Columbia University 2015 SRP Annual Updates

A. OVERALL CENTER HIGHLIGHTS:

Highlight #1: Child intelligence and reductions in water arsenic and manganese: A two-year follow-up study in Bangladesh. (Project #2)

The previous iteration of Project #2 had conducted a study of 303 children to test the hypothesis exposure to arsenic (As) and manganese (Mn) from drinking water in Bangladesh might be associated with lower child IQ in 10-year-old children, and that there might be an interaction between the two neurotoxicants. Indeed, both elements were independently associated with lower child IQ, but we did not observe an interaction (Wasserman et al., EHP, 2011). Recently, we tested the hypothesis that the provision of deep wells low in arsenic and manganese might reduce these exposures and thereby lead to an amelioration of the neurotoxicity of these elements, leading to an improvement in child IQ. The villages of all 303 study children were provided with a deep, safe well. In December, 2015, we reported that two years after the provision of safe wells, blood levels of arsenic and manganese did indeed fall significantly. Distance to the safe well was a predictor of the decline in exposures; the closer the well to the household, the greater the decline. While full scale IQ did not significantly increase, sub-scores related to *working memory did indeed significantly improve* (Wasserman et al., EHP, 2015). These findings, of considerable public health importance, indicate that the provision of low As, low Mn wells can substantially lower these exposures in childhood and suggest that a longer term follow up might reveal greater improvements in overall child IQ.

References for Highlight #1:

Wasserman, GA, Liu, X, Parvez, F, Factor-Litvak, P, Ahsan, H, Levy, D, Kline, J, van Geen, A, Mey, J, Slavkovich, V, Siddique, A, Islam, T, Graziano, JH: Arsenic and manganese exposure and children's intellectual function. Neurotoxicology 32: 450-7, 2011. PMID: 21453714.

Wasserman GA, Liu X, Parvez F, Factor-Litvak P, Kline J, Siddique AB, Shahriar H, Uddin MN, van Geen A, Mey JL, Balac O, Graziano JH: Child intelligence and reductions in water arsenic and manganese: A two-year follow-up study in Bangladesh. Environ Health Perspect, 2015 Dec 29, ahead of print. PMCID: PMC4062913

Highlight #2: Evaluation of an elementary school-based educational intervention for reducing arsenic exposure in Bangladesh (Project #2)

In a study related to our studies of arsenic exposure in children (Project #2), with co-support from the Fogarty Center of NIH, we sought to reduce childhood exposure to arsenic through the provision of deep wells low in arsenic, coupled with *arsenic education in elementary schools*. Fourteen schools and 840 students were involved. In half of the schools, teachers were provided with education and lesson plans for students related to the adverse effects of arsenic. The other half were only provided with education at the end of the study. The villages of all 840 students were provided with safe low-arsenic wells. When compared to baseline urine As

measurements, after one year of school-based arsenic education, the concentrations of arsenic in children's urine declined substantially in those children who received arsenic lessons in school, as compared to those who did not. Thus we provide evidence that the provision of school-based arsenic education is a highly cost-effective means of reducing arsenic exposure. Since the mothers of these children are the ones who actually fetch well water and bring it into the home, we note that it is highly likely that this school-based educational intervention actually reduced the exposure of the entire family.

Reference for Highlight #2:

Khan K, Ahmed E, Factor-Litvak P, Liu X, Siddique AB, Wasserman GA, Slavkovich V, Levy D, Mey JL, van Geen A, Graziano JH: Evaluation of an elementary school-based educational intervention for reducing arsenic exposure in Bangladesh. Environ Health Perspect. 2015 Dec;123(12):1331-6. doi: 10.1289/ehp.1409462. Epub 2015 May 8. PMCID: PMC4671245

Highlight #3: ***In situ* arsenic remediation using magnetite (Projects #4 & 5)**

Projects 4 and 5 have been identifying methods of improving groundwater As remediation using two approaches, one designed to enhance the removal of As from underground sediments (Sun et al., In Press a) and the other designed to stabilize this As in the solid phase, thereby preventing off-site transport and biological uptake (Sun et al., 2016; In Press b). Overall, these manuscripts, and others submitted and in preparation have shown that:

(1) Oxalate removes the labile portion of As that appear to be released by Fe(III) reduction, and thus may be effective to reduce groundwater As levels in source areas.

(2) Nitrate-Fe(II) additions are effective at retaining groundwater As, and do so by adsorbing As to nanoparticulate magnetite producing under aquifer conditions. In contrast, sulfate reduction, which often is prescribed at sites, often fails to sequester As.

(3) Long-term changes in Fe mineralogy cannot be ignored when evaluating the fate of As in natural systems.

An immediate outcome of this collaboration is that we are working with two new sites in the coming year to study nitrate injections in the field as a means of producing magnetite *in situ*, and how this nanoparticulate magnetite retains As for the long-term under ambient (reducing) conditions. We also are developing quantitative and easily portable reactive transport models to predict the long-term behavior of As at contaminated sites that could be used as part of the toolbox for site clean-up.

Highlight #4: Association between Arsenic Exposure from Drinking Water and Longitudinal Change in Blood Pressure among HEALS (Project #1)

Studies examining the relationship of arsenic exposure with longitudinal changes in blood pressure are lacking. We evaluated associations of arsenic exposure in relation to longitudinal

change in blood pressure in 10,853 participants in HEALS. Arsenic was measured in well water and in urine samples at baseline and in urine samples every 2 years after baseline. We found that individuals in the highest quartile of baseline water arsenic or urinary creatinine-adjusted arsenic had a greater annual increase in systolic blood pressure compared with those in the reference group (β = 0.48 mmHg/year; 95% CI: 0.35, 0.61, and β = 0.43 mmHg/year; 95% CI: 0.29, 0.56 for water arsenic and urinary creatinine-adjusted arsenic, respectively) in fully adjusted models. Likewise, individuals in the highest quartile of baseline arsenic exposure had a greater annual increase in diastolic blood pressure for water arsenic and urinary creatinine-adjusted arsenic, (β = 0.39 mmHg/year; 95% CI: 0.30, 0.49, and β = 0.45 mmHg/year; 95% CI: 0.36, 0.55, respectively) compared with those in the lowest quartile. **Significance:** To our knowledge, the present study is the first large epidemiologic study to examine the relationship between arsenic exposure from drinking water and longitudinal change in BP. The manuscript (1) was considered as an EHP Science Selection (2). These findings have important implications because even modest increases in blood pressure impact cardiovascular disease risk.

References for Highlight #4:

(1) Jiang J, Liu M, Parvez F, Wang B, Wu F, Eunus M, Bangalore S, Newman JD, Ahmed A, Islam T, Rakibuz-Zaman M, Hasan R, Sarwar G, Levy D, Slavkovich V, Argos M, Bryan MS, Farzan SF, Hayes RB, Graziano JH, Ahsan H, Chen Y. Association between Arsenic Exposure from Drinking Water and Longitudinal Change in Blood Pressure among HEALS Cohort Participants. Environ Health Perspect. 2015 Aug;123(8):806-12. doi: 10.1289/ehp.1409004. PMCID: PMC4529016.

(2) EHP Science Selection for August http://ehp.niehs.nih.gov/123-A218/

B. TRAINEE HIGHLIGHTS:

Despite the fact that the Columbia SRP does not have a Training Core, the program's faculty have devoted a great deal of time and effort into mentoring a remarkable set of PhD trainees, whose accomplishments are briefly summarized below.

- **Maria Argos:** One of the past SRP trainees, former PhD student Dr. Maria Argos has recently received an R01 grant to evaluate effects of arsenic on children's cardio-metabolic phenotypes, building on Project #1's HEALS study resource. Dr. Argos recently published a major paper reporting novel epigenetic signatures from a genomewide investigation of the DNA methylation markers [methyl-cytosine and hydroxymethyl-cytosine] using research resources supported by CU-SBRP. This publication (listed under B5) has generated significant attention from scientific community.

- **Felicia Castriota**, a former MPH student who worked on the SRP program is now a PhD student at the UC Berkeley SRP program, where she is working with Dr. Martyn Smith. We regret losing this outstanding young scientist to Berkeley!

- **Runti Choudhury**, a visiting PhD candidate from the Department of Civil Engineering at the Indian Institute of Technology, Guwahati (Assam) returned from LDEO to her home institution in September 2015 after a year of taking classes and conducting SRP-related research under a Fulbright Fellowship.

- **Sara Flanagan** is a doctoral student at the Graduate School of Public Health and Health Policy, City University of New York and a research associate of the Community Engagement Core of Columbia University's Superfund Research Program on the health effects and geochemistry of arsenic. She has been investigating motivators and barriers for water testing and treatment in households relying on private wells in arsenic-affected communities in central Maine and northern New Jersey. Her survey work in New Jersey has grown out of a successful collaboration between the CEC, RTC, and the New Jersey Department of Environmental Protection (NJDEP) which has made Columbia SRP a key academic partner for the New Jersey Department of Health's (NJDOH) new CDC-funded 5-year program to expand their work on private well water quality issues in New Jersey. Sara has applied for a KC Donnelly award to work with NJDEP on this endeavor.

