Chemical & Biological Constituents in the Environment and their Impact on Human and Ecosystem Health

A. Scope/audience

Knowledge on the inputs to and persistence in the environment of chemical and biological constituents and how their presence may affect public and ecosystem health is of personal to the public. Such information is also needed by regulatory agencies, and private, government, and commercial industries in order to control the use and impact of chemical and biological constituents and minimize or mitigate negative impacts to human health, our ecosystem and quality of life.

B. Overview & contribution in the past 5 years

Multitude adverse impacts to human and ecosystem health at a variety of scales have been documented from exposure to a broad range of chemicals and pathogens (collectively referred here as “agents”). Environmental loadings of these agents to terrestrial, aquatic, and atmospheric compartments are the result of human activities with continued increases in population and advances in technology. Understanding and predicting the linkages, at all scales, among the hydrologic, biogeochemical, and atmospheric processes that control the fate and transport of these agents, and the human and eco-toxicological implications of chronic and acute exposures to these agents is among the environmental grand challenges.

With increasing populations, more land is being converted for intensively managed agriculture, which, in turn, is leading to the increased discharges of fertilizers, pesticides, and other agrochemicals into the air, water and soil. With increasing urbanization, there have been increasing discharges of wastewater and urban runoff. Technologies targeted at increasing our quality of life and meeting the needs of our increased populations and energy needs are concomitantly compromising human and wildlife health, contributing to loss of habitats, and reducing ecosystem biodiversity. Secondary effects include disease vectors in humans and plants that are leading to the production and use of even a larger suite of chemicals. We still have not been successful at the cleanup of legacy chemicals or in sufficiently understanding their behavior, their modes of action, or their long-term health effects.

This overarching environmental grand challenge is multifaceted, involves complex and interlinked processes, operates at a wide range of spatial and temporal scales, and includes issues that are present within all of the other grand challenges our department has identified. Successfully addressing this challenge requires efforts across multiple disciplines, including life sciences, engineering, and social sciences. Historically, the faculty and staff of the Agronomy Department have been leaders in understanding and quantifying the processes and mechanisms that control the fate of several chemical classes, particularly in soil and water, from the molecular to the small field scale.

In the recent past, we have also expanded our academic offerings to better equip students across the campus to address this grand challenge, which included adding several undergraduate and graduate courses, significantly improving infrastructure to conduct research in this area, continuing leadership in directing the College of Agriculture (COA) Natural Resources and Environmental Science Interdisciplinary Undergraduate Program, and launching of two new campus-wide programs by our faculty (*pre-Environmental Studies; Ecological Science & Engineering Interdisciplinary Graduate Program*), and planning for Earth Systems Science IGP.

Our research in the last 5 years has contributed in five major areas within this grand challenge:

1. ***Air Emission and transport:*** Characterizing the emissions of gases such as hydrogen sulfide and ammonia and particulates (with bacteria) into the atmosphere and dispersion from confined animal production facilities.

2. ***Fate:*** characterizing how and at what magnitude chemicals interact and persist in soil and water environments from multiple classes (hormones, antibiotics, fluorotelomer compounds, aryl hydrocarbon receptor ligands, chlorinated solvents, arsenic, selenium, pesticides, perchlorate, phosphate, nitrate) as well as pathogens (primarily *e. coli*).

3. ***Remediation/reclamation:*** implementing and evaluating various remediation (phytoremediation, chemical flushing, soil amendments) and reclamation strategies at sites impacted by industrial- and military-impacted sites; developing predictive models and decision tools for evaluating the need for active remediation and remediation strategies and success;

4. ***Waste Reuse:*** evaluating the occurrence and release of selected constituents of concern in soils amended with waste products (e.g., paper mill residuals, coal combustion products, animal manure, poultry litter).

5. ***Bioavailability and Impact:*** assessing the impact of sorption organic contaminants on their bioavailability to bacteria and mammals; the effects of nanomaterials (fullerenes and carbon nanotubes) on biological processes in soil and waste water systems; the role of soil and soil-borne food pathogens in the “farm-to-fork” continuum, the environmental impacts of the biofuel products (alkanols), and the evolution of phylogenetically diversity and functionality of bacteria in long-term contaminated soils.

