Funding the Cleanup of Rivers and Harbors: Cities, Polluters, Ports, Developers, and the Promise of Circular Economy

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Abstract

Contaminated sediments in rivers, lakes, and harbors around the world result in diminished ecological health, degradation of environmental resources, economic losses, and, in rare cases, impacts to human health. Despite the ongoing interest in the cleanup of contaminated sediments in rivers and harbors, little progress has been made in reducing the number of contaminated sites worldwide. Much of the difficulty in advancing this cause can be attributed to the high cost of sediment cleanups and the difficulty in assigning financial responsibility for the cost of the cleanup. Simple schemes dependent on identifying polluters are fraught with underlying complexity. More elaborate approaches tied in with waterfront redevelopment show some promise but are yet to be applied routinely. New advances in the understanding of how sediments may, or may not, factor into circularity pose new challenges and opportunities, with the potential to complement new funding paradigms. The most promising possibilities for achieving circularity in sediment management lie in a kind of "punctuated circularity," which requires idiosyncratic, project-based beneficial use opportunities. However, these ideal situations are likely to remain rare for the foreseeable future, without advancements in technology and regulatory approaches, as well as development of market demand for the products made from contaminated sediments.

1. Introduction

The logic of newly energized "circular economy" discourse is appealing. Maximizing reuse of inputs, minimizing terrestrial impacts, and incorporating *ab initio* sustainability within product design and manufacture are worthwhile endeavors. But these principles' applicability to the cleanup of contaminated waterways is far from obvious. Cleanup responds primarily to legacy externalization of waste disposal costs and occasionally to management failures. Remediation involves making the best of a terrible situation through the redress of harms. It is difficult at first blush to see how making processes more circular will eliminate the continuing need to engage in reclamation activities when things go wrong.

Cleaning up contaminated rivers has proven to be an enormously expensive and time-consuming process. So much so that in many parts of the world the inventory of contaminated sediments is simply ignored or perhaps studied endlessly instead of addressing the problem. This is often due to an absence of sufficient funding. In addition, many countries lack the legal or regulatory framework to address contaminated sediment sites (Spadaro, 2011). Even countries where soil and groundwater are addressed with some efficiency, sediments are often ignored. Rhetorical arguments often suggest that the solution is as easy as "making the polluter pay." However, where applied, a singular focus on making historical polluters pay has had the counterintuitive effect of creating legal and technical complexities that ultimately impede progress toward the ultimate goal of implementing a long-term cleanup. Yet, the motivation to address sediment contamination only increases over time, with deposits of sediment contamination posing a considerable threat to water quality, the health of biota, reduction in public trust values of waterways, and in some cases, threats to human health. Making even "potentially responsible parties" liable for remediating contaminated sites sends the right deterrent signals but unleashes a torrent of resistance, litigation, wars among high paid experts, cost and delay.

Schemes involving collaboration between municipalities, ports, developers, and historical polluters can potentially accelerate cleanups and provide collateral benefits to communities. A successful example of such an approach is the Great Lakes Legacy Act (GLLA) of 2002.[1] The GLLA encourages the cleanup of contaminated sediments through

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[1] The GLLA was authorized in 2002 and reauthorized in 2008. Specifics about the act may be found at: https://www.epa.gov/great-lakes-aocs/about-great-lakes-legacy-act. The rules for implementation may be found at: https://www.federalregister.gov/documents/2006/05/01/06-4079/implementation-of-the-great-lakes-legacy-act-of-2002.

formal partnership agreements and cost sharing. Through these agreements, federal funding is leveraged with funding from state or local governments as well as from industry to remediate contaminated sediments. The GLLA, and the projects created under its auspices, generally address not only the cleanup of sediments but also the broader community needs for redevelopment and revitalization, increasing the involvement of the community and its role as a stakeholder in the cleanup process. This shared funding approach has the effect of encouraging more cost-effective resolutions and a collective sense of risk by all parties rather than the polarization of the “polluter pays” rule.

Another approach to addressing contaminated sediments has focused on the possibilities for beneficial use of contaminated sediments. This has been studied in various countries for over three decades. If it were possible to create a value-added attribute related to contaminated sediments, presumably the cost of cleanup could be offset by the value of an end product, such as a specialized building material. These studies, as yet, have failed to produce a successful approach. In most cases, technical and/or financial feasible is not observed. And even in cases where these factors are found acceptable, market resistance to the products produced is insurmountable.