- **Christine George:** A past trainee, Christine is now an Assistant Professor of EHS at the Bloomberg School of Public Health at Johns Hopkins and has received both a K-award and an RO1 from NIEHS, the latter as Co-PI with Dr. Ana Navas-Acien, a member of our External Advisory Board, who we have recruited to the Mailman School EHS department, effective April, 2016. Dr. George continues to collaborate with Dr. Graziano, and recently published a paper with Drs. Graziano and Navas-Acien relating arsenic exposure to the risk for childhood pneumonia in Bangladesh.

- **Megan Hall**, Dr. Gamble's former post-doctoral research fellow (currently an Assistant Professor) is co-first author on a manuscript describing the primary findings on Dr. Gamble's FACT study entitled, "Folic acid and creatine supplementation for lowering blood arsenic: A randomized controlled clinical trial" recently published in Environ Health Persp and selected for a highlight under "Science Selections." Dr. Hall is in the R00 phase of a K99/R00 award from NIEHS to study nutritional influences, particularly of choline and betaine, on arsenic methylation; this work has resulted in one publication and another two are in preparation.

- **Kristin Harper**, Dr. Gamble's former post-doctoral research fellow continues finishing up her analyses of differentially methylated CpGs by arsenic exposure using Illumina's new 450K array (see Highlight from a previous funding cycle and 2013 publication) and this data was validated by NextGen sequencing (manuscript in preparation). Kristin has also worked on a study of the relationship between arsenic exposure and oxidative stress

that has been published. She is currently a Freelance Science Writer and Editor for publications including The Scientist and the American Chemical Society.

- **Ezazul Haque**, a MS student in Public Health at the CUNY-Hunter, has been improving field-based methods of arsenic analysis in groundwater. In his research, he is using existing kits technologies and mobile phone camera images, integrated within a mobile data collection platform, to improve detection limits, provide continuous data, and integrate chemical and spatial data in real time. In the future we hope that this technology can be developed within a mobile phone application that provides real-time data and information based on testing results, to testers. He has been awarded a NIOSH grant in support of his education for his efforts.

- **Caitlin Howe** is a PhD student in Dr. Gamble's laboratory. She has been working on analyses related to our SRP Project in which we are analyzing associations between arsenic exposure and histone modifications as well as on s-adenosylhomocysteine and s-adenosylmethionine and both histone and arsenic methylation; this work has been published in the Journal of Nutrition and in Clinical Epigenetics. She also presented some preliminary findings as a poster at the FASEB Summer Research Conference on Folate and One Carbon Metabolism in August 2014, as a poster at the Society of Toxicology Annual Meeting in March 2015 on the sex-specific effects of arsenic on global histone modifications, and as a poster at the Annual Homocysteine Conference (Nancy, France, July 2015) at which she received first prize for outstanding poster. Caitlin is making excellent progress on the aims of her thesis proposal and will defend in the Spring of 2016. She has accepted a post-doctoral position at the University of California.

- **Khalid Khan:** A past SRP trainee, Khalid is now an Assistant Professor of Environmental Health at the School of Public Health at Indiana University. Khalid continues to collaborate with Dr. Graziano, and the final publication from his dissertation work at Columbia University appeared in the December 2015 issue of EHP (Khan et al., 2015: "Evaluation of an Elementary School-based Educational Intervention for Reducing Arsenic Exposure in Bangladesh"). Drs. Khan and Graziano were recently interviewed by staff from the Fogarty Center, which will prepare this material for the 50th Anniversary of NIEHS as a highlight of interactions between the Fogarty Center and NIEHS.

- **Franziska Landes** entered the PhD program in Earth & Environmental Sciences in September 2013, passed the master's level examination in 2015, and continues to be advised by the PI.

- **Anand Kumar**, a visiting PhD candidate from the Department of Regional Water Studies at TERI University in New Delhi, India, returned to his home institution in December 2014 after a 4-month stay during which he took classes and conducting SRP-related research under a fellowship from the USAID PEER grant to his advisor.

- **Md. Rajib Mozumder**, a geology graduate from the University of Dhaka, entered the PhD program in Earth & Environmental Sciences in September 2012, passed the master's level examination in 2014, his qualifying oral examination in 2015, and continues to be advised by the PI.

- **Alexandra Munoz** is a PhD student in Max Costa's lab at NYU. She has been involved in analyzing gene expression using Affymetrix gene chips. This work was recently published in Toxicology and Applied Pharmacology (2015).

- **Megan Niedzwiecki**, Dr. Gamble's former PhD student, successfully defended her thesis in December 2013. The title of her thesis was, "Mechanisms of Arsenic Toxicity in Humans: Interplay of Arsenic, Glutathione, and DNA Methylation in Bangladeshi Adults." She worked on laboratory and data analyses for the folate and oxidative stress (FOX) study from Aim 3 of Project 4 of Dr. Gamble's previous SRP Project. She studied the effects of redox status on methylation of arsenic and DNA which was one focus of her thesis (see Highlight from last year). Her work was selected for an oral presentation at The FASEB Summer Research Conference on Folate and One Carbon Metabolism in August 2014. Upon graduation in May of 2014, she received the Bernie Weinstein Award for the most outstanding doctoral research thesis. She is currently working as a post-doctoral research scientist working with Dr. Dean Jones at Emory.

- **Faruque Parvez:** A past trainee, Faruque was recently promoted to the title of Research Scientist in the EHS department at Columbia. He has been awarded two NIEHS grants: a) a ViCTER grant in collaboration with Scott Burchiel of the University of New Mexico; and b) an R01 grant, as PI. The ViCTER grant examines interactions between arsenic and cigarette smoking on the immune system, while the R01 is entirely focused on arsenic and immune function in participants in the HEALS cohort study (Project #1).

- **Brandilyn Peters**, Dr. Gamble's PhD student successfully defended her thesis in May 2015. Some of her work involved analyses of differentially methylated CpGs by arsenic exposure and was, along with Kristin (above), instrumental in generating preliminary data for our current SRP Project 3. She also analyzed all of the homocysteine data for aim 2. Brandi also conducted several studies related to the potential renal toxicity of arsenic exposure in Bangladesh; this work was published in PlosOne (2014), Free Rad Biol Med (2015), and Environ Res (2015). Brandi is the co-first author (along with Megan Hall) on the primary findings from the Folic Acid and Creatine clinical trial (Environ Health Persp, Dec 2015) and a related manuscript on the effect of Creatine supplementation on homocysteine and guanidinoacetate levels (J Nutr, 2015). Brandi presented some of her work as an oral presentation at The FASEB Summer Research Conference on Folate and One Carbon Metabolism in August 2014.

- **Tiffany Sanchez**, is a fifth year PhD student trainee involved with Project #2. The evaluation of the relationship between As exposure and non-malignant respiratory disease will comprise the basis of Tiffany's PhD dissertation. She will defend her

dissertation in May 2016. Tiffany has traveled to Bangladesh twice to monitor the study. She met with field staff, visited study participants and transported biological samples to New York for analyses. Tiffany presented a poster at the 2014 SRP's annual meeting in San Jose, CA, entitled "Limited impact of point-of-use filters on arsenic exposure in the Folate and Creatinine Trial (FACT)." A manuscript from that project has been submitted for publication. She also gave platform presentations at both the ISEE meeting and the SRP meetings. The SRP presentation was entitled "Identifying intermediary pulmonary effects among Bangladeshi adolescents with known lifetime arsenic exposure." Finally, Tiffany's Systematic Review on arsenic exposure and non-malignant lung outcomes will soon be published in Environmental Research.

- **Jing Sun**, entered the PhD program in Earth & Environmental Sciences in September 2010, passed the PhD thesis defense in October 2015, and deposited PhD thesis in December 2015. Jing attended the 2015 SRP Annual Meeting and received best poster award in the Environmental Sciences and Engineering category. Following thesis deposit, Jing continues to be appointed as a post-doctoral researcher under Project 4 and 5, and be supervised by the PIs Bostick and Chillrud.

C. RESEARCH TRANSLATION AND COMMUNITY ENGAGEMENT HIGHLIGHTS:

Highlight #1:

Title: Columbia's CEC and Maine State Agencies Promote Private Well Testing:

The Community Engagement Core partnered with Maine CDC and Maine Geological Survey to develop several versions of a well testing promotion mailer meant to alternately emphasize different psychological factors identified as significant to arsenic testing behavior through our community survey of private well households. These brochures were mailed in August 2015 to 2,000 randomly selected addresses in Waldo County, Maine, where about 78% of residents rely on private well water and state lab testing data reveals town As occurrence rates as high as 26% and wells with concentrations as high as 1700 µg/L. A follow-up survey will evaluate the effectiveness of the brochures and lessons learned will inform future outreach materials.

