source contamination. Such solutions can reduce pressure on WWTWs but are not a substitute for infrastructure needed to clean their discharges.
They then consider climate finance mechanisms for redirecting climate-damaging capital toward water infrastructure, assuming that this is the reason why utilities are unwilling to invest in green infrastructure. There is clearly some confusion here, as the green infrastructure that needs to be developed is for addressing non-point source pollution and should be financed by the sectors that cause it. As a result, they end up comparing apples with oranges.
There are several other limitations with the work. While the authors accept that the results and model they present is not intended for top-down planning, there seem to be major failings in the way they have framed the problem and the scope of the opportunity.

Reviewer #2 (Remarks to the Author):

The paper provides an interesting comparison of traditional gray treatment technologies and green technologies which include constructed wetlands, saturated buffers, and agricultural management practices. In general, the authors have done a good job with this paper.

Unfortunately, I have concerns with this paper, each of which are sufficient that I am unable to recommend publication of the paper as current draft. However, my concerns are capable of rectification if the authors are willing to conduct a major revision of the draft.

The key concerns are outlined below:

1. Results: 2.1 Nutrient Remediation Potential of Green Infrastructure
Although the author provides figures and tables, the analysis of results in this part is only 3 sentences. The rest are more like method introductions, such as how gray technology is handled. In my opinion, this section could deepen the analysis of these figures and tables.

2. Results: 2.2 Global Warming Potential of Gray vs Green Infrastructure
The author mentioned carbon credit potential. Could you briefly explain its concept in the result analysis of this part or in the introduction? Because this concept runs through the results and discussions of the article, but as a reader of a high-level comprehensive journal, you may not be very familiar with this concept.

3. Discussion:
The article focuses on two scenarios: Level 2 and Level5. I'm curious to what extent the result from Level 1 to Level 5 affects carbon credits. Can the authors provide an estimate of how many carbon credits would be available under different scenarios? The discussion in this part is critical to the entire article, as it can directly support or affect the reliability of the text results.
4. Discussion:
How applicable are the scenarios in this article to other regions besides the United States? For example, is it also applicable in some European countries or some Asian countries? Are there any types of studies and what are the differences?

5. Discussion:
This article uses a large number of public databases, and the processing and spatial superposition of these data may cause some errors. Therefore, I recommend adding uncertainty analysis to the Discussion section.

6. Discussion:
#Critically however, the business as usual gray infrastructure creates inequalities in clean water access in the United States, often failing to serve the most disadvantaged populations without access to the best facilities.#
Is this sentence the result of this article? If not, it is recommended to add references to improve persuasiveness.

7. Supplemental Information：
The readability of Figure 5 is very poor. The five Buffer types and three treatments make me dizzy. It would be better if the different types could be distinguished more clearly.

8. The authors are suggested to refer to the following literature:
Chung, Min Gon, et al. "Natural infrastructure in sustaining global urban freshwater ecosystem services." Nature Sustainability 4.12 (2021): 1068-1075.

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While it is true that the EPA would consider non-point sources of nutrients when setting discharge consents for WWTWs, this does not mean that the expectation is for them to address river water quality other than reducing their own nutrient discharges. They employ ”gray infrastructure” to reduce the pollution they cause, which should be reduced to a little as possible independent of how much receiving water bodies can cope with based on other non-point pollution sources.

NBSs can be employed by wastewater treatment facilities to reduce the nutrient load of their discharges (i.e. in stages such as effluent polishing) but as complementary to their treatment processes and not as a substitute. Still this is not what the authors are talking about, as by green infrastructure they do not seem to refer to actions to be taken by WWTWs but solutions such as riparian, floodplain, and wetlands restoration; regenerative agricultural practices; improved forestry management; and other efforts to reduce non-point source contamination. Such solutions can reduce pressure on WWTWs but are not a substitute for infrastructure needed to clean their discharges.

They then consider climate finance mechanisms for redirecting climate-damaging capital toward water infrastructure, assuming that this is the reason why utilities are unwilling to invest in green infrastructure. There is clearly some confusion here, as the green infrastructure that needs to be developed is for addressing non-point source pollution and should be financed by the sectors that cause it. As a result, they end up comparing apples with oranges.

There are several other limitations with the work. While the authors accept that the results and model they present is not intended for top-down planning, there seem to be major failings in the way they have framed the problem and the scope of the opportunity.

Author’s response: We greatly appreciate the thorough review. However, it seems that our manuscript did not sufficiently provide background to the reader on how the US Environmental Protection Agency regulates point-source and non-point source pollution under the Clean Water Act. We also further failed to provide appropriate context for the existing Voluntary Carbon Market, and how both buyers and sellers participate.

We have revised our manuscript Introduction to include relevant background to inform the reader on the existing legal landscape that motivates our work. Below we expand on this for the benefit of the Reviewer and Editor.

Existing water quality trading (WQT) programs are governed by the USEPA toward compliance with a National Pollutant Discharge Elimination System (NPDES) permit. The USEPA allows for what is known as Point Source to Non-Point Source (PS-NPS) water quality trading. This has been practiced in the United States for over three decades,as we have cited throughout the paper. While regulatorily supported, WQT has failed to reach the scale necessary to make a large-scale beneficial impact on surface water quality in the US, which is partially a reason for developing this analysis and article.