Facing these conditions head on, the application of “circularity” (elimination of waste throughout supply chains and disposal; continual reuse of resources; resulting reemergence of original ecologies) fits dredged-contaminants settings imperfectly, if at all. In this paper we make that case and then reimagine how circularity principles may nevertheless inform and upgrade current practice. In the near term, we recommend consideration of particularized “punctuated circularity” conditions potentially informing some cleanups. We briefly sketch key features of such punctuated scenarios, including the application of emerging reuse technologies, the summoning of collective will among polluters and regulators, and economic returns from reused sediments flowing in the first instance back to impacted communities and thereby helping offset the high cost of cleanup projects.

2. While Circularity May Be Achievable for Some Marginally Contaminated Sediments, Opportunities to Beneficially Use Those More Seriously Contaminated Will Remain Limited – Or, Who Will Buy Bricks Made of Toxic Mud?

The concept of incorporating contaminated sediments into a beneficial use scheme (now more commonly referred to as circular economy) is not new. Researchers and practical scientists and engineers have been evaluating the possibilities for over three decades.

2.1. Attempts at Sediment Reuse Strategies in the Netherlands and Germany Faced Limiting Costs and Market Interests

Early investigations in The Netherlands and Germany concentrated on the financial and technical feasibility of treatment of contaminated sediments as an alternative to placement in confined disposal facilities (CDFs).

Contaminated sediments dredged from the Port of Hamburg were treated and beneficially used as a sealing material for mounds of dredged sediments, as a substitute for clay in dike construction, and as a raw material in the manufacture of bricks and clay pellets (Detzner et al. 2004). The most successful beneficial reuse method applied treated sediments as a cover layer on mounds of dredged material. (Detzner et al. 2004). Use of treated silt as a substitute for clay in dike construction was technically successful; however, contractors were generally unable to meet economic, legal, and ecological requirements of proposed projects (Detzner et al. 2004). HZG Hanseaten-Stein Ziegelei GmbH developed a method for manufacturing bricks made of 70 percent treated sediments and 30 percent natural clay. HZG Hanseaten-Stein Ziegelei GmbH operated a factory producing these bricks using this method for four years; however this approach was unprofitable as disposal of sediments in mounds was significantly less expensive than conversion to brick products (Detzner et al. 2004). Contaminated sediments were also used in the manufacture of fired clay pellets; however, this process achieved only a 10 to 25 percent substitution for natural clay. Therefore, this technique has not been successfully applied on a large scale (Detzner et al. 2004). Additional constraints highlighted by the individuals pioneering beneficial reuse of contaminated sediments in Hamburg include the following (Bortone et al. 2004):

- The costs are much higher than the public is generally willing to pay
- There is no available market for the resulting materials as there is low public acceptance of products manufactured from contaminated materials
- Sustainable relocation of these sediments remains the method most in line with natural sedimentation processes

The Dutch government began a pilot program in 2003–2004 to evaluate the economic and technical feasibility of reusing contaminated sediments removed from the river Maas and the Gent-Terneuzen Canal during maintenance dredging events. These sediments are too contaminated to be relocated or reused elsewhere without treatment and would normally be disposed in a CDF. Dutch government contractors used various simple treatment methods (including dewatering, sand separation, land farming, and chemical immobilization) to render sediments usable as building materials that could comply with both Dutch legal requirements and project-specific engineering requirements. The results of the pilot program indicate that the treatment and reuse of contaminated sediments is only economically feasible under a narrow set of circumstances. The Dutch government determined that it would not use the reuse strategy to address the disposal of contaminated sediments in The Netherlands. Additional limitations hindering the feasibility of reuse of contaminated sediments include the widespread availability of clean materials at a lower cost, project managers and contractors perceive long-term risks associated with use of contaminated materials, and regulators treat contaminated materials as waste, which requires additional regulation and monitoring (van der Laan et al. 2007).

