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Short communication

Revisiting heavy metals in the environment: using wetlands for their removal

Joseph J. Delfino

Environmental Engineering Sciences, University of Florida, Gainesville, FL 32611-6450, USA

The D.T. Sendzimir Family Foundation, through its Head, Dr. Jan Sendzimir, committed its support for a multidisciplinary, international study of the retention of the heavy metal, lead, in wetland systems. Specifically, two sites were selected for study; one, the Sapp Battery Superfund Site in northwest Florida and a second site, the Biala River wetland in southern Poland. The former site first became contaminated by lead from a battery reclamation facility in 1970. The latter site has received lead containing discharges from mining activities dating back to the 16th century. In one respect, this toxic metal, lead, would become the basis of an intellectual bridge across the sea to connect two groups of researchers who would be examining the role of wetlands in sequestering lead from surface water systems and substantially reducing its mobility.

The book that is the title of this paper was published in the year 2000 (Odum et al., 2000). It was conceived by H.T. Odum to be the inclusive record of the research conducted in Florida and Poland and supported by the Sendzimir Foundation. The Florida research was led by H.T. Odum and me, with co-investigators L. Pritchard Jr., S. Ton, S.J. Doherty and J.D. Pate. The Polish research was led by W. Wojcik and M. Wojcik, along with S. Leszczynski and J. Stasik. This book, based on the research report submitted to the Sendzimir Foundation, contains additional material that was added after the conclusion of the original studies. The motive force for the study and for the preparation of this book was H.T. Odum who, in addition to being the author or co-author of various chapters, also performed the role of overall editor, and assumed the task of blending many different writing styles into a reasonable coherent book (Odum et al., 2000). The early chapters were especially influenced by H.T. Odum, as easily recognized by readers familiar with H.T.'s style. Therein he introduced the concept of energy and geochemical cycling in the environment.

This book details the results of extensive field studies in both countries represented by the researchers. It is a blend of geochemistry, ecological engineering, modeling, economics and legal-policy writing. As would be expected, emergy concepts are well represented. One of the several Appendices presents an Emergy Evaluation of the entire country of Poland, co-authored by W. Wojcik, J. Stasik and Odum, following the strategies initially employed by Odum (1996) for similar emergy evaluations in the USA. Included in Appendix A12, is a tabular summary that compares emergy flows and indices for the USA and Poland, covering the years 1983 (USA and Poland) and 1993 (Poland).

The reader is presented with a series of questions involving heavy metals, public policy and the environment early in the book. The questions are clustered under different headings, including heavy metals in the environment, organization of heavy metal cycles, evaluation of alternatives, toxicity, and initiatives in industrial ecology. A selection of some of these questions

E-mail address: jdelf@eng.ufl.edu (J.J. Delfino).

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is presented here, to indicate some of the challenges that human society faces when dealing with heavy metal contamination and also the scale of inquiry covered in the book. Readers familiar with H.T. Odum's inquisitive nature, and large scale thinking, will recognize his influence over the selection of questions that helped to guide the discussions presented in the book:

How can human society reorganize (our use of toxic materials) to reduce the toxic impacts of heavy metals?

Can heavy metal accumulations be made safe from human interaction including the natural ore deposits and industrial waste sites?

Can society eliminate the dangerous concentrations of heavy metals left over from earlier ill-advised uses?

How can the use and processing of heavy metals by the economy make use of the natural principles guiding scarce elements?

What incentives help consumers recycle and reuse heavy metals?

The book then moves from a consideration of the source, distribution, and use of metals to important questions that arise when society seeks alternative ways of dealing with elements that, by their nature, cannot degrade into something less toxic:

Can the real-wealth value (emergy) of heavy metals be given an equivalent economic basis?

Can we evaluate the present and potential role of wetlands and other natural filters in environmental self-regulation?

How can the useful properties of peat for maintaining a health biosphere be evaluated when economic profit evaluations appear to justify destructive uses?

A key question posed when considering various alternative ways to handle lead, a useful metal, but dangerous in the environment, appears in language that typified H.T. Odum's approach to natural systems:

Can we evaluate the present and potential role of wetlands and other natural filters in environmental self-regulation?

