Summary Report of the Arsenic Residuals Workshop

NIEHS SBRP – EPA

February 28 – March 1, 2005

Washington, D.C.

Introduction

The U.S. Environmental Protection Agency (EPA) and the National Institute of Environmental Health Sciences (NIEHS) Superfund Basic Research Program (SBRP) participated in an effort to informally and constructively discuss the implications of recent research that affects multiple EPA program offices.

The workshop focused on the science and research-related issues surrounding assessment and disposal of the arsenic-bearing solid residuals (ABSRs) of water treatment technologies. The initial goal was to identify the latest science that will support additional or alternative procedures to reduce or eliminate the potential public health hazards caused by disposal of these wastes. An additional goal identified at the workshop is to fully assess the groundwater contamination potential of drinking water treatment residuals from arsenic treatment, when these residues are disposed in accordance with state regulations. Participants included representatives of EPA's Office of Solid Waste (OSW), Office of Water (OW), Office of Solid Waste and Emergency Response (OSWER), and Office of Research and Development (ORD); select academicians; and SBRP staff and contractors. Appendix A contains contact information for all workshop participants.

Ms. Beth Anderson (NIEHS) described the SBRP and emphasized this unique pilot effort to bring together academic researchers and relevant EPA offices to address environmental and public health threats. This pilot effort is intended to:

- Promote the use of a recent research finding that has potential to identify future environmental/public health threats and potential strategies for addressing them.
- Encourage real time interaction among research scientists and environmental program experts and managers.
- Support short-term research to address science and science policy questions that could help inform agency decision-making to address these potential threats.
- Support actions to understand the potential for and minimize/prevent potential environmental health threats.

Dr. Wendell Ela, of the University of Arizona, introduced the workshop topic and the goals for bringing this diverse group of participants together. He described several unique aspects of this meeting including the limited size, intentionally narrow scope, and the broad multidisciplinary expertise and regulatory experience of the invited participants. Additionally, Ela described the unique opportunity to practice “proactive environmental engineering,” i.e. assessing and, where appropriate, acting ahead of the hazard actually affecting the public’s health. Because the ABSRs will be generated largely after the implementation of the new arsenic (As) MCL (maximum contaminant level) for drinking water in January 2006, there is an opportunity to assess the magnitude of the potential risks and, if appropriate, make warranted changes that could prevent the public from being exposed to arsenic from this source. To achieve this goal, workshop participants were asked to consider those potential solutions that could be implemented in a timely manner. Long-term options were also discussed as the topic warranted. Open discussion of all options was encouraged, and participants were asked to consider solutions that cut across conventional delineations.

The workshop considered three introductory questions posed by Ela as examples of the most helpful types of issues to address:

- What can be done to address this issue in the short term, i.e. 6-12 months?
- Now that residuals are being created, what advice can be given to states, utilities, etc.?
- What sort of regulatory/non-regulatory options are available?

Scope of the ABSR Issue

In Ela's 2004 Environmental Science & Technology paper (Appendix B), he cites EPA data that estimates the revised arsenic MCL standard will ultimately impact about 4,000 drinking water utilities. The data further estimates that over 95 % of those affected will be small utilities (*serving less than 3,301 people*). It is expected that these utilities will primarily implement arsenic removal using iron- or alumina- based sorbents. These processes result in the generation of ABSRs. Most ABSRs tested to date pass the Toxicity Characteristic (TC) regulation (see 40 CFR 261.24) and, consequently, are expected to be disposed in non-hazardous municipal solid waste (MSW) landfills or other landfills approved by states. Ela estimates that nationally approximately 6 million pounds of solid residuals containing approximately 30 thousand pounds of arsenic will be generated every year, and presumably disposed in MSW landfills. Ela's investigation indicates that the toxicity characteristic leaching procedure (TCLP), on which the TC regulation relies, is likely to underestimate leaching of arsenic from these residuals if disposed in a mature MSW landfill. Some portion of the arsenic contained in these residuals is likely to leach out and ultimately end up in the landfill leachate or the groundwater beneath the landfill. Residents near landfills dependent on the use of groundwater for their drinking water could be exposed to arsenic from this source, and potentially, additional Superfund sites could be generated at these landfills. However, none of Dr. Ela's published alternate leaching tests produced results that exceeded the TC regulatory level. Further, EPA regulations for MSW landfills require the use of composite liners with leachate collection systems, and groundwater monitoring, or a "no-migration" demonstration for key waste constituents of concern, including arsenic (see 40 CFR 258.40, 258.50-51). Therefore, fully understanding the potential for ABSRs to contaminate ground water and drinking water wells with arsenic is the critical next step in the process begun at the workshop.