2.2. High Costs and Uncertainty of Cost Recovery Limited Alternatives to Open-Ocean Disposal in New York-New Jersey Harbor

In the mid-1990s, concerns over ocean disposal of contaminated sediments in New York-New Jersey Harbor demanded further evaluation of treatment technologies for contaminated sediments. In 1993, New York and New Jersey state governments updated the criteria for open-ocean disposal of material dredged to maintain navigability of the New York-New Jersey Harbor. In response to these changes, the majority of material removed during maintenance dredging was disposed of elsewhere, leading to a surplus of contaminated sediments and a need to develop alternatives to open-ocean disposal (Douglas et al. 2003; Stern et al. 1998). The alternatives that were implemented with success include the use of treated dredged material as fill on brownfield and landfill sites to facilitate redevelopment of these areas (Douglas et al. 2003; Yozzo et al. 2004). The high cost of reuse as fill compared with disposal alone presented itself as the primary challenge in implementing this solution. The increased costs were a result of reduced material processing efficiency, due to both the physical heterogeneity of the material as well as the inconsistent supply, the high cost of treatment and decontamination of the material, and engineering and institutional controls implemented on a site-specific basis (Douglas et al. 2003; Stern et al. 1998). Other alternatives that were implemented with varying degrees of success include the use of dredged material as fill in abandoned mine sites, construction of in-water and upland habitat, filling of dead-end canals and basins, and use of contaminated sediments as raw construction material (Yozzo et al. 2004; Douglas et al. 2003). At the time, these alternate methods were either evaluated using bench or pilot scale studies or discussed conceptually (Stern et al. 1998; Douglas et al. 2003; Yozzo et al. 2004). The primary limitations on these methods were, again, high costs and the uncertainty of cost recovery (Stern et al. 1998; Douglas et al. 2003; Yozzo et al. 2004).

2.3. Sediment Reuse Efforts in France Were Limited by Market Interest

More recently, there have been additional efforts in France to beneficially use contaminated sediments in the form of bricks, similar to the earlier efforts in Germany described in section 2.1. These efforts evaluated an alternative method for disposal of contaminated sediments dredged during maintenance dredging events in the North of France, specifically treatment via the Novosol® [2] process and inclusion as a sand substitute in fired-clay bricks (Lafhaj et al. 2008; Samara et al. 2009). The Novosol® process includes two phases (Lafhaj et al. 2008):

1. The addition of chemical amendments to immobilize heavy metals
2. Heat treatment to remove organic contaminants and other organic material

After treatment, the sediments were substituted at various clay-to-sediment ratios for the sand normally included in fired-clay bricks (Lafhaj et al. 2008; Samara et al. 2009). Bricks made with a 15 percent sediment-to-clay ratio exhibited increased compressive strength and decreased porosity and water absorption when compared with traditional bricks made of quartz sand and clay (Samara et al. 2009). As the proportion of sediment to clay increased, the compressive strength and plasticity of the bricks decreased, while the porosity and water absorption increased (Lafhaj et al. 2008; Samara et al. 2009). Even with these variations, the physical parameters of sediment-amended bricks remained comparable to standard sand and clay bricks; at a 35 percent sediment-to-clay ratio, the compressive failure threshold was higher than for standard bricks (Lafhaj et al. 2008). When leaching tests were performed on the bricks, the leachate contained heavy metals at concentrations below French federal limits, indicating that the sediment-amended bricks could technically be considered non-hazardous materials (Lafhaj et al. 2008).

2.4. In Summary, Previous Efforts Fail to Present a Technically and Economically Feasible approach to Beneficial Reuse of Contaminated Sediments

None of the above-described efforts presents a technically and economically feasible method of reusing contaminated sediments. As the fundamental technical and financial barriers remain, it is not reasonable to expect a more positive outcome in the present or immediate future.

The difficulties facing successful reuse of contaminated sediments are myriad. First, the supply of contaminated sediments, the raw material for any reasonable circularity scheme, is undependable in quality, quantity, and geography. In contrast, municipal waste, sewage sludge, or biodegradable farm waste all offer reasonably reliable supply characteristics. Second, the technologies for removing, neutralizing, or decomposing the offending contaminants are energy-intensive, inefficient, and prone to incomplete results. Often, the treated sediments or other end products are expensive and contain undesirable concentrations of the original contaminants.