C. Current challenge

Our research must be conducted at increasingly smaller chemical concentrations and for very different chemical classes which requires a myriad of specialized instrumentation that is costly to purchase and maintain, and requires qualified staff. We have routinely taken internal and external opportunities to advance our instrumentation with maintenance primarily covered by external grants. Currently using our ICP-MS as a test, we are assessing how successful a re-charge approach will be for accruing funds for maintenance and repairs. We started with fees that were low enough to build a user base that would experience the value of such instrumentation, and then have been slowly increasing usage charges to meet the actual amount needed to cover expected maintenance and repair fees. We currently have a few administrative professionals that do a fair job of keeping up with much of our specialized instrumentation needs, but covering their salaries is an increasing challenge in light of decreasing availability of funds internally and externally with concomitant increases in graduate stipends and more faculty members forced to cover their summer salaries.

In addition, we must find ways to explore the relevance of lab- and field-scale research to emergent processes/effects at much larger scales, which often requires additional personnel and computational tools. This is necessary to conduct an appropriate assessment of risk to human and ecosystem health and develop useful predictive and management tools. Increasingly, successful funding requires collaborations with colleagues in other disciplinary units at Purdue, other universities, and R&D labs. Enhancing and building new collaborations has been facilitated by Purdue’s recently founded Discovery Park, which is made up of eleven Centers including the Energy Center, Center for the Environment, Birck Center for Nanotechnology, and Bindley Bioscience Center. The latter two centers also offer additional state of the art equipment that some of our faculty utilize.

D. Fundamental issues for the next 10 years

Opportunities for enhancing our programs and the associated challenges can be grouped into five broad categories:

1. ***Integration/Synthesis:*** Integrating and synthesizing knowledge from other disciplines to develop strategies regarding wastewater and waste water residuals, antibiotic resistant bacteria, management of pesticides and personal care products, nanomaterials, etc., and air quality.

2. ***Sustainable Practices:*** Research is needed on (1) the resilience and sustainability of current food and energy production systems and how they are coupled; (2) the increased reuse and recycling of wastes and wastewater and subsequent evaluations; (3) the environmental consequences of concentrated animal feeding operation (CAFO)-related activities; (4) the impact of a suite of nanomaterials on the ecosystem and human health, and information on exposure routes, environmental attenuation capacity, and the toxicity of various nanomaterials; and (5) the impacts of highly halogenated chemicals used as flame retardants and stain-proofing, and other personal-care products.

3. ***Scaling:*** Modeling and monitoring of emergent processes at multiple time and space scales. How does existing knowledge translate to understanding and predicting environmental processes emergent at larger scales (e.g., agricultural

impacts of on-farm practices to gulf hypoxia, mercury deposition and accumulation in freshwater ecosystems, nitrogen saturation of ecosystems, impacts of gaseous and particulate emissions from agriculture on public health)? Or, how do emerging large-scale phenomenon (e.g., climate change) impact local processes (e.g., crop yields, biogeochemical cycles)?

4. ***Linkages:*** Linkages to other disciplines (e.g., human health, ecotoxicology, biodiversity, environmental justice, regulation/policy, resource economics, human dimensions), other research teams (universities, national & international R&D institutes); and other agencies (state and federal agencies, non-profit organizations (NGOs); think tanks).

5. ***Decision Tools:*** Development of better predictive tools, policies, decision-making and management strategies to reduce degradation of soil, water and air quality from events such as the projected shifts in land-use practices (e.g., renewable energy crops), weather extremes (e.g., drought/floods; shifts in growing seasons) resulting from climate change, and rapid response to disease vectors (e.g., fungicide use for mitigation of Asian soybean rust).

E. Projects that Purdue and especially Agronomy can develop to address these issues

The following represent extensions of current projects or reflect faculty interests in future projects. Projects within each area will contribute to gaps that exist in each of the broad categories noted under fundamental issues to be addressed in the next 10 years.