*Wastewater treatment facilities (WWTFs) must construct gray infrastructure to reduce their pollutant loads under the NPDES. However, wasteload allocations (WLAs) in an individual NPDES permit are often calculated in response to pollutant levels in a river via the establishment of Total Maximum Daily Loads (TMDLs) as per these memoranda - and given the success of the Clean Water Act (CWA) since the 1970s, the percentage of instream pollutant loads directly attributable to NPDES permittees has become proportionately very low in many watersheds. Though PS pollutant inputs are often proportionately low, a high overall level of a given pollutant in a waterbody of concern often leads to significantly lower PS WLAs that may force a utility to the limits of existing technology. While there are other regulatory and non-regulatory (such as conservation funding from the US Department of Agriculture) pathways and attempts to improve instream water quality outside of Point Source (PS) permitting, none have had the levels of success over the last 50 years as the NPDES part of the CWA. So while improving the quality of an NPDES-permittee's discharge is not the *only* means to improve instream water quality, it has long been the dominant mechanism in the US to drive public investments in regional water quality.*

In response to Reviewer #1's comment that "this does not mean that the expectation is for them to address river water quality other than reducing their own nutrient discharges," we would direct Reviewer #1 to the United States Environmental Protection Agency's (EPA) webpage on Water Quality Trading, which is found under the website section for the NPDES at the following link: https://www.epa.gov/npdes/water-quality-trading. The first paragraph of this EPA webpage reads (bold is ours), "Water quality trading is a market-based approach that states, tribes, and territories ***may*** *wish to pursue as an effective means to attain water quality improvements. Water quality trading is an approach to control pollutants from multiple sources that collectively impact water quality conditions. When more stringent regulatory standards are put in place, water quality trading allows one source of pollution to control a pollutant at levels greater than required and sell 'credits' to another source, which uses the credits to* ***supplement their level of treatment in order to comply with regulatory requirements****. Pollutant reductions achieved through water quality trading must result in water quality that is as good as—or better than—what would be achieved through treatment and must not create pollutant 'hot spots.'" The webpage goes on to state, "many municipal wastewater treatment plants across the country are seeing more stringent nutrient limits in their permits. Traditionally, those facilities* ***would have to pay for new treatment technologies at the plant to meet the new limits****. Water quality trading can* ***allow facilities subject to strict requirements to purchase nutrient reductions from other treatment plants, farms, or other nutrient sources*** *to achieve the same or better water quality outcome at a lower cost." There are many other federal and state sources with definitions of WQT that are similar, but the effect is always the same: there is not an "expectation" for a WWTF to address river water quality other than reducing their own nutrient discharge, but that WQT can and should be used in lieu of certain*

facility upgrades. Thus, Reviewer #1's statement that a WWTFs discharges "should be reduced to a little as possible ***independent*** *of how much receiving water bodies can cope with based on other non-point pollution sources" is not how EPA formally allows and supports programs that allow facilities to purchase water quality credits instead of further upgrading their water treatment works - so functionally, the level of treatment at a facility and water quality in a watershed are not always regulated independently as Reviewer #1 contends, but instead EPA and state agencies support the use of WQT to regulate more holistically.*

In Reviewer #1's third paragraph, they state that facilities can use nature-based solutions (NBS) as "complementary to their treatment processes and not as a substitute." In EPA's 2003 Water Quality Trading Policy (which is linked to at the EPA's WQT webpage, and was cited in the Introduction of our paper), the third paragraph states clearly: "Water quality trading is an approach that offers greater efficiency in achieving water quality goals on a watershed basis. It allows one source to meet its regulatory obligations by using pollutant reductions created by another source that has lower pollution control costs." This sentence, and many others in the EPA WQT Policy, is clear that NBS can be used as a substitute to facility upgrades, not only as a complement.

Reviewer #1 states that our paper "seem(s) to refer to actions to be taken by WWTWs but solutions such as riparian, floodplain, and wetlands restoration; regenerative agricultural practices; improved forestry management; and other efforts to reduce nonpoint source contamination. Such solutions can reduce pressure on WWTWs but are not a substitute for infrastructure needed to clean their discharges." Reviewer #1 is correct in terms of the actions that the Authors are referring to. From EPA's 2003 WQT Policy, Section II.F. "EPA supports the creation of water quality trading credits in ways that achieve ancillary environmental benefits beyond the required reductions in specific pollutant loads, such as the creation and restoration of wetlands, floodplains and wildlife and;or waterfowl habitat." And, as stated by the Authors in the above paragraph, these actions are regulatorily supported via EPA's WQT Policy to be used as substitutes for facility upgrades, in the many situations where NBS and especially PS-NPS trades are preferable. As noted in the introduction of Section II, EPA writes: "EPA supports implementation of water quality trading by states, interstate agencies and tribes where trading:

> *A) Achieves early reductions and progress towards water quality standards pending development of Total Maximum Daily Loads (TMDLs) for impaired waters.*
>
> *B) Reduces the cost of implementing TMDLs through greater efficiency and flexible approaches.*
>
> *C) Establishes economic incentives for voluntary pollutant reductions from point and nonpoint sources within a watershed.*
>
> *D) Reduces the cost of compliance with water quality-based requirements.*
>
> *E)-H) here*

Reviewer #1 states "They then consider climate finance mechanisms for redirecting climate-damaging capital toward water infrastructure, assuming that this is the reason why utilities are unwilling to invest in green infrastructure." In terms of Reviewer #1's statement on the Author's assumptions, we feel that we have clearly laid out many reasons why utilities do not often invest in green infrastructure for NPDES

compliance. In the Introduction of the paper, we write (bolding our own): "These types of formal, market-based 'water quality trading' programs were established and recently strengthened by the EPA and several state-level regulators, but have not achieved significant scale, despite often being much more cost effective, ***primarily because distributed, nature-based or green solutions are not as readily monitored and performance is not easily verified*** *as established, gray infrastructure technology solutions. This technology–capability barrier leads to* ***risk adversity on the part of the regulator****. In turn, utilities* ***are unwilling to burden tax- and rate-payers with green infrastructure project costs*** *if a required regulator-provided permit is not forthcoming. Emerging technologies may support improved monitoring and management of nature-based or green water quality solutions.* ***Paired with these advances, climate finance may provide a private capital source to motivate utilities and regulators using green infrastructure to take pre-permit, early action.****" The Author's feel that we have clearly laid out in the Introduction of the paper that there are multiple reasons why gray infrastructure has long been the preferred solution in the US to achieve NPDES compliance and other water quality goals, but that climate finance paired with emerging technologies *may provide* a private capital source to motivate green infrastructure usage, which is factual.*

Reviewer #1 writes that "[t]here is clearly some confusion here, as the green infrastructure that needs to be developed is for addressing non-point source pollution and should be financed by the sectors that cause it. As a result, they end up comparing apples with oranges." Referring to the 2003 EPA WQT Policy as well as the 2019 EPA Memo 'Updating the EPA's Water Quality Trading Policy to Promote Market-Based MEchanisms for Improving Water Quality'. These citations, and others in the submitted paper, are clear that the Authors are not focused on NBS to improve water quality from PS (such as polishing a discharge with a natural treatment wetland) but instead are focused on the green infrastructure to address NPS, and are building from a solid regulatory framework that supports PS investment in NPS projects.

