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Opinion

Using a Phosphorus Flow Diagram as a Boundary Object to Inform Stakeholder Engagement

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Abstract: Phosphorus (P) is essential for life on Earth, yet its current management is unsustainable. Stakeholder engagement is urgently needed to help ensure that scientific and technical solutions to improve P sustainability meet the needs of diverse groups, yet there are comparatively few studies that provide insights into stakeholder views, perceptions, or concerns. In this opinion, we use a mass flow diagram of P as a boundary object to understand the complex challenges of sustainable P management. In particular, we map US stakeholder groups onto the mass flow diagram to incorporate human factors into mass flows at a national scale. Our approach is grounded in well-established social–scientific methodologies, such as stakeholder mapping and social network analysis, but is applied in a novel way that can be generalized to other mass flows and geographic areas. We then suggest ways that researchers can use the annotated flow diagram to identify both knowledge gaps and research gaps in stakeholder engagement, especially in interdisciplinary or convergence research contexts.

Keywords: stakeholder engagement; phosphorus; sustainability; boundary object

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1. Introduction

In 2008, a sudden spike in the global price of phosphorus (P) led to increased global awareness and concern about future scarcity of P and its potentially devastating impacts on food security [1]. Around the same time, major events such as toxic algal blooms and marine dead zones revealed the extent of the ecological damage caused by excess P in the environment [2].

To address this urgent problem, international researchers convened a series of initiatives, consortia, conferences, and workshops to engage various stakeholders and understand the scope of the challenge (e.g., the Sustainable Phosphorus Alliance, Sustainable Phosphorus Summits, and European Sustainable Phosphorus Platform). Ulrich and Schnug referred to these initiatives collectively as the “modern P sustainability movement” [3]. Much of the resulting publications from these initiatives have focused on synthesizing the contrasting perspectives of a wide range of stakeholder groups around a common set of shared goals and concerns related to P sustainability. These studies allowed researchers to comprehend the sheer complexity of the global P value chain and enumerate the possible challenges and interventions [4–8]. As a result of the past decade of research on P, we now know a great deal about the specific technical, management, and policy interventions that are needed to improve P sustainability at a global level [9]. For example, better oversight and management of fertilizer inputs could address eutrophication by preventing P from entering surface waters by way of agricultural runoff [10–16] or byproducts of the fertilizer production process [17]. Conversely, policy changes and/or market incentives could improve adoption of existing technologies to recover excess P from wastewater [18–20].

Despite this increased attention to the "wicked problem" [21] of P sustainability, empirical research involving stakeholders, which are individuals and groups who can affect or are affected by an activity, process, or decision [22–24], remains comparatively limited and diffused across numerous subfields [11,15,16,19,25–28]. Scholars have previously acknowledged that identifying stakeholders can be especially challenging for wicked problems or systemic risks [29], in part because the potential list of stakeholders could be infinite. For example, everyone who eats food produced by modern agriculture could be considered a stakeholder in the case of P sustainability. However, practically speaking, only certain groups have direct influence over P sustainability, such as groups who use P or have authority to make decisions about how P is managed. As a result, it is especially critical that researchers take steps to identify the specific stakeholders who can contribute to meaningful change.

At the same time, emerging best practices within the field of stakeholder research emphasize the importance of broadening outreach to include additional groups who have been historically marginalized or excluded from previous outreach efforts [30]. Other studies highlight the need for improved stakeholder coordination [31]. Thus, researchers must balance the practical demands of identifying a cohesive list of key stakeholders, while simultaneously broadening their lens to be more inclusive of underrepresented groups.

Given the challenges described above and the cross-disciplinary nature of the literature on P sustainability, we determined that a more systematic approach was needed to identify and assess potential stakeholders. In this opinion, we describe how we used a P flow diagram as a boundary object [32] to identify stakeholders associated with key P flows that can be used to inform future engagement efforts involving US stakeholders. Our approach is grounded in related social–scientific methodologies, such as stakeholder mapping [33,34] and social network analysis [35,36], but applied in a novel way, by drawing on an approach typically employed by scientists and engineers: a mass (or substance) flow diagram. We argue that this approach may have wider applications to help researchers identify and engage diverse stakeholders for other mass flows, especially in cross-disciplinary or convergence research contexts.