Highlight #2:

Title: Columbia's CEC and RTC Collaborate with NJ State Agencies to Understand Private Well Quality Issues:

Ongoing collaboration of RTC with county and state agencies in New Jersey responsible for groundwater arsenic issues led to a joint NJ-RTC-CEC project in 2014 to survey well owners in northern NJ to identify psychological and economic factors impacting private well testing behavior and treatment barriers using the same methodology as the CEC's household surveys implemented in Maine. The NJ Department of Health has recently been awarded CDC funding over the next 5 years to expand the work on private well water quality issues in New Jersey, with Columbia's SRP as a key academic partner. Findings from our 2014 survey of 670 private

well households and follow-up water sampling in 2015 will guide planned collaborative research projects focusing on the development of outreach materials and methods to promote private well testing and treatment.

Highlight #3:

Title: Columbia's RTC works with NJ State Agencies on Arsenic Awareness Issues Relevant to Testing and Treatment of Private Wells:

The ongoing collaboration of RTC with NJ state and county agencies continues to focus on educational outreach efforts aimed at private well owners in areas with high prevalence of elevated groundwater arsenic. The 2014 survey of arsenic treatment providers in NJ was completed and analyzed in 2015. Survey results were used to help construct FAQs on the NJ Arsenic Awareness website where videos are housed along with lists of testing companies and treatment providers. The arsenic treatment video, fourth in the series initiated in Barnard College Sustainable Development Workshops, was edited in 2015 and will be released following NJ state approval of FAQs for the companion website. The videos and companion website will form part of the Arsenic Awareness toolkit for use with communications and other interventions designed with input from the 2014 and 2015 NJ well owner surveys. Additional 2015 enhancements to the website include an arsenic treatment checklist and updated testing costs.

D. PROJECT/CORE PROGRESS UPDATES:

Project 1. A Cohort Study of Health Effects of Arsenic Exposure in Bangladesh: PI - Habibul Ahsan

The association between individual-level arsenic exposure and dermatological, pulmonary, and cardiovascular health outcomes has not been well established in the scientific literature, particularly at low-to-moderate exposure levels. Through our continued follow-up of the HEALS cohort, Farzan (2015) and Jiang (2015) showed associations of arsenic exposure with longitudinal changes in blood pressure as well as interaction of arsenic with common genetic variants in relation to blood pressure. Wu (2015) observed significant gene-arsenic interactions in relation to cardiovascular disease incidence by genetic variants related to endothelial dysfunction. Jansen (2015) observed that two distinct arsenic metabolism phenotypes show unique associations with age, sex, body mass index, 10q24.32 polymorphisms, and skin lesions. Gao (2015) showed that common genetic variants outside of the AS3MT region influence arsenic metabolism in Bangladeshi individuals, but the effects of these variants are very weak compared with variants near AS3MT. Furthermore, this study suggested that the high heritability estimates observed may be due to substantial effects for rare variants and/or unmeasured environmental factors. Gao (2015) observed that arsenic exposure was associated telomere-related gene expression and longer telomeres, suggesting telomere maintenance/damage as a potential mode of action for arsenic. Argos (2015) observed significant associations between arsenic exposure and gene-specific differential white blood cell

DNA methylation, suggesting that epigenetic modifications may be an important pathway underlying arsenic toxicity.

Project 2. Consequences of Arsenic and Manganese Exposure on Children: PI – Joseph Graziano

Project 2 addresses several questions concerning the health effects of exposure to arsenic and manganese in water (WAs and WMn, respectively) among adolescents. First, does the As-induced respiratory disease observed in adults also manifest itself in adolescents, and what are possible physiologic mechanisms? Second, to what extent do associations between WAs and both lung function brain function reflect the effects of exposure in utero and in infancy, periods of dramatic development for these systems? Third, are WAs and WMn associated with specific cognitive functions in addition to intelligence? We have consented and completed the recruitment and evaluation of of 661 adolescents (15-17 years old) (out of the planned 780) whose mothers are participants in the HEALS cohort study (Project #1). Based on mothers' well As, measured five times from 2000, we defined four groups with varying levels and patterns of exposure to As: Group 1) consistently low (mean WAs = 3 ppb); Group 2) consistently moderate (mean WAs = 26 ppb); Group 3) consistently high (mean WAs = 146 ppb); and Group 4) high from conception through roughly age one (mean WAs = 201 ppb) but much lower thereafter (mean WAs =13 ppb). Three specific aims target As exposure and pulmonary function (FEV1 and FVC) as well as biomarkers of lung dysfunction in exhaled breath condensate. An additional three aims focus on neuropsychologic outcomes assessed via the Cambridge Neuropsychological Test Automated Battery (CANTAB), and the WISC-IV. Final analyses of all of the specific aims are in progress.

Project 3. Impact of Nutrition on Arsenic-Induced Epigenetic Dysregulation: PI - Mary Gamble

The carcinogenic mechanisms of As are incompletely understood, but emerging evidence suggests that As exposure leads to dysregulation of epigenetic process that can influence gene expression and genomic stability. In our Bangladesh cohort we have demonstrated that chronic As exposure is associated with increased global DNA methylation, contingent on adequate folate status. We hypothesize that the mechanism underlying this relates to As-induced alterations in histone modifications.

Folate is a key regulator of one-carbon metabolism mediated methylation reactions, including epigenetic modifications such as methylation of DNA and histones. A large randomized trial in Bangladesh has evaluated the effects of folic acid (FA) supplementation on As methylation and blood As concentrations. We are currently conducting a cross-disciplinary collaboration using samples collected from this trial to carry out a set of aims related to nutrition/environment interactions. In these aims, we characterize the influence of As exposure on histone modifications, relate changes in histone modifications to changes in DNA methylation, and characterize the impact of FA supplementation on these marks (Howe 2016, in press). Finally,

we are identifying a set of genes that are differentially methylated by As exposure and will determine expression levels of genes found to be differentially methylated. These aims will begin to elucidate the molecular events that underlie the effects of As and folate on DNA methylation. The implications of identifying an influence of FA supplementation on histone modifications are considerable, as this represents a simple, low-cost, low-risk intervention as a potential therapeutic approach to reverse As-induced epigenetic dysregulation.

Project 4. Arsenic, Iron, Sulfur and Organic Carbon Speciation: PI - Ben Bostick

Understanding arsenic (As) mobilization and immobilization requires knowledge of molecular scale processes including mineralogical and microbial studies. Our project focuses on understanding these processes, and how they affect the evolution of groundwater composition (water quality) over time and space. Over the last year, we have performed repeated analysis of groundwater from a number of sites in Bangladesh to document the extensive and pervasive changes in As levels (and other groundwater constituents) in well water from shallow aquifers that are typically thought of as resilient to change. Over the past year we have further analyzed radiocarbon of DNA from groundwater aquifers and we have compared it to the radiocarbon signature of the phospholipid fatty acids extracted from sediment samples (Whaley-Martin et al., submitted), and characterized the microbial population active in the same locations (Gnanaprakasam et al., in prep). In addition we have improved our ability to analyze iron (Fe) mineralogy from aquifer samples using standard additions with synchrotron-based X-ray absorption spectroscopy (XAS) to quantify ferrihydrite and magnetite in sediment samples, Mössbauer Spectroscopy, and statistical methods such as principal components analysis (PCA) (Sun et al., Submitted, Bostick et al, in prep). These methods enable us to better understand Fe mineralogy which is critical in controlling in As release and movement in As impacted aquifers. They also have improved our ability to develop remediation strategies that depend on enhancing natural mineral transformation processes to create phases like magnetite that are capable of retaining As.

Project 5. Application of Enhanced Mitigation Methods for Groundwater Arsenic at US Superfund Sites: PI - Steve Chillrud

Magnetite is promising as a host-mineral for arsenic immobilization in that it is stable under a wide range of conditions, including both oxic conditions and iron(III) reducing conditions under which arsenic are often mobilized. Our laboratory results suggest that the oxidation of ferrous iron with nitrate can form an iron oxide assemblage containing nanoparticulate magnetite (Sun et al., 2016; submitted). Magnetite can incorporate arsenic into its structure during formation, in which case desorption and arsenic(V) reduction are less likely. Magnetite, once formed, also immobilizes arsenic by adsorption, and thus serves as a reactive filter when contaminated groundwater migrates through the treatment zone (Sun et al., 2016). A satisfactory identification of the geochemical and hydrological processes critical for arsenic immobilization and a good understanding of how they differ at field-scale, are needed to design field-deployable procedures. Therefore, reactive transport modeling was used to study and improve the nitrate-

iron(II) strategy (Sun et al., in prep). The modeling results suggest that the ratio between iron(II) and nitrate in the injectant regulates the extent and distribution of magnetite and ferrihydrite formation, and thus regulates the long-term potential of arsenic immobilization. Two-dimensional field-scale model scenarios were developed to compare the impact of chemical and operational parameters on the strategy. The field-scale modeling results favor scenarios that rely on the chromatographic mixing of iron(II) and nitrate after injection. Our model helps evaluate the effectiveness of the strategy of in situ porous reactive filters of magnetite in field systems and potentially helps achieve long-term groundwater arsenic remediation.