The Reviewer #1 opinion that these projects 'should be financed by the sectors that cause it' is an opinion that we certainly agree with in principle, but does not reflect 50+ years of applying a CWA that directly regulates PS and only has voluntary calls for action from NPS landowners has demonstrated that there is no specific, time-bound driver to require the financing of NPS projects by the sectors that cause NPS solution, which is a primary reason for authoring this paper and considering innovative financing mechanisms such as carbon finance.

Reviewer #2 (Remarks to the Author):

1. Results: 2.1 Nutrient Remediation Potential of Green Infrastructure

Although the author provides figures and tables, the analysis of results in this part is only 3 sentences. The rest are more like method introductions, such as how gray technology is handled. In my opinion, this section could deepen the analysis of these figures and tables.

The reviewer is correct. Section 2.1 lacks in analysis of the results and also provides some methods associated with gray technologies. As such, discussion in this section has been expanded to highlight the benefit of green treatment technologies even though they cannot meet full nutrient reduction targets. Specifically, the text that read "A similar analysis was completed for the deployment of gray technologies. In order to ensure green and gray treatments were compared evenly, the gray nutrient treatment levels were set equal to those of the green maximum treatment technologies even though they are not limited by agricultural land constraints. If these limitations were not placed on gray treatment technologies, they would treat more nutrients which would increase their treatment costs and emissions and exaggerate the benefit of green treatment methods." has been removed since it is restated in the methods section and the following text has been added: "These agricultural land limitations are seen in the desert southwest where limited agriculture land exists, in Missouri where high wastewater flow rates exist (Supplemental Figure 4), and in the northeast where land availability is limited due to high population densities. While green treatment methods can only treat less than 40% of nitrogen and 25% of phosphorus needed in the US, this would still represent a significant decrease in infrastructure compared to the scenario where green treatment methods are not used on a large scale. This is particularly true at the higher treatment levels where more advanced gray water treatment technologies are required. According to the EPA report, the only treatment technologies which can reach Level 5 concentration levels are those that use sidestream reverse osmosis filtration systems that suffer from issues of frequent fouling which both decreases treatment efficiency and increases operation expenses [16, 19, 20]. Therefore, reducing the need for any gray wastewater treatment infrastructure would be of benefit."

2. Results: 2.2 Global Warming Potential of Gray vs Green Infrastructure

The author mentioned carbon credit potential. Could you briefly explain its concept in the result analysis of this part or in the introduction? Because this concept runs through the results and discussions of the article, but as a reader of a high-level comprehensive journal, you may not be very familiar with this concept.

Concur. We have added a review of the Voluntary Carbon Market to the Introduction.

3. Discussion:
The article focuses on two scenarios: Level 2 and Level 5. I'm curious to what extent the result from Level 1 to Level 5 affects carbon credits. Can the authors provide an estimate of how many carbon credits would be available under different scenarios? The discussion in this part is critical to the entire article, as it can directly support or affect the reliability of the text results.

We have re-run our analysis for Levels 3 and 4 (Level 1 is a "no limit" water quality concentration and therefore cannot be analyzed) and have included these results, including the carbon credit generation and potential revenue, in our Results in Table 1.

4. Discussion:

How applicable are the scenarios in this article to other regions besides the United States? For example, is it also applicable in some European countries or some Asian countries? Are there any types of studies and what are the differences?

The USEPA has a unique approach to regulating point source discharges, and largely not regulating non-point source discharges. As such, it is difficult to extend this analysis globally. However, there are a number of other similar water quality trading programs globally. We have added a brief review and extrapolation to a global potential at the end of the Discussion section.

5. Discussion:
This article uses a large number of public databases, and the processing and spatial superposition of these data may cause some errors. Therefore, I recommend adding uncertainty analysis to the Discussion section.

The reviewer makes a good point and observation related to uncertainty in the work. In the manuscript's discussion section we include a discussion on the uncertainty of the work. Specifically, the green technologies being evaluated have been ground truthed in high impact areas (Corn Belt) but have not been demonstrated nationally. This is a limitation, but one that does not have a dramatic impact on the results as the areas where there is limited data are also the areas where green treatment technology deployment is limited based on the land and nutrient availability. The work here is intended to bound the problem and highlight the opportunity for case studies to be evaluated. The primary public datasets used in this research (EPA's EnviroAtlas, USDA Agricultural Census, and SPARROW) do not report uncertainty values for their datasets, which makes it very difficult to perform a proper uncertainty analysis on this work. In an effort to demonstrate the uncertainty in the work we have evaluated the performance of the system across the US at Levels 2 through 5, included detailed results in the supplementary material, and have expanded the discussion paragraph in the main manuscript related to uncertainty.

6. Discussion:
#Critically however, the business as usual gray infrastructure creates inequalities in clean water access in the United States, often failing to serve the most disadvantaged populations without access to the best facilities.#
Is this sentence the result of this article? If not, it is recommended to add references to improve persuasiveness.

We have deleted this sentence and replaced it with a statement regarding the employment benefits of green infrastructure projects, with a citation.

7. Supplemental Information :
The readability of Figure 5 is very poor. The five Buffer types and three treatments make me dizzy. It would be better if the different types could be distinguished more clearly.

The authors appreciate the feedback on the readability of this image. Based on the feedback received, Figure 5 has been revised to more clearly distinguish the different barrier types used. Additionally, the caption of the figure has been updated to more clearly define barrier methods used and discuss the differences between treatment methods.