2. The P Flow Diagram as a Boundary Object

In this opinion, we use a mass flow diagram of P as a boundary object to understand the complex challenges of sustainable P management in the US context. According to Leigh Star, boundary objects refer to physical or conceptual artifacts that allow people who come from different perspectives or disciplines to share a mental model of a common problem. Boundary objects allow individuals to see how they can contribute to solutions to the shared problem while also understanding how others who use different methods or approaches are contributing to the solution [32,37]. Our "revised" or "annotated" P flow diagram (Figure 1) is based on a schematic representation of P flows developed by Cordell and White [4]. This and similar versions of the same diagram have been adopted by other researchers in the field in the past decade [38–42].

Flow analyses are excellent examples of boundary objects; in addition to their more specific use within engineering, flow diagrams have been used to outline the array of challenges associated with a given material or nutrient flow (e.g., [43–48]). Given that mass flow diagrams have a broader usage outside engineering, then there is value in considering what ideas or concepts are excluded from a mass flow diagram and are, therefore, less likely to be part of researchers' own definition of either the problem or the solution to P sustainability.

We argue that the P flow diagram as described above is missing a critical component that has a tangible impact on researchers' ability to address the problem of P management and sustainability—the role of stakeholders in influencing or affecting P flows. In a typical P flow diagram, humans are but one part of the larger process of nutrient cycling; as such, humans are not generally represented as actors or agents who can affect flows. Although mass flow diagrams are not traditionally intended to capture stakeholder relationships, we note that omitting stakeholders obscures the influence that human decisions have on those flows. This poses challenges for researchers, industry, or other decision makers who use flow diagrams as boundary objects, because they may be literally unable to "see" potential barriers to adoption of novel technologies or solutions, simply because these aspects are not readily captured on a mass flow diagram.

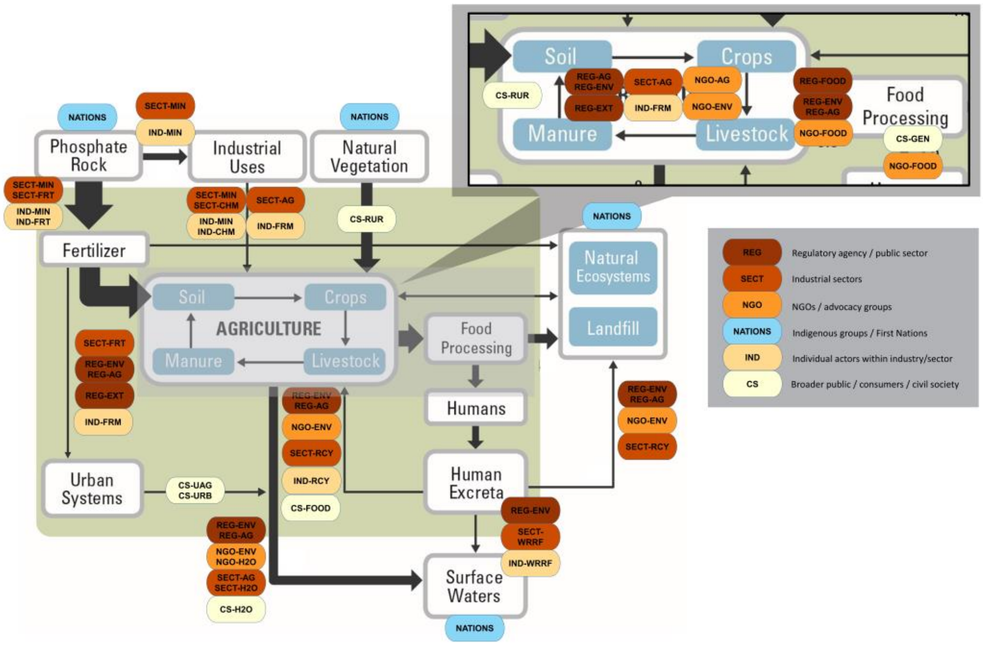

Figure 1. Phosphorus flow diagram with stakeholder groups mapped onto mass flows. Diagram developed by the STEPS Center and inspired by a version published by Cordell and White, Annu. Rev. Environ. Resour. 2014. 39:161–88 [4]. The arrow size indicates relative differences in sizes of flows.