A more accurate and quantitative understanding of the following issues will aid in evaluating this problem: a) where the residuals will be generated; b) what the localized annual volumes of residuals and their arsenic concentrations will be; c) where the residuals will be disposed; and d) the groundwater, landfill and land use conditions at and near the disposal site. Ms. Erica Blumenschein, of the University of Arizona, is gathering data that addresses these questions on a local scale. She presented an algorithm for attempting to better quantify the impact of this potential future threat. The algorithm is comprised of a series of steps to a) identify communities with arsenic groundwater concentrations greater than 10 ppb; b) identify local population distributions; c) estimate the arsenic mass to be disposed and the proximate landfill(s) in which this will be done; d) estimate the leachate and arsenic mobilization rates in the affected landfills; e) predict the landfill derived, down-gradient groundwater arsenic concentration as a function of distance from the landfill; and f) estimate the down-gradient population potentially exposed to increased arsenic by subsequent groundwater contamination. Initially, Blumenschein will consider three communities in Arizona with elevated arsenic levels in the groundwater (Rimrock, Ajo and Green Valley). When this algorithm is fully developed, it could be applied elsewhere to get a more complete representation of the potential impacts of the landfill disposal of these residuals. As discussed below, EPA/OSW has also developed a groundwater fate and transport model, the Industrial Waste Management Evaluation Model (IWEM), for assessing the well contamination potential of wastes disposed in landfills.

There were several helpful questions and suggestions raised that will be considered following the workshop. These comments included:

- EPA's OSW has some relevant studies on arsenic concentrations in landfill leachate that will be useful for the algorithm. OSW also has data on the amount of arsenic going into landfills from a variety of sources. (*OSW provided data on CD*)
- It was noted that leachate concentrations would vary according to the amount of precipitation and infiltration, which could also vary geographically.
- It was noted that it would be important to conduct sensitivity tests on the algorithm results to identify the most critical factors and their importance to the uncertainty of the results.
- There was discussion of the potential variability in leachate collection systems around the country. All MSWs are supposed to have leachate collection systems, unless they demonstrated that they weren't needed due to limited rainfall, etc. However, this is an area of State responsibility, and there is no one Federal data system for this information. Several states (Ohio, Delaware, Wisconsin and Florida) were noted as having MSW data systems that could be useful for this effort.

The balance of the meeting was divided into sessions focused on two major aspects of this arsenic residuals issue. The first session considered assessment of the leaching potential of the arsenic in drinking water treatment residuals. The central questions in this session were: is the TCLP the most accurate test for the arsenic-bearing solid residuals of drinking water treatment, and if not, are there other tests that are more reliable? The second session focused on the fate of the arsenic if the residuals are disposed in MSWs. The central questions in this session were: are residuals from some types of treatment suitable for landfilling, and if not, are there additional stabilization procedures that could make them suitable for landfilling?

Assessment of the Leaching Potential of Arsenic-Bearing Solid Residuals from Drinking Water Treatment Technologies

Mr. Greg Helms (OSW) presented an overview of the operations of the Resource Conservation and Recovery Act (RCRA)statute relating to the testing and disposal of arsenic bearing solid residuals (ABSRs). The TCLP is part of the TC regulation, and so is the definitive test for classifying waste with regard to the TC. The TCLP has been successfully applied as a screening test to a wide variety of solid wastes to assess the likelihood of their leaching contaminants from an MSW landfill. However, there have been several examples in the published literature of the TCLP under predicting arsenic leaching, and one lawsuit resulting from TCLP use to assess the leaching potential of arsenic from a highly alkaline waste when monofilled.