8. The authors are suggested to refer to the following literature:
Chung, Min Gon, et al. "Natural infrastructure in sustaining global urban freshwater ecosystem services." Nature Sustainability 4.12 (2021): 1068-1075.

The authors thank the reviewer for highlighting this study and see great symmetry for reference within the manuscript. As such, the following sentence in the introduction has been adjusted to reference this study: "In many cases, gray infrastructure could be substituted with green infrastructure including riparian, floodplain, and wetlands restoration; regenerative agricultural practices; improved forestry management; and other efforts to reduce non-point source contamination to enable point dischargers to meet water quality standards and sustain freshwater ecosystems [4]."

21st Feb 24

Dear Professor Thomas,

Your manuscript titled "Greening America's Rivers: The Potential of Climate Financing for Nature-Based Water Quality Improvement" has now been seen by 2 reviewers, and we include their comments at the end of this message. They continue to find your work of interest, but have raised some more important points. We remain interested in the possibility of publishing your study in Communications Earth & Environment but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. In particular, for publication in Communications Earth & Environment, we request that you:

- Clarify comparison of green-based solutions and grey infrastructure – please move text and explanation from the response letter
into the main text as suggested by reviewer 1.

- Acknowledge that there are nature-based solutions that Waste water treatment facilities can employ directly and without trading as
alternatives to the grey infrastructure they use for final effluent treatment as suggested by reviewer 1.

- Ensure consistency in terms related to green infrastructure and Nature-based solutions.

- Discuss barriers associated with water quality trading, uncertainties related to the lack of utility experience, and the lack of
widely available evidence from previous applications; address the limitations of your approach and the possibility of application
in other regions.

Please highlight all changes in the manuscript text file.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
[link redacted]
** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and

the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Martina Grecequet, PhD
Associate Editor,
Communications Earth & Environment

EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

Editorial Policy: Policy requirements (Download the link to your computer as a PDF.)

Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist:
Communications Earth & Environment formatting checklist

and also in our style and formatting guide Communications Earth & Environment formatting guide .

*** DATA: Communications Earth & Environment endorses the principles of the Enabling FAIR data project (http://www.copdess.org/enabling-fair-data-project/). We ask authors to make the data that support their conclusions available in permanent, publically accessible data repositories. (Please contact the editor if you are unable to make your data available).

All Communications Earth & Environment manuscripts must include a section titled "Data Availability" at the end of the Methods section or main text (if no Methods). More information on this policy, is available at http://www.nature.com/authors/policies/data/data-availability-statements-data-citations.pdf.

In particular, the Data availability statement should include:
- Unique identifiers (such as DOIs and hyperlinks for datasets in public repositories)
- Accession codes where appropriate
- If applicable, a statement regarding data available with restrictions
- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-

specific, community-recognized repositories, where possible and a list of recommended repositories is provided at http://www.nature.com/sdata/policies/repositories.

If a community resource is unavailable, data can be submitted to generalist repositories such as figshare or Dryad Digital Repository. Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section.

Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

Please see attachement

Reviewer #2 (Remarks to the Author):

The revised manuscript has basically resolved several of the doubts I raised during the first review, and I think it is close to the level of publication.

Overall, the authors have provided more figures and tables and improved their readability. They are basically explained and introduced. And, added a review of the Voluntary Carbon Market to the Introduction. Moreover, simulation and introduction of level 3 and level 4 were also added.

Due to the availability of data, the question of uncertainty about the analysis and the possibility of application in other regions is not well addressed in the text. Although, the author provides some descriptions and attempts. I understand that there are difficulties in answering these questions.

In addition, in the revised version of the manuscript, the picture on page 23 is not fully displayed. It is recommended to confirm before resubmitting.

Comments to authors' rebuttal and manuscript revision (in green):

Reviewer #1 (Remarks to the Author):

The authors acknowledge that freshwater quality in the United States is impaired by non-point source pollution from sources largely unregulated, but then imply that wastewater treatment facilities, as point-source river discharges which are regulated, have to construct "gray infrastructure" requiring significant capital and operational costs as well as embodied emissions from materials and indirect emissions from energy use, as the only means to improve river water quality.

While it is true that the EPA would consider non-point sources of nutrients when setting discharge consents for WWTWs, this does not mean that the expectation is for them to address river water quality other than reducing their own nutrient discharges. They employ "gray infrastructure" to reduce the pollution they cause, which should be reduced to a little as possible independent of how much receiving water bodies can cope with based on other non-point pollution sources.

NBSs can be employed by wastewater treatment facilities to reduce the nutrient load of their discharges (i.e. in stages such as effluent polishing) but as complementary to their treatment processes and not as a substitute. Still this is not what the authors are talking about, as by green infrastructure they do not seem to refer to actions to be taken by WWTWs but solutions such as riparian, floodplain, and wetlands restoration; regenerative agricultural practices; improved forestry management; and other efforts to reduce non-point source contamination. Such solutions can reduce pressure on WWTWs but are not a substitute for infrastructure needed to clean their discharges.

They then consider climate finance mechanisms for redirecting climate-damaging capital toward water infrastructure, assuming that this is the reason why utilities are unwilling to invest in green infrastructure. There is clearly some confusion here, as the green infrastructure that needs to be developed is for addressing non-point source pollution and should be financed by the sectors that cause it. As a result, they end up comparing apples with oranges.

There are several other limitations with the work. While the authors accept that the results and model they present is not intended for top-down planning, there seem to be major failings in the way they have framed the problem and the scope of the opportunity.

Author's response: We greatly appreciate the thorough review. However, it seems that our manuscript did not sufficiently provide background to the reader on how the US Environmental Protection Agency regulates point-source and non-point source pollution under the Clean Water Act. We also further failed to provide appropriate context for the existing Voluntary Carbon Market, and how both buyers and sellers participate.

We have revised our manuscript Introduction to include relevant background to inform the reader on the existing legal landscape that motivates our work. Below we expand on this for the benefit of the Reviewer and Editor.