Project 6. Defining the Sustainable Uses of Low-Arsenic Aquifers in Bangladesh: PI - Alexander van Geen

Since 2000, the Columbia University Superfund Program has felt under the obligation not only to study the mechanisms of arsenic (As) release and transport in groundwater but also to reduce exposure of the 35,000 villagers from Bangladesh participating in the Health Effects of Arsenic Longitudinal Study (HEALS) under Project 1. Project 6 has therefore focused on the vulnerability of shallow low-As aquifers tapped by most private household wells as well as deeper community wells installed primarily by the government. Recent results include the documentation of a convergence over the past decade of As concentrations towards an areal mean that is 10-times higher than the WHO guideline and EPA standard for drinking water of 10 ug/L in shallow aquifers in response to pumping for irrigation (Mozumder et al. under review). This unexpectedly rapid mixing of As has potential implications for perturbations of groundwater flow near US Superfund sites. On the positive side, systematic observations and modeling so far shows no evidence of As contamination at depth despite depressurization due to massive municipal pumping that extends to our study area 20-30 km east of Dhaka (Knappett et al., under review; Khan et al., under review). Especially because of the recently documented unpopularity of technologically functional As-removal filters at the household level (Sanchez et al., under review), the impact of deep community wells that deliver low-As groundwater needs to be maximized from a better understanding of the political-economy of currents assignments which favor the local elite (van Geen et al., 2015).

Administrative Core: Co-PIs - Joseph Graziano and Alexander van Geen

Drs. Graziano and van Geen are involved with other SRP investigators in providing mentorship to the many PhD students involved in our research projects, and work with them to guide their preparation of abstracts and presentations at the annual SRP meeting. Indeed, collectively, our PhD students have presented posters and presentations at numerous national meetings, including the annual SRP meeting, Society of Toxicology meeting, the FASEB summer research conference on folate and one carbon metabolism, the Geological Society of American, the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America.

All of our scientific team assembles monthly for a joint two-hour meeting, which rotates between the Health Sciences Campus and the Lamont-Doherty Earth Observatory Campus. Our monthly meetings often include two hours of seminars, typically one hour for biomedical and one for non-biomedical presentations. We also offer our seminars as webinars which are attended by many outsiders from EPA, NIH, DEP and academia. The seminar series includes a mix of internal and external speakers and has evolved into a world class set of events.

A meeting of our External Advisory Committee (EAC) was held on November 30, 2015. The committee provided valuable input regarding our specific aims for the upcoming competitive renewal application. We also note that Dr. CJ Chen, former Minister of Health in Taiwan and a member of our EAC for 15 years has resigned from our committee because he has just been elected to be Vice-President of Taiwan!

Core A. Data Management Core: PI - Richard Buchsbaum

During the past year, Diane Levy stepped down as PI of the data management core, replaced by Richard Buchsbaum, her colleague at the Statistical Analysis Center in the Department of Biostatistics. Ms. Levy remains in an advisory role, and continues to coordinate the importation of complex results for several projects into the central database (see below for details.) Her role in data extraction for analysis has been largely taken over by Nancy LoIacono, whom Ms. Levy trained and continues to assist as necessary. The remaining data management duties have been taken over by Mr. Buchsbaum.

As no new projects requiring data systems were inaugurated in the past year, the major task of the data management core has been assembling data collected elsewhere and integrating it into the central database. This has in large part been automated through the establishment of a data sharing website. Users with access to primary data collection (questionnaire data entry systems, lab results, clinical test results) can upload these data to the website, where the data files are stored, processed as necessary, and imported into the central database. All data currently being collected, with the exception of the unstructured lab data processed and imported by Ms. Levy, is imported via the website. In general, data is updated weekly, though users may upload data as frequently as desired. In addition, the web site provides a file-sharing utility, where data sets and associated files can be uploaded and shared with authorized users.

Core B. Trace Metals Core Laboratory: PI - Joseph Graziano

The biomedical projects (#1, 2 and 3) of this Superfund Program focus on the adverse health effects of arsenic on the health of adults (#1), adolescents (#2) and on the mechanisms whereby produces these adverse effects (#3). Naturally occurring arsenic in groundwater used for drinking and cooking is a problem in many regions of the world and in many households in the United States that rely on their own well water. The Trace Metals Core Laboratory enables these three above-mentioned research projects to achieve their objectives by providing a cost-effect central laboratory site that can accurately measure arsenic, arsenic metabolites, and other toxic metals in biological samples derived from the three biomedical research projects.

This laboratory participates in numerous quality control programs, national and international, and is thus the values obtained for the analysis of blood and urine samples are assured to be accurate.

Core C. Biogeochemistry Core Laboratory: PI - Alexander van Geen

Over 5300 samples of groundwater, along with about half as many samples analyzed QA/QC purposes (standards, blanks, replicates), were analyzed by high-resolution inductively coupled plasma mass spectrometry for the projects operating in Bangladesh and the U.S. (Projects 1, 2, 3, 4, 5, and 6). The resulting data contribute to several health studies including those by Peters et al. (2015), Wasserman et al. (in review), and Sanchez et al. (in review), as well as mitigation-related studies in Bangladesh (van Geen et al., 2015; Knappett et al., in review; Khan et al., in review; Choudhury et al., in review) and in the U.S. (Sun et al., 2016 and several other manuscripts by Sun et al. under revision or in review). In addition, 100 samples of exhaled breath condensates collected from children under Project 2 were analyzed for 8-isoprostane. Concentrations of 8-isoprostane were below the detection limit and the possibility of using malondialdehyde as an alternative biomarker of oxidative stress. Core C has also supported the analysis of several hundred sediment samples by XRF-fluorescence.

Core D. Hydrogeology Core Laboratory: PI - Peter Schlosser

Detailed knowledge of groundwater flow is essential for understanding geochemical processes in the subsurface. Identification of recharge and discharge areas and mechanisms, as well as flow lines are essential for delineating trends in geochemical evolution, including changes in arsenic concentrations, and to quantify reaction rates. Depressurization of the deep, low-arsenic aquifer below our study area of Araihazar in Bangladesh by massive pumping for the municipal water supply of Dhaka has been the focus of research supported under Core D. We have shown that the vast majority of 900+ deep community wells installed throughout Araihazar currently provide water that meets the WHO guideline for arsenic in drinking water (van Geen et al., 2015) but this may not remain the case. The concern is that the pronounced vertical head gradients could potentially induce downward flow of shallow high-arsenic groundwater (Knappett et al. in review). In addition to the direct observations of water levels in deep wells throughout Araihazar, Core D has contributed to the creation of a hydrogeological model that documents the impact of Dhaka pumping and for the first time, takes into account stratigraphic heterogeneity (Khan et al., in review). During the past year, Core D has also supported further application of a salt-spiking technique to detect leaky deep community wells and further investigation of such leaks using a downhole camera (Choudhury et al., in review).

Core E. Community Engagement Core: PI - Yan Zheng

The Community Engagement Core this year partnered with Maine CDC and Maine Geological Survey to evaluate a mass mailing intervention to promote well testing, informed by the behavior-influencing factors identified by household surveys in central Maine. Four different

versions of a mailer were developed to alternately emphasize arsenic risks, local norms (both for well contamination and for testing behavior), and to strengthen ability beliefs. These mailers were delivered to 2,000 randomly selected addresses of Waldo County, Maine, where about 78% of residents rely on private well water and state lab testing data reveals town As occurrence rates as high as 26% and wells with concentrations as high as 1700 µg/L. Return postcards were included to track requests for information and in a subset, requests for test kits, and a follow-up survey was mailed to all addresses in November 2015 to assess self-reported testing behavior change and solicit feedback on the mailer content. Lessons learned will inform future motivational materials and outreach.

Research Translation Core. Co-PI's: - Steve Chillrud and Sandra Baptista

The Columbia Research Translation Core (RTC) focuses on a broad range of government partnerships with local, state, federal, and international agencies concerned with the health impacts and geochemistry of arsenic and manganese exposures via drinking water, primarily from groundwater in the U.S. and Bangladesh. The RTC participated in the development of policy recommendations to reduce arsenic exposure in drinking water and food by contributing to the report *MDI Biological Laboratory Arsenic Summit: Approaches to Limiting Human Exposure to Arsenic* published in Current Environmental Health Reports (Stanton et al. 2015). The RTC continues to widely disseminate, via monthly seminars/webinars, listservers, conferences, and publications, the Center's significant findings and helps to facilitate the timely application of innovative approaches for testing, treatment, and remediation. Over the past two years RTC has partnered with CEC on a collaborative project with the New Jersey Department of Environmental Protection (NJDEP) to study well testing and treatment practices in 17 arsenic-affected towns in northern New Jersey. The project included a mailed survey completed by 670 private well households in 2014 and follow-up water testing for 119 households in 2015. The collaboration and findings have resulted in three upcoming manuscripts (Flanagan et al. *in prep*) and will be disseminated to New Jersey stakeholders. The findings will also inform joint activities to reduce drinking water exposures in New Jersey, developing new outreach and educational methods, including smartphone apps and the enhancement of existing websites. The RTC continues to provide geospatial expertise and enhance the NPL Superfund Footprint Mapper.