A recent compilation of case studies for beneficial reuse of sediments (Sittoni, 2019) confirms this conclusion. Of the 38 case studies Sittoni evaluated, only three address cleanups of contaminated sediments, all of which met with only limited success. For the foreseeable future, beneficial reuse, and the implied promise of sustainability and circularity, will remain elusive for contaminated sediments, even if arguably it is slowly becoming more feasible for dredged sediments overall.

3. Making the Polluters Pay is Plagued with Legal[3] and Technical Difficulties

Even when a legal framework is available to force a polluter to pay for sediment contamination, identifying the polluter(s) can be an elusive and daunting task. There are cases where identification of the polluter is straight forward and the identified entity is still viable. But in many cases, those parties that conducted the activities resulting in contamination may be defunct entities. All too often, the companies which caused the pollution are not present and have no viable corporate successor, resulting in so-called orphan sites. Equally vexing to some is the fact that sediment contamination can originate from non-industrial sources of contamination such as runoff from

[2] Novosol is a registered trademark of Solvey.
[3] This work takes note of the legal issues associated with the polluter pays approach but offers no legal advice.

urban centers, discharges from publicly owned treatment works, or even aerial fallout from distant industrial sources. Efforts to identify historical sources of pollution and fairly divide the cost of cleanup among responsible parties often require herculean technical and legal research and study. And it takes a long time.

Because of this time-consuming, seemingly never-ending approach, surprisingly little progress has been made in reducing the inventory of these contaminated sites worldwide. In the United States, where the risks of sediment contamination are perhaps most in the regulatory crosshairs, there is painfully slow progress and in most other countries, there is no progress at all. In many cases, the substitute for progress towards actual cleanup is prolonged study of the problem.

In a previous publication (Spadaro and Rosenthal, 2019) we proposed instead a new paradigm for waterway cleanup and waterfront redevelopment. The new paradigm requires vision to adopt any or all of the following strategies:

- Reframing and redefining the responsibilities for costs, including distributing more costs to those who benefit from waterway cleanup
- Encouraging municipalities and port authorities to catalyze cleanup efforts by adopting more proactive roles
- Driving real community investment through vision, leadership, and engagement
- Finding and leveraging alternative financing approaches, such as tax increment-based investments; funding for economic development, environmental protection, and sustainability; and public-interest capture of the inequitable windfalls that disproportionately benefit land speculators
- Tying some long-term investment gains to social and environmental benefits, such as ensuring that legacy residents can afford to remain in place, creating or reclaiming urban green spaces, and building resilience in the face of climate change

Some of what we propose is already in place in some locations, enacted through collaboration and nimble action. More can be done. For example, a coordinated financial system that ties long-term gains in waterfront values to payment for sediment cleanup would reallocate responsibilities and invigorate community investment at the inception of the remediation process.