Existing water quality trading (WQT) programs are governed by the USEPA toward compliance with a National Pollutant Discharge Elimination System (NPDES) permit. The USEPA allows for what is known as Point Source to Non-Point Source (PS-NPS) water quality trading. This has been practiced in the United States for over three decades,as we have cited throughout the paper. While regulatorily supported, WQT has failed to reach the scale necessary to make a large-scale beneficial impact on surface water quality in the US, which is partially a reason for developing this analysis and article.
*Wastewater treatment facilities (WWTFs) must construct gray infrastructure to reduce their pollutant loads under the NPDES. However, wasteload allocations (WLAs) in an individual NPDES permit are often calculated in response to pollutant levels in a river via the establishment of Total Maximum Daily Loads (TMDLs) as per these memoranda - and given the success of the Clean Water Act (CWA) since the 1970s, the percentage of instream pollutant loads directly attributable to NPDES permittees has become proportionately very low in many watersheds. Though PS pollutant inputs are often proportionately low, a high overall level of a given pollutant in a waterbody of concern often leads to significantly lower PS WLAs that may force a utility to the limits of existing technology. While there are other regulatory and non-regulatory (such as conservation funding from the US Department of Agriculture) pathways and attempts to improve instream water quality outside of Point Source (PS) permitting, none have had the levels of success over the last 50 years as the NPDES part of the CWA. So while improving the quality of an NPDES-permittee's discharge is not the *only* means to improve instream water quality, it has long been the dominant mechanism in the US to drive public investments in regional water quality.*

Reviewer's Response:

The authors' response to my review offers some clarity as to what they are proposing: They are comparing grey infrastructure that needs to be employed by single point sources such as Wastewater treatment facilities (WWTFs) to reduce their pollutant loads under the NPDES versus green based solutions that could be employed by non-point sources (i.e. farmers), such as riparian, floodplain, and wetlands restoration; regenerative agricultural practices; improved forestry management; etc that could reduce pollutant loads in the catchment to allow WWTWs to meet water quality standards **through trading**.

However, this is still not clear in parts of the manuscript where it looks like they directly "*compare traditional grey treatment technologies to green technologies which include constructed wetlands, saturated buffers, and agricultural management practices*" as alternatives for WWTFs to reduce their pollutant loads under the NPDES, without explaining that the second option could only be available to WWTFs through trading.

Moreover, in the last paragraph of the introduction they state (bolding my own):
In this research, we evaluate the economic and environmental potential of nutrient trading programs. The economic and life-cycle greenhouse gas (GHG) emissions savings ***by using green wastewater treatment methods in place of gray wastewater treatment methods*** *is evaluated.*
I now understand that they refer to green based solutions such as constructed wetlands, saturated buffers, and agricultural management practices but **green wastewater treatment methods** are something very different. For example, the authors need to acknowledge that there are NBS that WWTFs can employ directly and without trading as alternatives to grey infrastructure they use for final effluent treatment such as slow-rate soil infiltration systems, reed beds, willow systems, surface aerated ponds etc.

In fact, the terms: *Green Infrastructure; Green Wastewater Treatment Methods; Green Technologies; Green Treatment Technologies; Nature-Based Solutions; Green Solutions and Green Water Quality Solutions* are used interchangeably throughout the manuscript adding to the confusion.

Their primary analysis evaluates the benefits seen by nutrient (nitrogen and phosphorus) reduction delivered by *Green compared to Grey Infrastructure*, framed as "*the national deployment of gray versus green technologies to treat water to different levels",* which is very confusing, as what they really compare is the performance of nature based initiatives by non point sources compared to the performance of WWTFs for reducing nutrients to a level that can be delivered by the nature based initiatives.

This comparison in other words only makes sense for any additional reduction in nutrient loads WWTFs might need to deliver, when such reduction can be achieved through green infrastructure, in which case they can engage in trading. The authors make that clear in their response where they state *("…given the success of the Clean Water Act (CWA) since the 1970s, the percentage of instream pollutant loads directly attributable to NPDES permittees has become proportionately very low in many watersheds. Though PS pollutant inputs are often proportionately low, a high overall level of a given pollutant in a waterbody of concern often leads to significantly lower PS WLAs that may force a utility to the limits of existing technology.",* but not in the manuscript.

In response to Reviewer #1's comment that "this does not mean that the expectation is for them to address river water quality other than reducing their own nutrient discharges," we would direct Reviewer #1 to the United States Environmental Protection Agency's (EPA) webpage on Water Quality Trading, which is found under the website section for the NPDES at the following link: https://www.epa.gov/npdes/water-quality-trading. The first paragraph of this EPA webpage reads (bold is ours), "Water quality trading is a market-based approach that states, tribes, and territories ***may*** *wish to pursue as an effective means to attain water quality improvements. Water quality trading is an approach to control pollutants from multiple sources that collectively impact water quality conditions. When more stringent regulatory standards are put in place, water quality trading allows one source of pollution to control a pollutant at levels greater than required and sell 'credits' to another source, which uses the credits uses the credits to supplement their level of treatment in order to comply with regulatory requirements. Pollutant reductions achieved through water quality trading must result in water quality that is as good as—or better than—what would be achieved through treatment and must not create pollutant 'hot spots.'" The webpage goes on to state, "many municipal wastewater treatment plants across the country are seeing more stringent nutrient limits in their permits. Traditionally, those facilities* ***would have to pay for new treatment technologies at the plant to meet the new limits****. Water quality trading can* ***allow facilities subject to strict requirements to purchase nutrient reductions from other treatment plants, farms, or other nutrient sources*** *to achieve the same or better water quality outcome at a lower cost." There are many other federal and state sources with definitions of WQT that are similar, but the effect is always the same: there is not an "expectation" for a WWTF to address river water quality other than reducing their own nutrient discharge, but that WQT can and should be used in lieu of certain facility upgrades. Thus, Reviewer #1's statement that a WWTFs discharges "should be reduced to a little as possible* ***independent*** *of how much receiving water bodies can cope with based on other non-point*

pollution sources" is not how EPA formally allows and supports programs that allow facilities to purchase water quality credits instead of further upgrading their water treatment works - so functionally, the level of treatment at a facility and water quality in a watershed are not always regulated independently as Reviewer #1 contends, but instead EPA and state agencies support the use of WQT to regulate more holistically.