Given the utility of the P flow diagram as a boundary object, it is important to address this gap and incorporate stakeholders into the diagram itself. Mapping stakeholders onto the P flow diagram has the potential to allow researchers to improve their collective understanding of not just the flow of mass, but the actors and groups whose decisions shape mass flows. By incorporating human actors and groups into ecological processes, we are inspired by methodologies such as stakeholder mapping and social network analysis. We also build on the work of other researchers who have called for incorporating social, economic, and political factors into substance flow analysis [49], and a recent example where researchers have used substance flow analysis to guide the design of stakeholder engagement workshops [50]. However, to the best of our knowledge, this is the first time that this diagram has been used to map stakeholders onto specific P flows, and it may be the first time that a mass flow diagram has been used as a tool for stakeholder mapping.

3. The Process of Mapping Stakeholders onto the P Flow Diagram

To develop an "annotated" P flow diagram that includes US stakeholders (Figure 1), we conducted a literature review to identify the most relevant people and groups that are already known to researchers. We began with a broad survey of the peer-reviewed literature related to P sustainability, as well as a more focused search on existing studies that engaged US stakeholders. This initial review employed variations on the key words "stakeholder engagement", "phosphorus", and "sustainability", and focused on papers published since 2000 that provided topical overviews, meta-analyses, reviews, and/or empirical research. A large number of the papers that appeared in these initial searches described a process or model that could be used for prospective engagement, without providing much insight on the stakeholders themselves. These findings are consistent with Kliskey et al. [51], where the authors observed "a pattern of recognition of stakeholder engagement importance, whereas the integration of engagement into research lags behind significantly".

Next, we broadened our search to include topical overviews related to specific P flows (e.g., "wastewater" and "phosphorus") to refine our understanding of relevant stakeholders in those flows. We intentionally took an iterative approach to this stage of reviewing the literature because a systematic survey of all possible studies related to all aspects of the P flow diagram was neither feasible nor practical for our purposes. However, the practice of reading widely across many fields helped us think creatively about potential gaps in stakeholder inclusion while overcoming disciplinary silos.

To produce Figure 1, we applied the collective knowledge gathered from the literature review to map stakeholders onto each "flow" on the P flow diagram. We divided stakeholders into six major categories: (1) regulatory agency/public sector, (2) industrial sector, (3) nongovernmental organizations (NGOs) and/or advocacy groups, (4) indigenous peoples/first nations, (5) individual actors within a given industry or sector, and (6) civil society, which includes consumers as well as the broader public. These categories are identified in the figure by a color and prefix ("e.g., "NGO-"). Within these broad categories, we specify the industry, sector, or issue relevant to that flow with a suffix (e.g., "-AG"). For example, for the flow of "human excreta" to "agriculture", the figure denotes that relevant stakeholders could include regulatory agencies in agriculture and environmental protection (REG-AG and REG-ENV), consumers concerned about food (CS-FOOD), P recycling industry interests (SECT-RCY), and individual members of that sector engaged in recycling and reuse of P (IND-RCY). In Table 1, we further elaborate on the meaning of each abbreviation with brief examples.

Table 1. List of US stakeholder groups by category, as depicted in the annotated P flow diagram shown in Figure 1.

Code	Descriptive Category	Short Description	Groups That This Category Could Include
CS-H2O	Consumers/civil society	Water users	Individuals who use beaches, lakes, streams, and other water bodies for recreational or personal use
CS-UAG	Consumers/civil society	Urban farmers	Farmers and/or home gardeners living in urban areas with stormwater treatment
CS-URB	Consumers/civil society	Urban dwellers	Individuals who live and/or work in urban/suburban areas
CS-RUR	Consumers/civil society	Rural dwellers	Individuals who live and/or work in rural areas
IND-RCY	Individual users or actors	Users of recycled P	Individual users of recycled P products (e.g., biosolids users; some overlap with farmers)
IND-FRM	Individual users or actors	Farmers	Individual farmers, ranchers, and/or growers
IND-FRT	Individual users or actors	Fertilizer users	Individual fertilizer users (e.g., urban gardeners, homeowners, and farmers, both large- and small-scale)
IND-WRRF	Individual users or actors	Wastewater treatment facilities	Individuals who work at wastewater resource recovery facilities (WWRFs), e.g., operators
NATIONS	Indigenous Peoples	Indigenous groups	First Nations and/or Indigenous Peoples (whether organized as groups or as individuals) who possess sovereign rights and/or respected interests in land and water resources