E. PROJECT/CORE PUBLICATIONS:

Project 1

Publications:

Jansen RJ, Argos M, Tong L, Li J, Rakibuz-Zaman M, Islam MT, Slavkovich V, Ahmed A, Navas-Acien A, Parvez F, Chen Y, Gamble MV, Graziano JH, Pierce BL, Ahsan H. Determinants and consequences of arsenic metabolism efficiency among 4,794 individuals: demographics, lifestyle, genetics, and toxicity. Cancer Epidemiol Biomarkers Prev. 2015. pii: cebp.0718.2015. PubMed PMID: 26677206.

Karagas MR, Gossai A, Pierce B, Ahsan H. Drinking Water Arsenic Contamination, Skin Lesions, and Malignancies: A Systematic Review of the Global Evidence. Curr Environ Health Rep. 2015; 2(1):52-68. PubMed PMID: 26231242; PubMed Central PMCID: PMC4522704.

Farzan SF, Karagas MR, Jiang J, Wu F, Liu M, Newman JD, Jasmine F, Kibriya MG, Paul-Brutus R, Parvez F, Argos M, Bryan MS, Eunus M, Ahmed A, Islam T, Rakibuz-Zaman M, Hasan R, Sarwar G, Slavkovich V, Graziano J, Ahsan H, Chen Y. Gene-arsenic interaction in longitudinal changes of blood pressure: Findings from the Health Effects of Arsenic Longitudinal Study (HEALS) in Bangladesh. Toxicol Appl Pharmacol. 2015; 288(1):95-105. PubMed PMID: 26220686; PubMed Central PMCID: PMC4606937.

Pesola GR, Argos M, Chen Y, Parvez F, Ahmed A, Hasan R, Rakibuz-Zaman M, Islam T, Eunus M, Sarwar G, Chinchilli VM, Neugut AI, Ahsan H. Dipstick proteinuria as a predictor of all-cause and cardiovascular disease mortality in Bangladesh: A prospective cohort study. Prev Med. 2015; 78:72-7. PubMed PMID: 26190365.

Jiang J, Liu M, Parvez F, Wang B, Wu F, Eunus M, Bangalore S, Newman JD, Ahmed A, Islam T, Rakibuz-Zaman M, Hasan R, Sarwar G, Levy D, Slavkovich V, Argos M, Bryan MS, Farzan SF, Hayes RB, Graziano JH, Ahsan H, Chen Y. Association between Arsenic Exposure from Drinking Water and Longitudinal Change in Blood Pressure among HEALS Cohort Participants. Environ Health Perspect. 2015; 123(8):806-12. PubMed PMID: 25816368; PubMed Central PMCID: PMC4529016.

Gao J, Tong L, Argos M, Bryan MS, Ahmed A, Rakibuz-Zaman M, Kibriya MG, Jasmine F, Slavkovich V, Graziano JH, Ahsan H, Pierce BL. The Genetic Architecture of Arsenic Metabolism Efficiency:A SNP-Based Heritability Study of Bangladeshi Adults. Environ Health Perspect. 2015; 123(10):985-92. PubMed PMID: 25768001; PubMed Central PMCID: PMC4590755.

Aschebrook-Kilfoy B, Argos M, Pierce BL, Tong L, Jasmine F, Roy S, Parvez F, Ahmed A, Islam T, Kibriya MG, Ahsan H. Genome-wide association study of parity in Bangladeshi women. PLoS One. 2015; 10(3):e0118488. PubMed PMID: 25742292; PubMed Central PMCID: PMC4350917.

Jiang J, Liu M, Parvez F, Wang B, Wu F, Eunus M, Bangalore S, Ahmed A, Islam T, Rakibuz-Zaman M, Hasan R, Sarwar G, Levy D, Argos M, Scannell Bryan M, Graziano J, Hayes RB, Ahsan H, Chen Y. Association of major dietary patterns and blood pressure longitudinal change in Bangladesh. J Hypertens. 2015; 33(6):1193-200. PubMed PMID: 25693059; PubMed Central PMCID: PMC4606930.

Wu F, Jasmine F, Kibriya MG, Liu M, Cheng X, Parvez F, Islam T, Ahmed A, Rakibuz-Zaman M, Jiang J, Roy S, Paul-Brutus R, Slavkovich V, Islam T, Levy D, VanderWeele TJ, Pierce BL, Graziano JH, Ahsan H, Chen Y. Interaction between arsenic exposure from drinking water and genetic polymorphisms on cardiovascular disease in Bangladesh: a prospective

case-cohort study. Environ Health Perspect. 2015; 123(5):451-7. PubMed PMID: 25575156; PubMed Central PMCID: PMC4421763.

Gao J, Roy S, Tong L, Argos M, Jasmine F, Rahaman R, Rakibuz-Zaman M, Parvez F, Ahmed A, Hore SK, Sarwar G, Slavkovich V, Yunus M, Rahman M, Baron JA, Graziano JH, Ahsan H, Pierce BL. Arsenic exposure, telomere length, and expression of telomere-related genes among Bangladeshi individuals. Environ Res. 2015; 136:462-9. PubMed PMID: 25460668; PubMed Central PMCID: PMC4264833.

Argos M, Chen L, Jasmine F, Tong L, Pierce BL, Roy S, Paul-Brutus R, Gamble MV, Harper KN, Parvez F, Rahman M, Rakibuz-Zaman M, Slavkovich V, Baron JA, Graziano JH, Kibriya MG, Ahsan H. Gene-specific differential DNA methylation and chronic arsenic exposure in an epigenome-wide association study of adults in Bangladesh. Environ Health Perspect. 2015; 123(1):64-71. PubMed PMID: 25325195; PubMed Central PMCID: PMC4286273.

Oral/poster presentations:

Ahsan, H, et al. Epigenomic profiles of arsenic exposure in human, *International Society for Environmental Epidemiology*, Sao Paulo, Brazil, August 30-September 2, 2015.

Ahsan, H, et al., *International Workshop on Diet-related and Nutrition Status Biomarkers*, Hamilton, Canada, October 28-29, 2015.

Ahsan, H, et al., *Collaborative on Food with Arsenic and associated Risk and Regulation (C-FARR)*, Dartmouth College, Hanover, New Hampshire, USA, November 2-3, 2015.

Project 2

Publications:

Wasserman, G, Liu, X, Parvez, F, Factor-Litvak, P, Kline, J, Siddique, AB, Shahriar, H, Uddin, MN, van Geen, A, Mey, JL, Balac, O, Graziano, JH: Child intelligence and reductions in water arsenic and manganese: A two-year follow-up study in Bangladesh. Environ Health Perspect, Dec 2015, ahead of print. PMID: 26713676.

Khan, K, Ahmed, E, Factor-Litvak, P, Liu, X, Siddique, S, Slavkovich, V, Wasserman, G, Levy, D, Mey, JL, van Geen, A, Graziano, JH: Evaluation of an Elementary School-Based Educational Intervention for Arsenic Exposure in Bangladesh. Environ Health Perspect. 2015 Dec;123(12):1331-6. doi: 10.1289/ehp.1409462. Epub 2015 May 8. PMCID:PMC4671245

George, CM, Brooks WA, Graziano JH, Nonyane BA, Hossain L, Goswami D, Zaman K, Yunus M, Khan AF, Jahan Y, Ahmed D, Slavkovich V, Higdon M, Deloria-Knoll M, O' Brien KL. Arsenic exposure is associated with pediatric pneumonia in rural Bangladesh: a case control study. Environ Health. 2015 Oct 23;14:83. doi: 10.1186/s12940-015-0069-9. PMCID:PMC4619558

Presentations:

March 7th, 2015: Presentation to the Lang Youth Medical Program on Saturday, March 7, 2015 at 9:30am-11:00am. Presentation talked about environmental health in general, and on our arsenic research in Bangladesh. (see http://nyp.org/services/lang-youth.html)

March 12th: Grand Rounds in Pediatrics at Mount Sinai Medical Center, entitled: "Poisons in the Well: Exposure, consequences and remediation of well water arsenic and manganese in Bangladesh"

April 14th: Gave testimony to the State Senate in Maine regarding a bill that would require household wells to be tested for arsenic at the time of a real estate transaction. The bill was a result of our publication regarding the association between household well water arsenic concentrations and child IQ in Maine schoolchildren. (The bill passed, but the governor vetoed it.)

September 22nd: Grand Rounds at Case Western Reserve University, seminar title as that for March 12th.

Project 3

Publications in the Current Funding Cycle:

1. Peters BA, Hall MN, Liu X, Neugut YD, Pilsner JR, Levy D, Ilievski V, Slavkovich V, Islam T, Factor-Litvak P, Graziano JH and Gamble MV. Creatinine, arsenic metabolism and renal function in an arsenic-exposed population in Bangladesh. PlosOne 2014 Dec 1;9(12):e113760. PMCID: PMC4249915.