In Reviewer #1's third paragraph, they state that facilities can use nature-based solutions (NBS) as "complementary to their treatment processes and not as a substitute." In EPA's 2003 Water Quality Trading Policy (which is linked to at the EPA's WQT webpage, and was cited in the Introduction of our paper), the third paragraph states clearly: "Water quality trading is an approach that offers greater efficiency in achieving water quality goals on a watershed basis. It allows one source to meet its regulatory obligations by using pollutant reductions created by another source that has lower pollution control costs." This sentence, and many others in the EPA WQT Policy, is clear that NBS can be used as a substitute to facility upgrades, not only as a complement.

Reviewer's Response:

I appreciate the authors response, but they should also differentiate from what normally happens and what the EPA allows to happen, as they are missing my point. All I am saying is that WWTFs priority is to reduce their pollutant loads, and while the EPA has been encouraging them to use trading, this is really not as an alternative but to supplement their treatment efforts to comply with regulatory requirements. I am sure the authors appreciate that purchased water quality credits are not an alternative for wastewater treatment facilities other than for further upgrading their performance, which is what I refer to as complementary in my initial review.

In any case, I am happy with how the authors addressed that in their response, but I would like to see it explained in the manuscript as well.

Reviewer #1 states that our paper "seem(s) to refer to actions to be taken by WWTWs but solutions such as riparian, floodplain, and wetlands restoration; regenerative agricultural practices; improved forestry management; and other efforts to reduce nonpoint source contamination. Such solutions can reduce pressure on WWTWs but are not a substitute for infrastructure needed to clean their discharges." Reviewer #1 is correct in terms of the actions that the Authors are referring to. From EPA's 2003 WQT Policy, Section II.F. "EPA supports the creation of water quality trading credits in ways that achieve ancillary environmental benefits beyond the required reductions in specific pollutant loads, such as the creation and restoration of wetlands, floodplains and wildlife and;or waterfowl habitat." And, as stated by the Authors in the above paragraph, these actions are regulatorily supported via EPA's WQT Policy to be used as substitutes for facility upgrades, in the many situations where NBS and especially PS-NPS trades are preferable. As noted in the introduction of Section II, EPA writes: "EPA supports implementation of water quality trading by states, interstate agencies and tribes where trading:

A) Achieves early reductions and progress towards water quality standards pending development of Total Maximum Daily Loads (TMDLs) for impaired waters.

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Reviewer #1 writes that "[t]here is clearly some confusion here, as the green infrastructure that needs to be developed is for addressing non-point source pollution and should be financed by the sectors that cause it. As a result, they end up comparing apples with oranges." Referring to the 2003 EPA WQT Policy as well as the 2019 EPA Memo 'Updating the EPA's Water Quality Trading Policy to Promote Market-Based MEchanisms for Improving Water Quality'. These citations, and others in the submitted paper, are clear that the Authors are not focused on NBS to improve water quality from PS (such as polishing a discharge with a natural treatment wetland) but instead are focused on the green infrastructure to address NPS, and are building from a solid regulatory framework that supports PS investment in NPS projects. The Reviewer #1 opinion that these projects 'should be financed by the sectors that cause it' is an opinion that we certainly agree with in principle, but does not reflect 50+ years of applying a CWA that directly regulates PS and only has voluntary calls for action from NPS landowners has demonstrated that there is no specific, time-bound driver to require the financing of NPS projects by the sectors that cause NPS solution, which is a primary reason for authoring this paper and considering innovative financing mechanisms such as carbon finance.

Reviewer's Response:

I am glad that the authors agreed with my comments above, the result of a confusion caused by how they frame the comparison between gray and green infrastructure and the terms they use, but as I said above, the issue has still not been addressed in the manuscript. The authors cannot claim that this is clear, referring to the citations they use in the paper, when the terms they use could mean different things to different readers.

Reviewer #1 states "They then consider climate finance mechanisms for redirecting climate-damaging capital toward water infrastructure, assuming that this is the reason why utilities are unwilling to invest in green infrastructure." In terms of Reviewer #1's statement on the Author's assumptions, we feel that we have clearly laid out many reasons why utilities do not often invest in green infrastructure for NPDES compliance. In the Introduction of the paper, we write (bolding our own): "These types of formal, market-based 'water quality trading' programs were established and recently strengthened by the EPA and several state-level regulators, but have not achieved significant scale, despite often being much more cost effective, ***primarily because distributed, nature-based or green solutions are not as readily monitored and performance is not easily verified*** *as established, gray infrastructure technology solutions. This technology–capability barrier leads to* ***risk adversity on the part of the regulator****. In turn, utilities* ***are unwilling to burden tax- and rate-payers with green infrastructure project costs*** *if a required regulator-provided permit is not forthcoming. Emerging technologies may support improved monitoring and management of nature-based or green water quality solutions.* ***Paired with these advances, climate finance may provide a private capital source to motivate utilities and regulators using green infrastructure to take pre-permit, early action.****" The Author's feel that we have clearly laid out in the Introduction of the paper that there are multiple reasons why gray infrastructure has long been the preferred solution in the US to achieve NPDES compliance and other water quality goals, but that climate finance paired with emerging technologies *may provide* a private capital source to motivate green infrastructure usage, which is factual.*

Reviewer's Response:

The authors need to appreciate that their work is currently framed as a simple comparison between Gray and Green infrastructure, when what they compare is their application **in a marginal situation** (the case when WWTFs need to further upgrade their treatment processes to deliver an additional reduction in their pollutants loads), while they become alternatives **through trading**.

This means that the reason why utilities might be unwilling to invest in this alternative is not just related to green infrastructure but to the process of trading as well. The authors acknowledge both, but only assume that the reason market-based 'water quality trading' programs have not achieved significant scale, despite as they state often being much more cost effective, is primarily because distributed, nature-based or green solutions are not as readily monitored and performance is not easily verified as established, gray infrastructure technology solutions, ignoring literature that raises questions the appropriateness of trading for water management.