Table 1. *Cont.*

Code	Descriptive Category	Short Description	Groups That This Category Could Include
NGO-AG	NGOs/advocacy groups	Agricultural NGOs	Organizations that advocate for changes in agriculture, e.g., labor, animal welfare (some overlap with food and environmental NGOs)
NGO-ENV	NGOs/advocacy groups	Environmental NGOs	Organizations that advocate for improvements to environmental quality
NGO-FOOD	NGOs/advocacy groups	Food NGOs	Organizations that advocate for improvements to food systems, e.g., food security, food safety, food justice
NGO-H2O	NGOs/advocacy groups	Water NGOs	Organizations that advocate for improvements to water quality
REG-AG	Public sector	Agricultural regulators	US regulatory agenc(ies) that oversee agriculture (state and federal)
REG-ENV	Public sector	Environmental regulators	US regulatory agenc(ies) that oversee environmental issues (state and federal)
REG-EXT	Public sector	Extension agents	USDA Cooperative Extension
REG-FOOD	Public sector	Food and drug regulators	US regulatory agenc(ies) that oversee food and drugs (state and federal)
SECT-AG	Industrial sectors	Agribusiness	Businesses engaged in various aspects of food, crop, and livestock production; interests represented by commodity-specific trade associations and farm organizations
SECT-RCY	Industrial sectors	Recycling sector	Firms and advocacy organizations engaged in recycling or beneficial reuse of P, including biosolids and P recovery technology
SECT-FRT	Industrial sectors	Fertilizer industry	Fertilizer industry, as represented by firms and trade associations
SECT-H2O	Industrial sectors	Commercial water use industry	Groups who use lakes, rivers, streams and other water bodies for business purposes (e.g., commercial fishing, tourism)
SECT-MIN	Industrial sectors	Mining industry	Phosphate rock mining operations, including processing and storage of mining waste
SECT-WRRF	Industrial sectors	Water resource recovery sector	WWRFs and professional organizations that represent WWRF interests

As Table 1 indicates, we identified and located some stakeholders from the extant literature, but we also suggested additional stakeholders on the basis of gaps in knowledge and/or gaps in inclusion in other studies. In some areas, we propose possible stakeholders who may not have been previously involved in other studies; for example, in "P loss to surface waters", we suggested that researchers consider possible stakeholders from commercial and recreational fishing. In other cases, we include known stakeholders even if we could not identify a body of published research that reported on their views and needs. For example, mining and fertilizer interests are members of the Sustainable Phosphorus Alliance [52], but their perspectives and concerns are not well captured in the peer-reviewed literature, other than in a few critical studies [25,53]. On the basis of these findings, we expect that deeper engagement with mining and fertilizer interests will be necessary in the future to move forward with P sustainability, so that those industries feel included in broader conversations about sustainability. We acknowledge that these patterns of inclusion and exclusion may also be a consequence of self-selection by stakeholders to participate in research studies: for example, academics and experts in public-sector roles are often over-represented relative to other groups. These issues may be reflective of broader challenges in sustainability research, and not limited to P [54].

In many respects, the process of developing the revised P flow diagram was similar to other exercises in stakeholder analysis, in that it required conscious decisions about which groups belong, and what level of granularity should be included in the analysis [23,30]. For example, in our diagram, we chose to distinguish industry sectors from individuals in a given sector to acknowledge that those groups are different audiences and require different engagement strategies. Thus, “agribusiness” includes a wide range of firms and trade associations that spans commodity chains, while “farmers” refers specifically to individuals engaged in farming. Even if farmers are influenced by or part of agribusiness, the diagram does not assume that agribusiness interests are an effective proxy for their interests. On another note, while we recognize that the term “stakeholder” is generally inappropriate to use in reference to Tribal Nations and other Indigenous communities [55,56], we included Indigenous Peoples in our map in order to elevate their specific interests in land and water resources as deserving of inclusion, while also remaining distinct from the interests of other groups or organizations.