While there are indications that TCLP may under predict arsenic leaching from some wastes, it is not clear that revision of the TCLP is warranted, and EPA does not currently have plans to revise the test. Program resources are limited and any regulatory change would require development of a significant amount of scientific information, and would take an extended timeframe before promulgation. Nor is listing of arsenic drinking water treatment residuals plausible given limited resources, likely industry opposition, and the lack of data to support a listing determination. The initial discussion highlighted the following possible short–term actions:

- Characterize the magnitude of the problem, based on the anticipated volume and As concentrations in drinking water treatment residuals on a local and/or regional scale.
- Use the Industrial Waste Management Evaluation Model (IWEM) to identify what type of landfill is best for disposal of the ABSRs. It is recommended that results from the best leach test available are used as input to IWEM to have the most accurate assessment.
- Send ABSRs to a well-run landfill (e.g. compliant with the 40 CFR Part 258 regulations).

Longer-term actions:

- Compare the problem posed by drinking water treatment residuals disposal (15 tons As/year) with other As waste disposal issues, such as CCA-treated wood disposal (5,000 – 10,000 tons As/year). There was also discussion of evaluating other sources of As.

- Consider new approaches to leach testing that would better address broad applicability, factors affecting leaching, lab/ field validation, and the practical applicability of the results.

Dr. David Kosson, of Vanderbilt University, discussed his research on a conceptual approach to leaching evaluation that is being implemented into a multi-tiered leaching protocol, summarized as follows:

- Measure the intrinsic leaching characteristics of the material in terms of pH and complexation influences
- Evaluate the release in the context of field scenario
  - External influencing factors such as carbonation, oxidation
  - Hydrology
  - Mineralogical changes
- Use geochemical speciation and mass transfer models to estimate release for alternative scenarios
  - Model complexity to match information needs
  - Many scenarios can be evaluated from a single data set

He described LeachXS, a software tool being jointly developed by The Netherlands Energy Research Foundation (ECN), Vanderbilt University (USA) and DHI Water and Environment (Denmark), including test methods selection, database, data presentation, evaluation, geochemical speciation modeling, and scenario assessment.

Kosson's key messages were:

- Measure intrinsic leaching characteristics, use geochemical speciation and mass transfer models in conjunction with management scenarios to estimate constituent release.
- Use results to assess impacts and to develop acceptance criteria and monitoring strategies.
- The tools exist and data are currently being obtained to achieve assessments for specific scenarios of residuals disposal. Tailoring for specific uses is needed.
- “Classes” of drinking water treatment residuals likely can be identified. After initial characterization, simplified testing (i.e., an index test) can be used to confirm conformance with previously defined class.

The ensuing discussion raised several significant points:

- There was discussion of how quickly arsenic residuals will leach compared to, for example, CCA-treated wood. It was hypothesized that arsenic in CCA-treated wood may be more bound up and less likely to leach as quickly as the arsenic in ABSRs.
- There is an overall need to better assess leaching under reducing conditions, not only of arsenic, but also of other oxyanions. In this context, Kosson described the use of abiotic reductants in the leach solution (such as sodium ascorbate and

sodium borohydride) to improve very low electropotential conditions (~-445mV). The observation was that ferrous sulfide precipitation occurred with concomitant arsenic adsorption to the solid.

- Dr. Jim Field, of the University of Arizona, noted that under mature landfill conditions (anaerobic), microbial activity may contribute to increased arsenic leaching from these residuals.
- Only California has developed an alternative to the TCLP, the WET test. States are not likely to actively pursue alternative tests.
- A question arose as to where arsenic residuals will be sent. For example, this will be the first "waste" from many drinking water facilities. It cannot be assumed that all wastes will be sent to MSWs. This will depend on state regulations—some may require such disposal; others may not.
- There are some beneficial reuse studies underway, for example dealing with land application, to assess whether they may result in adverse environmental impacts.
- There was a question whether there were any studies on colloidal transport. No one knew of any research underway.
- The TCLP has been abused by using it beyond its original purpose. For example, some treatment methods treat to reduce the TCLP results, but that can make the waste more of a problem under real field conditions. Ideally, a material's intrinsic leaching characteristics would be measured, as described in Kosson's presentation.
- Ideally, the technology vendors would fully evaluate their products to ensure that their use and disposal does not create any environmental or public health hazard. However, at the present time there is a competitive disadvantage to doing so, because they currently have no long-term residuals disposal liability (that goes to the utility that purchases the technology) and, if other vendors evaluate only against TCLP results any product evaluated against a more aggressive (albeit more appropriate) test will likely appear to have poorer residual performance.
- The forgoing point raised the question as to what incentives are available to encourage the private sector to adopt any recommendations made by this group. One response was that without utility (consumer) pressure there is little other short-term leverage that can be applied.