4. Contaminated Sediments and Beneficial Reuse: Imagining Moments of "Punctuated Circularity"

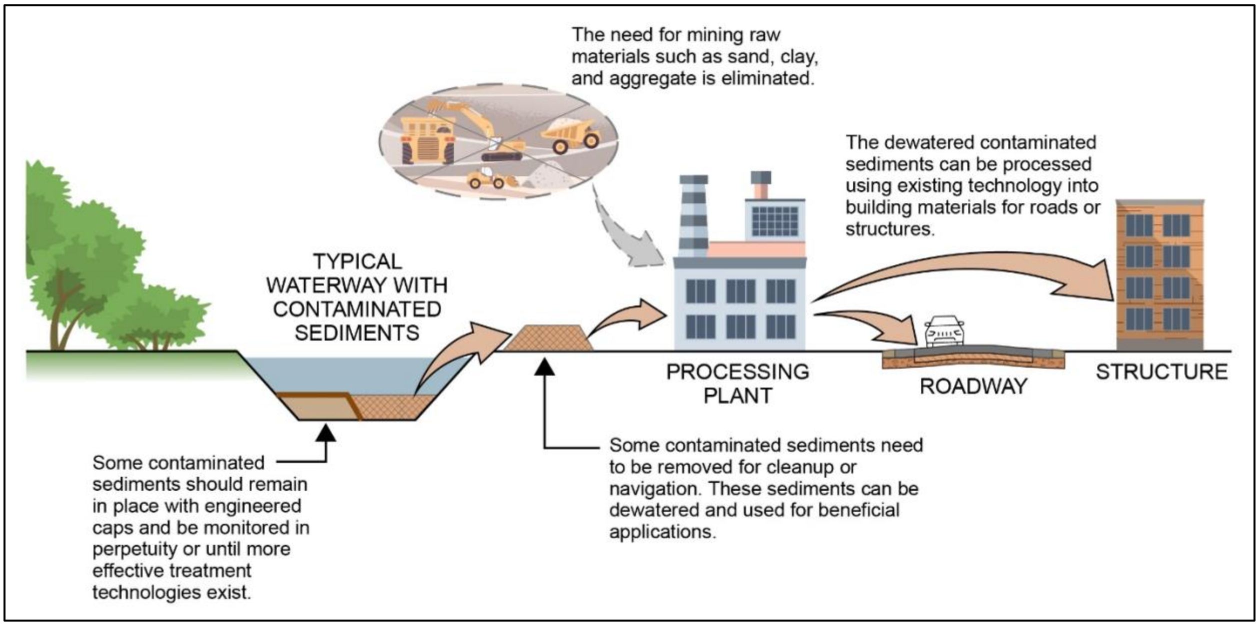
The discussion thus far intends to demonstrate that the application of circular-economy principles to the world of contaminated sediments and ports/harborways cleanup is fraught. But we wish to proceed onward from this general assessment, to imagine situations and contexts where the vision of sustainable reuse of cleanup byproducts can perhaps be brought to bear. To accomplish this we first must look generally at the misalignment in these concepts' attempted application toward sedimentary reuse. We develop idealized conceptions of circularity – what we call prescriptive (by design), and reactive (by necessity) – and land upon a feasible combination of plans and actions we denote as "punctuated" circularity.

The pursuit of a more circular economy is indeed laudable. Productive efficiency and environmental management can be mutually reinforcing, in principle. Within defined parameters, circularity can be achievable and yield both direct and ancillary benefits for society. However, the parameters undergirding circularity apply to contaminated sediments imperfectly, if at all.

Circularity means to redesign cradle-to-reuse products, making the utilization of natural resources more self-contained, environmentally responsible, and sustainable. The conceptual target is the "take-make-waste extractive industrial model"; it is informed by ecological learning and technological redesign, emphasizing three principles:

“Design out waste and pollution; Keep products and materials in use; Regenerate natural systems” (Ellen MacArthur Foundation, 2020). In a decentralized market system mediated by price signals, keeping products and materials “in use” presupposes vibrant supply-demand interactions. Circular economy visionaries imagine a world where the behaviors of factor suppliers, manufacturers, and end-stage users converge. We have little doubt that this will be feasible, ultimately, across a number of sectors. But, as we have demonstrated, it is unrealistic and infeasible to imagine introducing the dangerous pollutants present in industrial ports, harbors, and canals into a circular economy.

The accompanying diagram imagines a world where contaminated sediments are employed in producing masonry materials for construction projects. These “toxic-mud bricks” would be brought to market in circular reuse fashion, but would then have to compete with traditional bricks lacking such a label. If and when the toxic-mud bricks manage to prevail in the marketplace (itself an adventurous proposition), their presence would displace typical demand, allowing the raw materials used to make traditional bricks to remain in their natural state. Conservation results, and this would be a gain attributable to circular thinking.. But, before such factors of production can become established in the supply chain, the design of reuse technologies involves entrepreneurial as well as technical risk. There may be circumstances where such treatment/reuse is mandated (a circularity one might term “prescriptive””) or simply the result of project-based initiative (e.g., "We've got a load of usable sediment sitting in this waterway; can't we *do* something with it?") At the very least, the professions’ adoption of circular thinking might energize the needed innovation and the identification of projects where it would make sense. And in a fully circular world, contaminated sediments may not even be addressed until their reuse in some fashion is made part of the original extraction and its justification.



Here we observe two interesting phenomena: 1) circularity is a *flexible* concept, challenging all of us to extend it toward our fields of practice in whatever ways possible and 2) circularity has become a source of fascination in the contaminated sediments professions, among a community of accomplished and esteemed colleagues. Therefore, as much as we may question circularity’s immediate application in the world of contaminated sediments, we wish to learn where conceptions of circularity in sediment remediation can logically steer us.