2. Howe CG and Gamble MV. Enzymatic cleavage of histone H3: a new consideration when measuring histone modifications in human samples. Clin Epigen 2015 Jan 22; 7(1):7. PMCID:PMC4307743

3. Argos M, Chen L, Jasmine F, Tong L, Pierce BL, Roy S, Paul-Brutus R, Gamble MV, Harper KN, Parvez F, Rahman M, Rakibuz-Zaman M, Slavkovich V, Baron JA, Graziano JH, Kibriya MG, Ahsan H. Gene-specific differential DNA methylation and chronic arsenic exposure in an epigenome-wide association study of adults in Bangladesh. Environ Health Perspect 2015 Jan; 123(1):64-71. PMCID: PMC4286273.

4. Peters BA, Liu X, Hall MN, Ilievski V, Slavkovich V, Siddique AB, Alam S, Islam T, Graziano JH and Gamble MV. Arsenic exposure, inflammation and renal function in Bangladeshi adults: effect modification by plasma glutathione redox potential. Free Rad Biol Med April 23, 2015; 85:174-82. PMCID: PMC4679178

5. Muñoz A, Chervona Y, Hall M, Kluz T, Gamble MV and Costa M. Sex-specific patterns and deregulation of endocrine pathways in the gene expression profiles of Bangladeshi adults

exposed to arsenic contaminated drinking water. Toxicol Appl Pharmacol 2015 May 1; 284(3):330-8. PMCID: PMC4410068.

6. Peters BA, Hall MN, Liu X, Parvez F, Siddique AB, Shahriar MH, Uddin MN, Islam T, Ilievski V, Graziano JH, and Gamble MV. Low-Dose Creatine Supplementation Lowers Plasma Guanidinoacetate, but Not Plasma Homocysteine, in a Double-Blind, Randomized, Placebo-Controlled Trial. J Nutr 2015 Oct;145(10):2245-52. PMCID: PMC4580963

7. Reed MC, Gamble MV, Hall MN, Nijhout HF. Mathematical analysis of the regulation of competing methyltransferases. BMC Syst Biol 2015 Oct 14;9:69. PMCID: PMC4606511

8. Niedzwiecki MM, Liu X, Hall MN, Thomas T, Slavkovich V, Ilievski V, Levy D, Alam S, Siddique AB, Parvez F, Graziano JH, and Gamble MV. Sex-specific associations of arsenic exposure with global DNA methylation and hydroxymethylation in leukocytes: Results from two studies in Bangladesh. Cancer Epidemiol Biomarkers Prev. 2015 Nov;24(11):1748-57. PMCID: PMC4633312

9. Peters BA, Hall MN, Liu , Slavkovich V, Ilievski V, Alam S, Siddique AB, Graziano JH and Gamble MV. Renal function is associated with indicators of arsenic methylation capacity in Bangladeshi adults. Environ Research 2015 Nov; 143(Part A):123-30. PMID: 26476787 [PubMed - in process]

10. Peters BA, Hall MN, Liu X, Parvez F, Siddique AB, Shahriar MH, Slavkovich V, Ilievski V, Factor-Litvak P, Graziano JH, Gamble MV. Folic acid and creatine as therapeutic approaches to lower blood arsenic: A randomized-controlled trial. Envir Health Persp 2015 Dec;123(12):1294-1301. PMCID: PMC4671237

11. Howe CG, Liu X, Hall MN, Slavkovich V, Ilievski V, Parvez F, Siddique AB, Shahriar H, Uddin N, Islam T, Graziano JH, Costa M, Gamble MV. Exposure to arsenic-contaminated drinking water and global measures of H3K36me2, H3K36me3, and H3K79me2 in Bangladeshi adults (Accepted EHP).

Oral/Poster Presentations:

Dr. Gamble and members of her laboratory attended three scientific conferences in 2015. In April, Dr. Gamble and Caitlin Howe attended the Annual Conference of the Office for the Study of Sex Differences; Caitlin's poster was awarded a prize and financial reimbursement for her travel expenses. Dr. Gamble, Dr. Hall and Caitlin Howe attended the 10th Annual Conference on One Carbon Metabolism, B Vitamins and Homocysteine in Nancy, France in July 2015. Caitlin's poster was awarded first prize. In November, Dr. Gamble, Caitlin Howe and Tiffany Sanchez attended the Annual SRP Meeting in Puerto Rico. Caitlin's poster was a "runner-up" for first prize. Tiffany was invited to give an oral presentation.

Project 4

Publications:

1. Jing Sun, Steven Chillrud, Brian Mailloux, Martin Stute, Rajesh Singh, Hailiang Dong, Christopher Lepre, and Benjamín Bostick. Enhanced and stabilized arsenic retention in microcosms through the microbial oxidation of ferrous iron by nitrate. Chemosphere, 2016, 144: 1106-1115.

2. Jing Sun, Andrew Quicksall, Steven Chillrud, Brian Mailloux, and Benjamín Bostick. Arsenic mobilization from sediments in microcosms under sulfate reduction. Accepted by Chemosphere.

3. Jing Sun, Benjamín Bostick, Brian Mailloux, James Ross, and Steven Chillrud. Use of oxalic acid for mobilizing arsenic from contaminated sediments and decreasing vulnerability to reduction. Accepted (pending changes) by Journal of Hazardous Materials.

4. Jing Sun, Steven Chillrud, Brian Mailloux, and Benjamín Bostick. In situ magnetite formation and long-term arsenic immobilization under advective flow by the oxidation of ferrous iron by nitrate. Submitted to Environmental Science & Technology, January 2016.

5. Jing Sun, Brian Mailloux, Steven Chillrud, Alexander van Geen, and Benjamín Bostick. Quantifying ferrihydrite in sediments by the method of standard-additions using EXAFS spectroscopy. Revision submitted to Analytical Chemistry, January 2016.

6. Jing Sun, Henning Prommer, Adam Siade, Steven Chillrud, Brian Mailloux, and Benjamín Bostick. Modeling of iron mineral transformation and arsenic fate under the oxidation of ferrous iron by nitrate. In Preparation for Environmental Science & Technology.

7. Jing Sun, Steven Chillrud, Brian Mailloux, Henning Prommer, and Benjamín Bostick. Mechanisms of arsenic(V) mobilization from iron oxide minerals in the presence of oxalic acid. In Preparation for Environmental Science & Technology.

8. Whaley-Martin, K.J., Mailloux, B., Silvern, R.F. , Kim, C., Bostick, B.C. , Ahmed, K. M., Choudhury, I., van Geen, A. , Slater, G.F., 2015, Radiocarbon Bacterial Lipid Analysis to Track Carbon Sources Stimulating Microbially-Mediated Arsenic Release in Bangladesh Aquifers, Submitted January, 2016 to Environmental Science and Technology.

9. Edwin T Gnanaprakasam, E. T., Lloyd, J. R., Boothman, C., Ahmed, K. M., Chowdhury, I., Bostick, B. C., van Geen, A., Mailloux, B. J., 2015, Microbial Arsenate reduction in sediment is critical for arsenic release in Bangladesh aquifers, In Preparation for Environmental Science and Technology.

10. Mailloux, B. J., Bostick, B. C., Ellis, T., van Geen, L., Nguyen, K., McElroy, M., Chowdry, I., Ahmed, K. M., 2015, A Decades Long Time Series Analysis of Arsenic Concentrations from Four Well Nests in Bangladesh, In Preparation.

11. Benjamín Bostick, Jing Sun, and Brian Mailloux. Principal Components Analysis of Iron X-ray Absorption Spectra as a Tool to Determine Sediment Origin and Alteration in South and Southeast Asian Sediments, In Preparation.

12. Benjamín Bostick, Jing Sun, Steven Chillrud, Brian Mailloux, and Alexander van Geen. Iron Reduction Rate and Adsorption Rates Control Arsenic Concentrations in Reducing Environments. In Preparation.

13. Ezazul Haque, Brian Mailloux, Daisy de Wulff, Jing Sun, Alexander van Geen, and Benjamín Bostick. Quantitative Arsenic Concentrations Using Mobile Phone Photometry. In preparation for Environmental Science & Technology Letters, expected submission date February, 2016.

14. Elizabeth Shoenfelt, Ivan Mihajlov, Jing Sun, Steven Chillrud, Brian Mailloux, Alexander van Geen and Benjamin C. Bostick. An X-ray Microprobe Study of Diffusion Limitation at the Micron Scale for As adsorption on natural sands. In Preparation for Langmuir.

Oral/poster presentations:

1. Benjamín C. Bostick, Jing Sun, Mason Stahl, Brian Mailloux, Ivan Mihajlov, Steve Chillrud and Alexander van Geen. An Alternative Model of Arsenic Reductive Release and Arsenic Partitioning. American Chemical Society National Meeting, Denver CO, March 2015.