This question is one that Odum asked with regularity when studying various natural systems. Whether it was treated domestic wastewater, or now, toxic lead, being discharged into wetlands, the concept was the same; "*Wetlands can capture and denature toxic substances, raising the possibility that safety for human society can be achieved with little cost by letting nature's ecosystems work for society as they have worked for the biogeosphere in the past.*" This is classic Odum thinking, always pushing nature for answers to problems created by human beings. It's not that Odum would always seek out undisturbed wetlands and then figure out ways to try to pressure them into accepting human insults and then observing their self-organized recovery over time. Rather, he was alert to respond to opportunities presented by systems that had been stressed and which were in need of remediation. He was already known for his successes in designing experiments to do this with less troublesome discharges, such as treated sewage in cypress swamps (Ewel and Odum, 1984).

In the case of the Sapp Battery Superfund site, lead and battery acid had already caused extensive damage. The goal was to see if the wetland ecosystem might recover through its own self-regulatory processes. Ton et al. (1993, 1998) discussed the extent of the lead infiltration into the wetlands adjacent to the Sapp Battery Site and also performed an ecological-economic evaluation of various management alternatives that were proposed to restore the site. The authors predicted that natural self-regulatory processes would be the most favorable approach to restoration.

We have to understand that toxic pollutants can enter the environment through various means. They can be either organic or inorganic substances. Most of the organic compounds eventually degrade, some quickly, some slowly, some completely, and some minimally. Biodegradation processes depend on the ability of microorganisms to develop enzymatic mechanisms for attacking complex organic structures. Inorganic materials present different challenges, especially those that are metal elements with little else bound to them, except perhaps the ions to which they are complexed, present different challenges. Mercury, and its increasing presence in the wetland soils of Florida's Everglades since the early 1900s, is a prime example (Rood et al., 1995). Lead is another example. As an element, it cannot be degraded to a substance lesser than the elemental form itself. This fact presented the opportunities that led to the research discussed in this book (Odum et al., 2000).

As a conclusion to the last set of exploratory questions, Odum sought initiatives in industrial ecology:

> Can industries such as battery makers take over the whole cycle of processing, use, reuse, and control of environmental recycle?
>
> What is the pattern of heavy metal use and processing appropriate and economical for a time of less fuel availability and contracting economy?

Through these questions, Odum was forging typical ecological engineering questions that have started to be recognized by others and merged into the broader field of industrial ecology. In the world in which H.T. grew up and matured, the word "ecology" fought for years to be accepted on its own recognizance. H.T. Odum was no doubt proud that, due in large part to his efforts, "ecology" has been legitimately coupled with engineering, economics and industry. Many years had passed before the broader scientific, engineering, and business communities recognized and ultimately accepted these terms in their conjoined fashion, but we all knew who thought up these ideas first.

A comprehensive overview of the interaction of lead with organic matter and other wetland ecosystem components is given in Chapter 3 of this book. The chapter also reviews the history of lead mining, sources and distribution in the environment, toxicity, and, most importantly, lead in wetlands. Included were methods of heavy metals removal from wetlands as well as evaluations of alternatives for lead processing and models to simulate the behavior of lead in the environment.

The biogeochemical cycle of lead and the energy hierarchy (Chapter 4) is done in classic Odum style, utilizing systems model diagrams. Odum stated: "*The universe has many levels of hierarchy, with materials converging to small centers, and these in turn converging to larger centers.*" He calculated emergy values for lead and then prepared the case for a wetland to act as a heavy metal filter. "*As more wetlands are studied it is becoming apparent that wetlands self-organize in great variety, adapting to various kinds of inflows of water, organic matter, sediments, and various chemicals, including the heavy metals.*" Self-organization is a reoccurring theme in much of H.T. Odum's writings.

Concluding this important chapter, Odum calculated the value of lead ores used by the economy to be 12 billion emdollars per year, which is a 200 times greater contribution than the lead dispersed in the earth's main cycle. He also found lead dispersed in wastes to be valued at about 71 million emdollars, which is close in magnitude to the value of the natural lead cycle.

Parts II and III of the book summarize the research that was conducted in the field and laboratories in Florida and in Poland, supported by the grant from the Sendzimir Foundation. L. Pritchard and S. Ton, graduate students at that time who were studying with Odum and Delfino, carried out their thesis research in Florida. Pritchard conducted an ecological assessment of the so-called Steel City swamps which were located adjacent to the Sapp Battery Superfund site. He tested tree seedling survival and growth in the swamps (with some success but periodic high water levels prevented large numbers of the seedlings from surviving). He concluded that natural aquatic ecosystem processes were functioning and perhaps showing some sign of returning to normalcy. A return of the wetland forest was predicted to be a slow process, due to slower turnover times and the problem with seedling survival in the intensively acidic and toxic environment.