The process described above can be conducted to understand stakeholders related to P flows in other regions and localities. This process can also be readily applied to other mass flows, particularly other nutrients such as nitrogen. Nevertheless, it is important to recognize that stakeholder mapping is more of an art than a science. Other approaches to classifying and understanding stakeholder groups as they relate to individual flows are not only possible, but encouraged. For example, one could envision a revised version of this diagram that also includes the direction of influence and degrees of power or authority each group has over given flows, although additional work would be needed through social science tools such as interviews and social network analysis to ascertain these power dynamics and relationships.

4. Applications for the Annotated P Flow Diagram

The annotated P flow diagram (Figure 1) can be a versatile tool to inform future research and promote inclusive engagement. First and foremost, researchers who specialize in stakeholder or community engagement can use this diagram (or one tailored to their region or community) to identify and address gaps in inclusion in existing or planned stakeholder activities. For example, in a recent stakeholder study, we found that the largest numbers of survey respondents reported expertise in agriculture and water quality, and we had comparatively few respondents who represented the mining industry or consumer goods. For future survey work or other engagement efforts (e.g., upcoming stakeholder meetings), this diagram can help us identify the groups who should be prioritized in outreach and recruitment efforts [57]. Stakeholder researchers can also use this diagram to identify research gaps, i.e., areas where little is published about stakeholder views, and prioritize research that addresses those gaps. Individuals engaged in “knowledge transfer” can use this diagram to identify key groups that will be most likely to promote effective technology transfer. However, perhaps the most important group might be other researchers whose work does not explicitly involve stakeholders; this version of the diagram can help those researchers visualize which stakeholders might be interested in or affected by their research outcomes, in a format that is legible to them. Lastly, this diagram could be used in stakeholder engagement activities, either to elicit stakeholder perceptions about influence and power relations, or more generally to encourage a more systemic approach to understanding the challenges of P sustainability [50].

We recognize that the approach described here is one of many strategies to promote inclusive stakeholder engagement. In addition to reviewing the literature, it will be valuable for P sustainability researchers to draw on the relationships, networks, and existing coalitions built by previous researchers, while also seeking out previously underrepresented or excluded groups [3,24,30]. In order to “see” possible stakeholders who are not currently involved or even mentioned in the extant literature, researchers may also benefit from fieldwork, ethnographic methods, and methods derived from participatory and/or community-engaged research [58]. For example, we expect that the diagram presented in Figure 1 will be further refined as we collect more information about stakeholder relationships and networks in the course of our own research.

5. Conclusions

In this opinion, we used the P flow diagram as a boundary object to identify and organize potential US stakeholders in P sustainability, grounded in existing knowledge from literature on stakeholder engagement in P sustainability. The process outlined here reflects existing best practices in stakeholder research to define stakeholders as those who can influence, as well as those who are influenced by, decisions about the environment, subject to pragmatic constraints on participation. Furthermore, the approach proposed here responds to calls by other researchers to employ inclusive practices to involve previously overlooked stakeholders rather than relying on the "usual suspects" already known to decision makers and researchers [24]. This approach is broadly generalizable, in that it can be used by other researchers to develop similar maps of P flows that better reflect the stakeholder groups in their own communities, and it can also be used by researchers who study other mass flows, such as nitrogen. Crucially, the annotated diagram will be useful for researchers who may not be familiar with stakeholder or community-based research, but whose work might nevertheless benefit from broader awareness of those who may be impacted by the outcomes of their research. Mapping stakeholder groups onto the P flow diagram, thus, allows researchers to identify gaps in representation in both existing engagement strategies and in the published literature, which suggests priority areas for future directions in use-inspired scientific research.

It is important to note that this adaptation of the P flow diagram is needed not due to any flaw in flow diagrams, but precisely because flow diagrams are such a valuable interdisciplinary tool to illustrate a complex environmental problem such as P sustainability. By adding stakeholders to an already well-established boundary object, researchers can understand the issue even more clearly, by recognizing that there are complex human relationships that may have an impact on scientific or technological interventions along each flow. Appreciating that complexity is key to developing the practices and technologies needed to shift the system behavior in a more sustainable direction.

Thus, mapping stakeholders onto the P flow diagram, as we performed here, is an important first step for researchers to understand not only the balance of mass flows of P, but also the potential impacts of proposed solutions that affect those flows.

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