1. Lab-scale (molecular to soil core) Characterization and Assessment

   a. Development and use of nanomaterials is on the rise, thus increasing their likelihood of being discharged to the environment. Assessment of their impact on aquatic and microbial communities will aid in evaluating their overall risk to the ecosystem and may lead to responsible regulatory decisions for their production, use, and disposal manufacturing and disposal strategies. Turco’s research group in conjunction with colleagues in Forestry and Natural Resources (FNR) and Civil Engineering (CE) have proposals in review to support research focused on characterizing the environmental attenuation capacity and toxicity of various nanometals such as nonmetals and those used in solid state lighting and have proposals in review to support the work.
   b. Legacy chemicals have been designated as such due to their persistence, long-term effects, and continual challenge regarding their clean up, which is in part due to our lack of understanding on how they behave in the environment. Johnston’s research group in conjunction with colleagues at Michigan State University (MSU) is characterizing the poorly understood mechanisms that control sorption of Aryl

hydrocarbon (Ah) receptor ligands, which include many legacy chemicals such as chlorinated dioxins, PAHs, and PCBs, to clay minerals and other fine-grained soil and sediment components. Using these well-defined systems they plan to probe the bioavailability of sorbed nonpolar organic contaminants to bacteria and mammals. This research is currently supported by the Superfund Basic Research Program Center centered at MSU.

c. Highly fluorinated and brominated compounds were manufactured to replace highly chlorinated compounds as flame retardants as well as a myriad of other technologies including stain and stick resistant coatings that enhance our quality of life. However, the very characteristics that impart their unique properties also cause them to persist in the environment. Many of these compounds and their associated metabolites are detected globally in soil, water, biota, and humans and some are suspected of inducing various health issues including hypo or hyper thyroidism and endocrine-disrupting behavior. L.S. Lee’s research group is characterizing the distribution and chemical and biological stability of fluorotelomer compounds in soil, water, municipal waste water treatment systems, landfills, and selected ecosystems to aid in responsible regulatory decisions for their production, use, and disposal. In addition, Lee through her role in the Center for the Environment (C4E), has been working on campus-wide effort that is linking faculty with strength in chemical fate of highly halogenated compounds to those assessing effects including links to clinical studies in the Vet School and at the IUPUI Medical Center.

2. Field-scale Characterization and Assessment
    a. Evidence indicates that concentrated animal feeding operations (CAFO) waste may have the potential to introduce hormonally-active compounds, such as natural and synthetic steroids, into surface and ground waters and to terrestrial systems through manure applications. However, there is still little known on hormone persistence in manure-applied fields and subsequent attenuation of hormone release from manure-treated fields; the contribution of tile-drained fields on hormone loads to aquatic systems; and the impact of hormone mixtures relevant to animal wastes on aquatic species. This uncertainty is particularly important to EPA as regulatory efforts to control unacceptable impacts associated with CAFOs are implemented. Lee’s research group in conjunction with colleagues in CE and FNR along with USEPA Molecular Indicators Research Branch (Cincinnati, OH), USEPA ORD, NHEERL (Research Triangle Park, NC); and the USEPA Mid-Continent Ecology Division, Duluth, MN is conducting research to assess and predict the contribution of hormones loads to aquatic systems from tile-drained agricultural fields under different manure and lagoon effluent applications practices and evaluate the

level of impact to aquatic biodiversity towards improving management strategies as needed.

b. Application of organic-rich agricultural, industrial, and municipal by-products to land is one way to minimize unproductive disposal into landfills and optimize the nutrient value of such material. Camberato, Schwab, Graveel, and Van Scoyoc are leading efforts to evaluate and develop strategies for optimizing productive use of these materials.
c. The number of Brownfields (abandoned industrial sites) is growing with our current economic challenges. By designation, Brownfields are inherently unproductive, an eyesore to a community, and wastes at these sites contribute to air and water pollution. Schwab along with others in the department are targeting research to implement and evaluate the establishment of vegetation in waste materials (steel mill slag, ash, petroleum sludge) towards minimizing air and water pollution of these industrial wastes at these sites.
d. There is a growing need to improve the performance of existing wetlands as well as construct new wetlands for treatment of various types of discharges including agricultural drainage, municipal wastewater, and industrial wastewater. Bowling and Rao among others in conjunction with colleagues in ABE and CE are targeting research aimed at evaluating the use and performance of natural and constructed wetlands for the treatment of wastewater in agricultural, industrial, and urban settings.