The article would improve significantly if some of the barriers associated with water quality trading were also considered to explain why markets for pollution credits have been rather unsuccessful in the pursuit of regulating surface water pollution in the past and discuss some the uncertainties associated with the lack of utilities experience with these, as well as the lack of widely available evidence from previous applications (the few studies have been challenged by quality data, low sample size, and the difficulty in controlling for the array of institutional factors that drive the success or failure of the programs) to increase their confidence in the process.

Author reply to latest reviewer comments in red, bold, below.

Reviewer #1 (Remarks to the Author):

The authors acknowledge that freshwater quality in the United States is impaired by non-point source pollution from sources largely unregulated, but then imply that wastewater treatment facilities, as pointsource river discharges which are regulated, have to construct ”gray infrastructure” requiring significant capital and operational costs as well as embodied emissions from materials and indirect emissions from energy use, as the only means to improve river water quality.

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They then consider climate finance mechanisms for redirecting climate-damaging capital toward water infrastructure, assuming that this is the reason why utilities are unwilling to invest in green infrastructure. There is clearly some confusion here, as the green infrastructure that needs to be developed is for addressing non-point source pollution and should be financed by the sectors that cause it. As a result, they end up comparing apples with oranges.

There are several other limitations with the work. While the authors accept that the results and model they present is not intended for top-down planning, there seem to be major failings in the way they have framed the problem and the scope of the opportunity.

Author’s response: We greatly appreciate the thorough review. However, it seems that our manuscript did not sufficiently provide background to the reader on how the US Environmental Protection Agency regulates point-source and non-point source pollution under the Clean Water Act. We also further failed to provide appropriate context for the existing Voluntary Carbon Market, and how both buyers and sellers participate.

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Reviewer's Response:

The authors' response to my review offers some clarity as to what they are proposing: They are comparing grey infrastructure that needs to be employed by single point sources such as Wastewater treatment facilities (WWTFs) to reduce their pollutant loads under the NPDES versus green based solutions that could be employed by non-point sources (i.e. farmers), such as riparian, floodplain, and wetlands restoration; regenerative agricultural practices; improved forestry management; etc that could reduce pollutant loads in the catchment to allow WWTWs to meet water quality standards **through trading**.

However, this is still not clear in parts of the manuscript where it looks like they directly "*compare traditional grey treatment technologies to green technologies which include constructed wetlands, saturated buffers, and agricultural management practices*" as alternatives for WWTFs to reduce their pollutant loads under the NPDES, without explaining that the second option could only be available to WWTFs through trading.

Moreover, in the last paragraph of the introduction they state (bolding my own):

In this research, we evaluate the economic and environmental potential of nutrient trading programs. The economic and life-cycle greenhouse gas (GHG) emissions savings ***by using green wastewater treatment methods in place of gray wastewater treatment methods*** *is evaluated.*

I now understand that they refer to green based solutions such as constructed wetlands, saturated buffers, and agricultural management practices but **green wastewater treatment methods** are something very different. For example, the authors need to acknowledge that there are NBS that WWTFs can employ directly and without trading as alternatives to grey infrastructure they use for final effluent treatment such as slow-rate soil infiltration systems, reed beds, willow systems, surface aerated ponds etc.

In fact, the terms: *Green Infrastructure; Green Wastewater Treatment Methods; Green Technologies; Green Treatment Technologies; Nature-Based Solutions; Green Solutions and Green Water Quality Solutions* are used interchangeably throughout the manuscript adding to the confusion.

Their primary analysis evaluates the benefits seen by nutrient (nitrogen and phosphorus) reduction delivered by *Green compared to Grey Infrastructure*, framed as "*the national deployment of gray versus green technologies to treat water to different levels",* which is very confusing, as what they really compare is the performance of nature based initiatives by non point sources compared to the performance of WWTFs for reducing nutrients to a level that can be delivered by the nature based initiatives.

This comparison in other words only makes sense for any additional reduction in nutrient loads WWTFs might need to deliver, when such reduction can be achieved through green infrastructure, in which case they can engage in trading. The authors make that clear in their response where they state *("…given the success of the Clean Water Act (CWA) since the 1970s, the percentage of instream pollutant loads directly attributable to NPDES permittees has become proportionately very low in many watersheds. Though PS pollutant inputs are often proportionately low, a high overall level of a given pollutant in a waterbody of concern often leads to significantly lower PS WLAs that may force a utility to the limits of existing technology.",* but not in the manuscript.

We thank the reviewer for their continued engagement, and we agree and appreciate their points on our lack of precision with these terms.

In the latest version, we have scrubbed all mentions of nature-based, green infrastructure; green wastewater treatment; etc and replaced in all instances with "green infrastructure based water quality trading".

We have removed incorrect references to "wastewater treatment" and we have also revised the title and abstract to be more precise, as "Greening America's Rivers: The Potential of Carbon Markets to Accelerate Green Infrastructure Based Water Quality Trading".

We have also revised and re-organized the introduction to immediately introduce water quality trading as the premise of this paper overall, within the explicit context of NEW upgrades.

In response to Reviewer #1's comment that "this does not mean that the expectation is for them to address river water quality other than reducing their own nutrient discharges," we would direct Reviewer #1 to the United States Environmental Protection Agency's (EPA) webpage on Water Quality Trading, which is found under the website section for the NPDES at the following link: https://www.epa.gov/npdes/water-quality-trading. The first paragraph of this EPA webpage reads (bold is ours), "Water quality trading is a market-based approach that states, tribes, and territories ***may*** *wish to pursue as an effective means to attain water quality improvements. Water quality trading*