2. Benjamín C. Bostick, Jing Sun, Mason Stahl, Brian Mailloux, Ivan Mihajlov, Steve Chillrud and Alexander van Geen. The Expanding Footprint of Asian Arsenic Crisis. CSIRO-Water and Land Seminar series, Perth Australia, Feb. 2015.

3. Benjamín Bostick, Jing Sun, Steven Chillrud, Brian Mailloux, and Alexander van Geen. Regional-Scale Feedbacks That Affect Pore Scale Processes and the Spatiotemporal Distribution of Arsenic Contamination. Soil Science Society of America national meeting (Keynote), Minneapolis MN, November 2015.

4. Benjamín Bostick, Jing Sun, Steven Chillrud, Brian Mailloux, and Alexander van Geen. Insights from a kinetics-based model describing aqueous arsenic concentrations at Superfund sites. The SRP Annual Meeting. San Juan, Puerto Rico, November 2015.

5. Jing Sun, Henning Prommer, Adam Siade, Steven Chillrud, Brian Mailloux, and Benjamin Bostick. Use of reactive transport modeling for understanding and designing the magnetite based arsenic immobilization strategy. The SRP Annual Meeting. San Juan, Puerto Rico, November 2015.

6. Benjamin Bostick, Ezazul Haque, Daisy DeWulf, and Brian Mailloux. 2015. Incorporating Real-Time Chemical Measurements into Mobile Technology: Mobile Phone Colorimetry. Columbia University Environmental Engineering-Water Quality Group meeting. June 2015.

7. Jing Sun, Henning Prommer, Adam Siade, Steven Chillrud, Brian Mailloux, and Benjamin Bostick. Long-term fate of arsenic under the oxidation of ferrous iron by nitrate. The annual meeting of the American Geophysical Union. San Francisco, December 2015.

8. Benjamin Bostick. Arsenic Remediation at Superfund Sites. USGS-Menlo Park Geochemistry group seminar. June, 2015.

9. Benjamín C. Bostick, Robert Newton, Susan Vincent, Dorothy Peteet, Ray Sambrotto, Peter Schlosser, J. Elizabeth Corbett. Lamont-Doherty's Secondary School Field Research Program: Using Goal-Oriented Applied Research as a Means of Building Comprehensive and Integrated Scientific Understanding. American Geophysical Union National Meeting. San Francisco, December 2015.

Book Chapters:

1. Benjamín C. Bostick. Equilibrium. Springer Meteor. Encyclopedia of Geochemistry. In revision.

2. Benjamín C. Bostick. Mössbauer Spectroscopy. Springer Meteor. Encyclopedia of Geochemistry. In revision.

3. Benjamín C. Bostick. Equilibrium Constant. Springer Meteor. Encyclopedia of Geochemistry. In revision.

Project 5

Publications:

1. Jing Sun, Steven Chillrud, Brian Mailloux, Martin Stute, Rajesh Singh, Hailiang Dong, Christopher Lepre, and Benjamín Bostick. Enhanced and stabilized arsenic retention in microcosms through the microbial oxidation of ferrous iron by nitrate. Chemosphere, 2016, 144: 1106-1115.

2. Jing Sun, Andrew Quicksall, Steven Chillrud, Brian Mailloux, and Benjamín Bostick. Arsenic mobilization from sediments in microcosms under sulfate reduction. Accepted by Chemosphere.

3. Jing Sun, Benjamín Bostick, Brian Mailloux, James Ross, and Steven Chillrud. Use of oxalic acid for mobilizing arsenic from contaminated sediments and decreasing vulnerability to reduction. Accepted (pending changes) by Journal of Hazardous Materials.

4. Jing Sun, Steven Chillrud, Brian Mailloux, and Benjamín Bostick. In situ magnetite formation and long-term arsenic immobilization under advective flow by the oxidation of ferrous iron by nitrate. Submitted to Environmental Science & Technology, January 2016.

5. Jing Sun, Brian Mailloux, Steven Chillrud, Alexander van Geen, and Benjamín Bostick. Quantifying ferrihydrite in sediments by the method of standard-additions using EXAFS spectroscopy. Revision submitted to Analytical Chemistry, January 2016.

6. Jing Sun, Henning Prommer, Adam Siade, Steven Chillrud, Brian Mailloux, and Benjamín Bostick. Modeling of iron mineral transformation and arsenic fate under the oxidation of ferrous iron by nitrate. In Preparation for Environmental Science & Technology.

7. Jing Sun, Steven Chillrud, Brian Mailloux, Henning Prommer, and Benjamín Bostick. Mechanisms of arsenic(V) mobilization from iron oxide minerals in the presence of oxalic acid. In Preparation for Environmental Science & Technology.

Oral/poster presentations:

1. Benjamín Bostick. Arsenic Remediation at Superfund Sites. USGS-Menlo Park Geochemistry group seminar. June, 2015.

2. Jing Sun, Henning Prommer, Adam Siade, Steven Chillrud, Brian Mailloux, and Benjamin Bostick. Use of reactive transport modeling for understanding and designing the magnetite based arsenic immobilization strategy. The SRP Annual Meeting. San Juan, Puerto Rico, November 2015.

3. Steven Chillrud, Jing Sun, Benjamín Bostick, Brian Mailloux, and James Ross. Use of oxalic acid for mobilizing arsenic from contaminated sediments and decreasing vulnerability to reduction. The SRP Annual Meeting. San Juan, Puerto Rico, November 2015.

4. Benjamín Bostick, Jing Sun, Steven Chillrud, Brian Mailloux, and Alexander van Geen. Insights from a kinetics-based model describing aqueous arsenic concentrations at Superfund sites. The SRP Annual Meeting. San Juan, Puerto Rico, November 2015.

5. Jing Sun, Henning Prommer, Adam Siade, Steven Chillrud, Brian Mailloux, and Benjamin Bostick. Long-term fate of arsenic under the oxidation of ferrous iron by nitrate. The annual meeting of the American Geophysical Union. San Francisco, December 2015.

6. Benjamín Bostick, Robert Newton, Susan Vincent, Dorothy Peteet, Ray Sambrotto, Peter Schlosser, J. Elizabeth Corbett. Lamont-Doherty's Secondary School Field Research Program: Using Goal-Oriented Applied Research as a Means of Building Comprehensive and Integrated Scientific Understanding. American Geophysical Union National Meeting. San Francisco, December 2015.

Project 6

Publications:

1. Radloff KA, Y Zheng, M Stute, B Weinman, B Bostick, I Mihajlov, M Bounds, MM Rahman, MR Huq, KM Ahmed, P Schlosser, A van Geen. Adsorption and flushing of arsenic in a rapidly recharged shallow aquifer of Bangladesh. Applied Geochemistry, accepted October 2015. NIHMSID747884

2. van Geen A, KM Ahmed, EB Ahmed, I Choudhurry, MR Mozumder, BC Bostick, BJ Mailloux. Inequitable allocation of deep community wells for reducing arsenic exposure in Bangladesh. Journal of Water, Sanitation and Hygiene for Development, accepted October 2015. NIHMSID747882

3. Peters, BA, MN Hall, X Liu, P Factor-Litvak, F Parvez, A van Geen, JL Mey, AB Siddique, MH Shahriar, MN Uddin, MT Islam, V Slavkovich, V Ilievski, JH Graziano, MV Gamble. Folic acid and creatine as therapeutic approaches to lower blood arsenic: A randomized-controlled trial. Environmental Health Perspectives 123, 1294–1301, 2015.

4. Khan K, EB Ahmed, P Factor-Litvak, X Liu, Z Rahman, HA Ferdous, AB Siddique, GA Wasserman, V Slavkovich, D Levy, J Mey, A van Geen, JH Graziano. Evaluation of an elementary school-based educational intervention for reducing arsenic exposure in Bangladesh. Environmental Health Perspectives 123, 1331–1336, 2015.

5. Pfaff A, Schoenfeld A, Ahmed KM, van Geen A. Reduction in exposure to arsenic limited by insufficient testing and awareness in Bangladesh. Submitted to Journal of Water, Sanitation and Hygiene for Development, January 2016.

6. Barnwal, P., A. van Geen, J. von der Goltz, C.K. Singh. Cost-sharing in environmental health products: evidence from arsenic testing of drinking-water wells in Bihar, India. Submitted January 2016.

7. Khan M.R., Koneshloo M., Knappett P.S.K. Ahmed, K.M., Bostick B.C., Mailloux, B.J., Mozumder R.H., Zahid A., Harvey C.F., van Geen A., Holly A. Michael H.A. Mega-city pumping in fluvio-deltaic aquifer creates complex vulnerability of arsenic-safe groundwater to contamination. Submitted to Nature Geoscience, January 2016.

8. Sanchez T.R., Levy D., Siddique A.B., Shahriar M.H., Uddin M.N., Lomax-Luu A., Graziano J., van Geen A., Gamble M.V. Limited reduction of urinary arsenic from a nutritional intervention that relied on household-level treatment to reduce exposure in Bangladesh. Submitted to Environmental Health, January 2016.