First, we must distill certain use-case categories from generalizable circularity principles, outlined here as *prescriptive circularity*, *reactive circularity*, and, a conception we believe will most accurately capture cleanup-project realities, *punctuated circularity*. These categories may be loosely defined as follows.

- *Prescriptive circularity* involves a prescribed set of conditions adopted by participants, most likely through a mix of voluntary industry standards and coercive regulatory gestures. Responsible redesign occupies this realm, as it must; the notion that brighter minds envisioning future improvements can re-engineer systems necessarily requires that they can command the reform of those systems. Prescription of this kind can succeed, particularly where a progressive user of resources can "flip the switch," as it were, by signaling to upstream factor producers that future transactions will depend upon implementation of new manufacturing regimes. Walmart can tell milk producers they will lose its business if they do not adopt aggressive carbon reduction steps (Mui 2007); Levi Strauss can make its supplier-lists transparent and tell remote garmenting shops abroad their contracts will not be renewed unless labor practices are reformed (Doorey 2011). Often such production will cost more for those bulk purchasers. The feasibility of prescriptive circularity depends, in part, upon such actors signaling their willingness to absorb higher factor prices, at their own risk. Embedding social progress in transactional reality (that is, achieving circularity rather than just imagining it) will often require such heroic risk-taking, regardless of how sensible re-engineering systems may appear on paper.

- With *reactive circularity* we attempt to conceptualize how new systems for treating contaminated sediments can best work, under current conditions. Aligning the logic of circularity with the structure of remediation practice forces us to move the engineering frame from the "prescriptive" toward the logic of reaction. We cannot imagine a circular economy free of malfeasance and mistakes; cleanups will remain necessary, and they require, by their very nature, reactive engineering. Contaminated sediments are hardly "in the cradle," in the way circularity conceptualizes origin-driven resource sustainability. Outside the harvesting of natural radiological stores for industrial application, an example where circular thinking is much needed, the circular models we have seen rarely address, if ever, the issue of disposing of industrial-byproduct contaminants. Technological advances can alter that picture, perhaps; all too often over the thirty years of beneficial-reuse analysis, however, longed-for innovation has not come to fruition. Slack industry and governance resources instead have been spent upon wasteful adversarial efforts to enforce polluter-pays principles. As frustrating as this has been for thought leaders in the sector, there remains hope that lower-cost conversion technologies will be developed. And unless we envision such wholesale transformation in the sector, we will never be inspired to invest meaningfully towards its realization. For the sediment-recovery industry to realize the promise of circularity, it must hew to the notion that the economic costs of recovery remain less than the economic value of what is recovered ($C_R < V_R$). Given the project-based idiosyncrasies of sediment "opportunities," industry-wide progress in this realm remains elusive at best. Therefore, it is necessary to aim toward maximizing gains in project-specific, punctuated ways.

- *Punctuated circularity* involves adjusting contaminated-sediment practices in ways that embody circular-economy fundamentals. From a golf course produced with dredged material in the Port of Oakland to more recent experiments using treated dredged material in port-slip refill (for example, Tomley 2016), the opportunities are situationally constrained, requiring ingenuity and resourcefulness. For the foreseeable future, every opportunity for punctuated circularity will involve a pilot experiment necessitating long-range monitoring of downstream impact. Unlike the fully engineered, prescriptive cases of circularity, success will not be preordained. But we accept and endorse the notion that sediment management and treatment can be accompanied, within future best practice, by the fullest possible evaluation of sediment placement and reuse potential. Unlike the dispersed benefits of circularized production, the geographic fixity of real-world cleanup projects adds a dimension of geographic equity. Punctuated circularity must address, in meaningful ways, the specifics of each situation. Every traditional cleanup project setting has its own sedimentary features, hydrology, and geosocial context. In cases we have summarized in recent work, a key circular ingredient will be to ensure that communities historically burdened by disrupted ports and harbors will be the ones to reap the long-term benefits of remediation projects. For example, were economically beneficial uses to be found for the dredged contaminated sediments currently beleaguering the Gowanus Canal and its abutting neighborhoods, circularity would require that some portion of that benefit be redistributed directly to that community to help it absorb both historical externalities and the remediation costs to come. An initial exposition of the premises for punctuated circularity, in our view, would detail 1) *ex ante* risk-based estimation of reuse plans; 2) institutional commitments ensuring the feasibility of circular project features; and 3) fulfillment of geospatial compensation prerequisites, to allow source communities to become beneficiary communities to the greatest extent possible.