is an approach to control pollutants from multiple sources that collectively impact water quality conditions. When more stringent regulatory standards are put in place, water quality trading allows one source of pollution to control a pollutant at levels greater than required and sell 'credits' to another source, which uses the credits uses the credits to supplement their level of treatment in order to comply with regulatory requirements. Pollutant reductions achieved through water quality trading must result in water quality that is as good as—or better than—what would be achieved through treatment and must not create pollutant 'hot spots.'" The webpage goes on to state, "many municipal wastewater treatment plants across the country are seeing more stringent nutrient limits in their permits. Traditionally, those facilities ***would have to pay for new treatment technologies at the plant to meet the new limits****. Water quality trading can* ***allow facilities subject to strict requirements to purchase nutrient reductions from other treatment plants, farms, or other nutrient sources*** *to achieve the same or better water quality outcome at a lower cost." There are many other federal and state sources with definitions of WQT that are similar, but the effect is always the same: there is not an "expectation" for a WWTF to address river water quality other than reducing their own nutrient discharge, but that WQT can and should be used in lieu of certain facility upgrades. Thus, Reviewer #1's statement that a WWTFs discharges "should be reduced to a little as possible* ***independent*** *of how much receiving water bodies can cope with based on other non-point pollution sources" is not how EPA formally allows and supports programs that allow facilities to purchase water quality credits instead of further upgrading their water treatment works - so functionally, the level of treatment at a facility and water quality in a watershed are not always regulated independently as Reviewer #1 contends, but instead EPA and state agencies support the use of WQT to regulate more holistically.*

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In any case, I am happy with how the authors addressed that in their response, but I would like to see it explained in the manuscript as well.

We agree and appreciate this advice. We have included some of our earlier reply to the reviewer explaining the permitting system and technology upgrade obligations within the text of the manuscript itself, as suggested by the reviewer.

Reviewer #1 states that our paper "seem(s) to refer to actions to be taken by WWTWs but solutions such as riparian, floodplain, and wetlands restoration; regenerative agricultural practices; improved forestry management; and other efforts to reduce nonpoint source contamination. Such solutions can reduce pressure on WWTWs but are not a substitute for infrastructure needed to clean their discharges." Reviewer #1 is correct in terms of the actions that the Authors are referring to. From EPA's 2003 WQT Policy, Section II.F. "EPA supports the creation of water quality trading credits in ways that achieve ancillary environmental benefits beyond the required reductions in specific pollutant loads, such as the creation and restoration of wetlands, floodplains and wildlife and;or waterfowl habitat." And, as stated by the Authors in the above paragraph, these actions are regulatorily supported via EPA's WQT Policy to be used as substitutes for facility upgrades, in the many situations where NBS and especially PS-NPS trades are preferable. As noted in the introduction of Section II, EPA writes: "EPA supports implementation of water quality trading by states, interstate agencies and tribes where trading:

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I am glad that the authors agreed with my comments above, the result of a confusion caused by how they frame the comparison between gray and green infrastructure and the terms they use, but as I said above, the issue has still not been addressed in the manuscript. The authors cannot claim that this is clear, referring to the citations they use in the paper, when the terms they use could mean different things to different readers.

We agree, as described above we have scrubbed the manuscript to ensure consistency and accuracy in these terms.

Reviewer #1 states "They then consider climate finance mechanisms for redirecting climate-damaging capital toward water infrastructure, assuming that this is the reason why utilities are unwilling to invest in green infrastructure." In terms of Reviewer #1's statement on the Author's assumptions, we feel that we have clearly laid out many reasons why utilities do not often invest in green infrastructure for NPDES compliance. In the Introduction of the paper, we write (bolding our own): "These types of formal, marketbased 'water quality trading' programs were established and recently strengthened by the EPA and several state-level regulators, but have not achieved significant scale, despite often being much more cost effective, ***primarily because distributed, nature-based or green solutions are not as readily monitored and performance is not easily verified*** *as established, gray infrastructure technology solutions. This technology–capability barrier leads to* ***risk adversity on the part of the regulator****. In turn, utilities* ***are unwilling to burden tax- and rate-payers with green infrastructure project costs*** *if a required regulatorprovided permit is not forthcoming. Emerging technologies may support improved monitoring and management of nature-based or green water quality solutions.* ***Paired with these advances, climate finance may provide a private capital source to motivate utilities and regulators using green infrastructure to take pre-permit, early action.****" The Author's feel that we have clearly laid out in the Introduction of the paper that there are multiple reasons why gray infrastructure has long been the preferred solution in the US to achieve NPDES compliance and other water quality goals, but that climate finance paired with emerging technologies *may provide* a private capital source to motivate green infrastructure usage, which is factual.*

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difficulty in controlling for the array of institutional factors that drive the success or failure of the programs) to increase their confidence in the process.

We concur. We have deleted our summary and instead replaced it with the following, better cited text:

Two recent studies have analyzed factors that contribute to the existence of water quality trading programs. In one study, a a negative association between urban activity and the presence of WQT markets was observed, aligning with the historical context of WQT evolving as a tool to incentivize reductions in agricultural runoff. Further, this study identifies a significant relationship between certain types of permit approaches taken by regulators and the likelihood of WQT market activity. Interestingly, the presence of impaired waterways does not consistently correlate with WQT markets, leading the authors to suggest a potential policy lag in addressing water quality issues \citep{Liu2023WhatTrading}. In another recent analysis, insights on active and inactive Water Quality Trading (WQT) programs were drawn from 19 reviews. 84 factors were identified in regulatory, institutional, environmental, economic, and social categories. Regulatory barriers, encompassing official rules set by government or regulatory agencies, were most frequently mentioned in 31\% of cases. Economic, institutional, and environmental factors were considered relatively equally important in 19\%, 19\%, and 18\% of cases, respectively. Specifically, the ability to directly monitor the success of WQT programs in addressing water quality was highlighted as a major institutional barrier \citep{Bendor2021PredictingMarkets}. Emerging technologies may support improved monitoring and management of green infrastructure water quality solutions (e.g.\citep{Bedell2022AValidation, Brown2017TracingModel, Ahearn2005LandCalifornia, Hohner2019WildfiresQuality, Basso2020AssessingQuality, Loiselle2020ProjectingWatershed}). These studies emphasize the significance of regulatory support and utility technical capacity to enable WQT programs.

5th Mar 24

Dear Professor Thomas,

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Best regards,

Martina Grecequet, PhD
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