9. Mihajlov I., M. Stute, P. Schlosser, B. J. Mailloux, Y. Zheng, I. Choudhury, K.M. Ahmed, A. van Geen. Recharge of low-arsenic aquifers tapped by community wells in Araihazar, Bangladesh, inferred from environmental isotopes. Submitted to Water Resources Research, October 2015.

10. Choudhury, I., K.M. Ahmed, M. Hasan, M.R.H. Mozumder, P.S.K. Knappett, T. Ellis, A. van Geen. Evidence for elevated levels of arsenic in public wells of Bangladesh due to improper installation. Revision submitted to Groundwater, December 2015.

11. Aziz, Z., B. Bostick, Y. Zheng, M.R Huq, M.M. Rahman, K.M. Ahmed, and A. van Geen, Evidence of decoupling between arsenic and phosphate in shallow groundwater of Bangladesh and potential implications, Revision submitted to Applied Geochemistry, January 2016.

12. Sun J, Mailloux B, Chillrud S, van Geen A, Bostick B. Quantifying ferrihydrite in sediments by the method of standard-additions using EXAFS spectroscopy. Submitted to Analytical Chemistry, September 2015.

13. Wasserman, GA, X Liu, F Parvez, P Factor-Litvak, J Kline, AB Siddique, H Shahriar, M Nasirrudin, A van Geen, J Mey, O Balac, JH Graziano. Reducing well-water arsenic exposure and changes in child intelligence. Submitted to Environmental Health Perspectives, March 2014.

14. Knappett, PSK, BJ Mailloux, I Choudhury, M Khan, H Michael, S Barua, DR Mondal, M Steckler, H Akter, KM Ahmed, B Bostick, C Harvey, M Shamsudduha, I Mihajlov, R Mozumder, A. van Geen. Vulnerability of low-arsenic aquifers to municipal pumping in Bangladesh. Journal of Hydrology, revision submitted December 2015.

15. Mozumder, R., C. Harvey, B. Mailloux, B. Bostick, T. Ellis, E. B. Ahmed, K.M. Ahmed, A. van Geen. Changes in the distribution of arsenic in shallow aquifers of Bangladesh induced by irrigation pumping. Submitted to Nature Geoscience, January 2016.

Oral/poster presentations:

1. KHAN, Mahfuzur R., NATH, Bibhash, HUHMANN, Brittany L., CHOUDHURY, Imtiaz, CHAKRABORTY, M., MUKHERJEE, Abhijit, AHMED, Kazi Matin, HARVEY, Charles F., VAN GEEN, Alexander and MICHAEL, Holly A. Origin of arsenic rich, young groundwater in deep tubewells in the central southwestern Bengal basin. Oral presentation at the annual meeting of the Geological Society of America, Baltimore, November 2015.

2. NATH, Bibhash, KHAN, Mahfuzur R., HUHMANN, Brittany L., CHAKRABORTY, Madhumita, MUKHERJEE, Abhijit, AHMED, Kazi Matin, MICHAEL, Holly A., BOSTICK, Benjamin C., MAILLOUX, Brian J. and VAN GEEN, Alexander. Groundwater chemistry of deep (>300 feet) high-As aquifers across the India-Bangladesh border. Oral presentation at the annual meeting of the Geological Society of America, Baltimore, November 2015.

3. MOZUMDER, M. Rajib Hassan, MAILLOUX, Brian, BOSTICK, Benjamin C., AHMED, Ershad Bin, AHMED, Kazi Matin, CHEN, Therese, ELLIS, Tyler, HARVEY, Charles F., STUTE, Martin and VAN GEEN, Alexander. Transient arsenic concentrations in a shallow aquifer of Bangladesh induced by irrigation pumping. Oral presentation at the annual meeting of the Geological Society of America, Baltimore, November 2015.

4. HUHMANN, Brittany L., UDDIN, Anjal, CHOUDHURY, Imtiaz, DUXBURY, John, BOSTICK, Benjamin C., AHMED, Kazi Matin, VAN GEEN, Alexander, HARVEY, Charles. Replacement of arsenic-contaminated soil for improved rice yields in Bangladesh. Oral presentation at the annual meeting of the Geological Society of America, Baltimore, November 2015.

5. Shuai, P., A. Hossain, K. Rhodes, P. S. K. Knappett, N. Dimova, M. B. Cardenas, K. M. Ahmed, H.A. Michael, R. Mozumder, A. van Geen. Modeling arsenic mobilization in a riverbank aquifer under the influence of a tidally fluctuating river and irrigation pumping. Poster presentation at the annual meeting of the American Geophysical Union. San Francisco, December 2015.

6. Sanchez, Tiffany. Abu B. Siddique, Mohammad Hasan Shahriar, Mohammad Nasir Uddin, Angela Lomax, Diane Levy, Joseph Graziano, Alexander van Geen, Mary V. Gamble. Limited impact of point-of-use filters on arsenic exposure in the Folate and Creatinine Trial (FACT). Poster presentation at the annual SRP meeting held in Puerto Rico, November 2015.

Cores A-D

There are no unique core specific publications from these cores but the publications from the projects above heavily rely on their contributions.

Core E

Publications:

Flanagan, S.V., Spayd, S., Procopio, N., Marvinney, R.G., Smith, A.E., Chillrud, S.N., Braman, S., and Y. Zheng (in preparation) Arsenic in private well water of New Jersey and Maine: Socioeconomic vulnerability to exposure.

Flanagan, S.V., Spayd, S., Procopio, N., Chillrud, S.N., Ross, J., Braman, S., and Y. Zheng (in preparation) Arsenic in private well water of New Jersey: Who benefits most from traditional testing promotion?

Flanagan, S.V., Spayd, S., Procopio, N., Chillrud, S.N., Braman, S., and Y. Zheng (in preparation) Arsenic in private well water of New Jersey: Impact of Private Well Testing Act on household testing and mitigation behavior.

Flanagan, S.V. and Y. Zheng (in preparation) The case for universal arsenic screening of private well water in the U.S.

Presentations:

Flanagan, S.V., Zheng, Y., Braman, S., Chillrud, S., Ross, J., Louis, J., Procopio, N., and S. Spayd (2015, August). Evaluation of factors that favor or hinder the testing and treatment of private well water: A household survey in areas of New Jersey where well waters frequently exceed the drinking water standard for arsenic. Presentation to representatives of New Jersey Departments of Health and Environmental Protection. Trenton, New Jersey.

Flanagan, S., Butts, K., Smith, A., Marvinney, R., and Y. Zheng. (2015, November). Arsenic in private well water – Collaboration on community engagement in Maine. Poster presented at NIEHS SRP Annual Meeting. San Juan, Puerto Rico.

Chillrud, S., Braman, S., Flanagan, S. and Y. Zheng (2015, November). Collaboration to reduce arsenic exposure from private well water in New Jersey. Poster presented at NIEHS SRP Annual Meeting. San Juan, Puerto Rico.

RTC

Publications:

Flanagan, S.V., Spayd, S., Procopio, N., Marvinney, R.G., Smith, A.E., Chillrud, S.N., Braman, S., and Y. Zheng (in preparation) Arsenic in private well water of New Jersey and Maine: Socioeconomic vulnerability to exposure.

Flanagan, S.V., Spayd, S., Procopio, N., Chillrud, S.N., Ross, J., Braman, S., and Y. Zheng (in preparation) Arsenic in private well water of New Jersey: Who benefits most from traditional testing promotion?

Flanagan, S.V., Spayd, S., Procopio, N., Chillrud, S.N., Braman, S., and Y. Zheng. (in preparation) Arsenic in private well water of New Jersey: Impact of Private Well Testing Act on household testing and mitigation behavior.

Stanton, B.A., Caldwell, K., Congdon, C.B., Disney, J., Donahue, M., Ferguson, E., Flemings, E., Golden, M., Guerinot, M.L., Highman, J., James, K., Kim, C., Lantz, R.C., Marvinney, R.G., Mayer, G., Miller, D., Navas-Acien, A., Nordstrom, D.K., Postema, S., Rardin, L., Rosen, B., SenGupta, A., Shaw, J., Stanton, E. and Susca, P. (2015) MDI Biological Laboratory Arsenic Summit: Approaches to Limiting Human Exposure to Arsenic. Current Environmental Health Reports 2(3):329-337. Available online 26 June 2015. DOI 10.1007/s40572-015-0057-9.

Presentations:

Chillrud, S., Braman, S., Flanagan, S., and Y. Zheng (2015, November). Collaboration to reduce arsenic exposure from private well water in New Jersey. Poster presented at RT/CE Poster Session, NIEHS SRP Annual Meeting, San Juan, Puerto Rico.

Flanagan, S.V., Zheng, Y., Braman, S., Chillrud, S., Ross, J., Louis, J., Procopio, N., and S. Spayd (2015, August). Evaluation of factors that favor or hinder the testing and treatment of private well water: A household survey in areas of New Jersey where well waters frequently exceed the drinking water standard for arsenic. Presentation to representatives of New Jersey Departments of Health and Environmental Protection. Trenton, New Jersey.