Ton's research concerned the status of lead concentrations in the waters and sediments of the Steele City swamps. He found low concentrations in the surface waters which decreased with distance from the original battery site, and similar patterns were found for lead in the surficial sediments in the swamps. The lead in the sediments was primarily bound to organic matter (humic acids). The lead in the water phase was also shown to be complexed, in part, with humic substances. Ton conducted simulation studies of the system, after providing numerical values for storages and flows in his model. The program code is provided as an appendix in the book. The simulation model predicted that some 20 years following the early 1990s would be required for a reasonable degree of recovery of the wetland, with recovery defined in terms of diminished lead concentrations in the surface water and plants. As the lead levels decline, plant biomass is expected to return to its more normal growth cycle.

W. Wojcik and M. Wojcik summarize their studies of lead in the Biala River wetland in southern Poland, west of Krakow City (Chapter 9). These wetlands, in contrast to those in northern Florida, have received lead (and zinc) from mine discharges for some 400 years. Flows in the Biala River have been highly variable over the past 50–60 years, with mine drainage making up the majority of the flow. Wastewater treatment plant effluents represent the remaining flow. Compared with the swamps in Florida that had lead levels in the hundreds of parts per million (ppm), the Biala River wetland locations had lead concentrations at levels approaching 5000 ppm with zinc concentrations often reaching levels of 10,000 ppm (1%). These are extraordinarily high concentrations. Nevertheless, plant communities in the Biala River wetland seemed to have adapted to this unusually high lead and zinc environment, with the plants having lead concentrations in the thousands of parts per million. Wojcik's proposed that part of the wetland could provide essential lead filtration services, while maintaining its main functions. This is in keeping with Odum's philosophy, espoused earlier, which would allow wetlands to capture toxic substances and work to provide essential services to human society through this sequesterization process. An extension of this concept could be a study of the feasibility of harvesting the plants to remove the lead from the system and then to recover it or to place the residues in a more secure enclosure.

Pritchard conducted an ecological economic evaluation of lead retention in wetlands following Odum's guidelines (Chapter 11 and Appendices A11a and A11b). He looked at different lead battery recovery processes and also the treatment of wastewaters at an existing lead reprocessing smelter. By performing calculations using emergy evaluation as well as more typical economic valuations, he showed that there was a net economic benefit from using the wetlands for retaining lead (despite some ecological damage), compared with a more aggressive chemical treatment system that would not involve any damage to a wetland ecosystem. Pritchard indicated that the capacity for retaining toxic substances, such as lead, might be one of the best uses and highest values of wetlands (using emergy based calculations) while standard economic models probably underestimated the replacement values of the wetlands and also the value of ecological damage.

A useful feature of the book is the extensive set of appendices. Considerable amounts of data (both from the literature as well as original data from Florida and Poland) are presented in various appendices, as are field and laboratory analytical methods, and computer code. An extensive bibliography dealing with lead contamination, wetlands, ecology and economics is also provided.

H.T. Odum was certainly a proponent of studying natural systems and perturbations therein. When challenged by the Sendzimir Foundation to conduct studies of wetlands that were already impacted by toxics, and which required a scientific basis for their possible restoration plans, Odum readily accepted the opportunity, much to the benefit of our collaborative team and society in general. Questions that remain to be answered by the wetlands community, regulators, and concerned citizens are: "Do we use natural wetlands as allies in our efforts to reduce pollutant loading to open waters or should we develop and employ newly constructed wetlands for these important tasks?" Also, "Do we know how to evaluate the absorption capacity of wetlands (natural or artificial) to accept waste loads containing degradable materials (organics in sewage), nutrients (N, P), or toxic organics and metals." And, "Can phytoremediation techniques be employed in conjunction with natural/created wetlands to ameliorate the impacts of chemical loading to wetlands?" Finally, and perhaps most important of all, "Will we remember to employ H.T. Odum's guiding principles in our future work, not just to test hypotheses, but to insure that we allow nature to work with society for the betterment of stressed ecosystems everywhere?"

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