With regard to contaminated sediments we believe punctuated circularity is the most useful construct. It is necessarily constrained by currently unavoidable limits on converting toxic sediments into materials safe, useful, and reliable in all instances. Best engineering and design practices dictate that profoundly compromised waterway soils be capped and left in place, not dredged for reuse. Indeed, containment itself is likely the best counterfactual to the concept of circularity. But circularity considerations can be instituted promptly upon initiating cleanup and reclamation projects by asking the very questions circularity economists insist upon:

- How will sediment-lifecourse impacts, such as possible human exposure to remaining toxins, be predicted and managed?
- How can the *origin loci* of resources (the human communities nearby) become structurally enrolled in managing these downstream consequences and benefiting from the economic value of dredged sediment reuse?
- What processes govern adaptation and compliance once design is circularized?

We see an example of such punctuated circularity in the world of transportation infrastructure. The renewal of the highway grid, even if it is to be traversed more and more by electric and even autonomous vehicles (Todorovic et al. 2017), will necessitate roadway restoration. Road-bed application of contaminated soils has been attempted and may be worthy of further exploration in the context of dredged sediments. Two-step stabilization and solidification reduces leachability, and surface paving acts as a cap (EPA Region2 2017; Mater, Sperb 2006). Study of dredged-sediment and reuse in road-bed construction is still in its early stages, both in terms of technical feasibility (mechanical) and its eventual environmental performance. The "sedimateriaux" approach devised at the University of Douai (France) shows great promise, concentrating on road underlays, paved shoulders, and technical backfill for road and shoulder infrastructure (Abriak et al. 2015; Foged et al. 2007).

For now, singular cleanup projects would need performable commitments for such road-bed reuse as an alternative to the typical treatment-disposal placements. Unless government leads the way via structured revision of regulatory regimes, requirement-waivers would need to be obtained on a punctuated, project-by-project basis. On the other end of the transaction, transportation authorities and road-bed contractors would have to commit to such reuse in lieu of traditional aggregates and other materials. And to the extent that high transit and treatment costs keep reused sediments from being price-competitive with customary road-bed construction supplies, subsidy and accompanying regulatory conditions cannot be avoided.

More generally, market behavior often will be difficult for circularity designers to alter. We can design sediment reuse and market the resulting products. If they are not demanded in substantial quantities compared to cheaper less circular alternatives, we will not attain the social objective. These transactional realities limit the application of circularity concepts across the board.

5. Summary and Suggested Approach

Contaminated sediments in rivers and harbors present a difficult to resolve environmental, social, and economic issue. The "polluter pays" approach has largely failed to achieve the presumably desired effect of reducing the inventory of contaminated sediment sites. When economic returns to beneficial reuse can be captured, these must be incorporated into the financing of cleanups. Further, those communities suffering the greatest losses due to the original contamination should enjoy the foremost entitlement to claimant priority in circular applications.

But harmonizing extraction and end-use, in the case of toxic sediments, will not occur absent investment and leadership. We see no path forward without substantial subsidy and collective (public) risk taking. Existing rubrics of cleanup regulation invariably lead to adversarial legalism, exorbitant costs, and delays approaching permanent disregard, grand plans stuck in the toxic mud. It is difficult to prioritize circularity in this realm. Addressing the backlog of contaminated sites matters far more.

Market actors lack sufficient incentives to carry the commercial risk involved, especially among PRPs. To fulfill a more circular vision of how remediation can work in this context, government's role will have to transform. Regulatory agencies must mediate not only the design, financing, and liability for safe sediment removal and treatment, they must become insurers of cutting-edge experiments in beneficial sediment reuse and related technologies. Through punctuated circularity, we envision federal- and state-level participation working in conjunction with local leadership. A restored port has future economic value, and those returns will manifest locally and regionally. The future economic value of a restored and enhanced waterway, along with that of adjacent real estate and neighboring commercial activity, can be leveraged in support of this kind of investment. Measured borrowing against future gains generates a virtuous cycle: perhaps this is the readiest variety of circular thinking applicable to realities of contaminated sediments.

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