3. Landscape-scale Characterization and Assessment
    a. Multi-scale modeling and monitoring of Midwestern landscapes to link atmospheric, hydrologic, pedologic and biogeochemical processes is needed to better predict and control effects exasperated by rapid land use changes and climate change. Niyogi, Bowling, Crawford, Owens, Schulze, Zhuang, Owens, Rao, and Johnston among others in conjunction with Agricultural and Biological Engineering (ABE) and Earth and Atmospheric Sciences (EAS) are working on several funded efforts as well as new proposals to better characterize the factors affecting these complex processes and their linkages.
    b. Use Geographic Information Systems (GIS) that integrate detailed soil survey, digital elevation models, and other data sources to understand and predict how chemical and biological pollutants are likely to move through impacted landscapes over time, and to identify which parts of landscapes are more sensitive to pollutants than others (Bowling, Rao, Owens, Crawford).
    c. Air emissions from agriculture and non agricultural sources whether gaseous or particulate sources need to be understood in a multi-scale framework to assess their impacts on farm operations and public health or policy regulations to regional impacts that can affect the air quality and climate. Integration of in-situ and remotely sensed measurements, and developing approaches to assimilate these data into regional

models for developing predictive if – then scenarios is a challenge. Partners: ABE, LARS, RCAC, State Climate office, C4E, CC.

F. The science team (expertise needed)

The science team would include the entire faculty in the Soil and Earth Systems group as well as a few in the Crop Sciences group. Many of the foci detailed within this grand challenge directly link to the other grand challenges including landscape-scale management for sustainable plant production and ecosystems, climate change, and biofuels. Many of the projects under way or being constructed involve collaborations with faculty from (1) other departments/colleges at Purdue including Agricultural and Biological Engineering (ABE), Forestry and Natural Resources (FNR), Civil Engineering, and Earth and Atmospheric Sciences (EAS); (2) Centers at Purdue including Center for the Environment, Energy Center, Nanotechnology Center, and the Bioscience Center; (3) regulatory agencies including USEPA, DNR, and USGS; and (4) other universities.

G. Time frame

Ongoing

H. Evaluation of success

Discovery and dissemination of new knowledge that is published in refereed journals; students educated sufficiently in the key concepts such that they can apply them as they enter the work force; changed behavior of the public, government, and industry that leads to improved soil, air, and water quality, and ecosystem and human health; and products and processes that minimize impact to the environment.

I. Dissemination of information to decision makers/scientific community/public

Information in this area is typically delivered through traditional scientific publications, but we need to be more active in delivering information in other forms that can be of immediate use to those outside our scientific community. Coordination with federal and state agencies can provide alternative dissemination methods through agency reports, workshops, Web casts, and Web-based documents.

J. Resources needed

This grand challenge requires multiple types of sophisticated laboratory instrumentation, which requires consistent support of qualified people/support staff to maintain and facilitate instrument use and continual enhancements in equipment infrastructure. We also need long term support of field-based observatories and a reasonable computational infrastructure. External grants alone are not sufficient to maintain the variety of specialized equipment needed or to cover entire salaries on a routine basis to fund support staff. In order to maintain consistent and high quality work, there needs to be a reasonable level of internal support designated for this purpose.

K. Conclusion/recommendations/vision for the future

Our faculty work in total work at multiple scales; however, the primary strength and research contribution of each faculty member or faculty subgroup tends to be at a single scale. Future challenges require that we link and integrate the knowledge we obtain at each of these different scales with purpose to increase the value of our individual or subgroup efforts, improve larger-scale predictions, and to contribute to more effective policies that improve our quality of life as well as future generations.