A number of salient, general observations also were made during this session's discussion:

- "Arsenic is forever. It's going to be there…We're going to deal with it in perpetuity."
- Another general approach to regulating wastes would be to determine a management scenario for classes of waste, defining management practices for each class of waste, and thereby avoiding reliance on a specific test for major decisions on the best fate for wastes. There are too many field applications and potential tests to be able to rely upon a specific test to accurately predict the threat potential.
- Most research in the treatment field is not even looking at the environmental impact of ABSRs, which is symptomatic of the issue. However, there is

significant EPA research on leaching from wastes and treatment of those wastes. See: EPA/625/R-03/010 and EPA-542-R-02-004.

Arsenic Drinking Water Treatment Residuals and Their Potential Treatment Prior to Disposal

Dr. Eduardo Sáez, of the University of Arizona, gave an overview of the present drinking water treatment technologies for arsenic removal and the generation of ABSRs. But as Sáez said in summary, “There is no silver bullet," because it is believed that none of the alternatives that would likely generate more benign residuals are cost-competitive with the use of iron-based sorbents.

In addition to the consideration of alternative technologies, Sáez described an approach to deal with arsenic treatment residuals by isolating and sequestering the arsenic. The goal would be to engineer an additional (pre-disposal) procedure to stabilize the arsenic in the residuals. The residuals would be converted to a form with a very slow, known release back into the environment. This "mineralization" step could conceivably alter the residuals to a form that does not leach as readily. Additional discussion covered the following points:

- Small water supply treatment systems cannot afford additional treatment or post-treatment costs. The cost of the present adsorptive systems (typically the most affordable treatment option) without additional residuals disposal costs will already stress the many utilities’ ability to comply and remain economically viable.
- More data are needed on the number of small water treatment systems and their geographic distribution (that can be compared to the number and distribution of landfills as was raised in the “Scope of the Arsenic Issue” section above).

Mr. Jeff Kempic (OW) described the history of the revised arsenic drinking water rule and its implementation. Compliance with the rule can be extended to as late as 2015. There is considerable geographic variability in the concentrations of arsenic in water supply systems around the country (Appendix C). Areas of the country such as the Northeast and the West are particularly impacted. Most of the water supply systems that will have to treat for arsenic are very small. Surprisingly, the use of iron-based sorbents was not considered as one of the more likely treatment methods five years or more ago when the regulatory support materials were being developed. EPA has committed $20 million to research to conduct multiple arsenic treatment technology demonstrations at sites around the country (12 sites in Round 1, and around 30 more to be in round 2). Most of these deal with iron or alumina media. As noted earlier, none of these demonstrations is evaluating the impact of disposal of the residuals. The discussion included the following ideas:

- Small water treatment systems are going with whatever the treatment technology vendors are telling them now. There is no discussion of potentially adverse impacts of arsenic bearing residuals.
- There is also a concern that alternative technologies (e.g. ion exchange) would result in a concentrated arsenic liquid resulting in other potential environmental threats (e.g. high arsenic loading in wastewater treatment sludge with ramifications on land application of the biosolids, precipitated arsenic salts in drying pond beds creating an airborne particulate hazard with wind erosion).
- The question arose as to what was the general “run length” for the adsorbent media (iron/alumina)? The answer was about one year. Would shorter run times affect the rate and amount of leaching of arsenic from the residuals? It was suggested that part of the answer to this query may lie in the observation that nearly all of the arsenic sorbed to the iron and alumina sorbents tested will mobilize under landfill conditions, so more sorbents with a lower loading (due to shorter run times) will only increase the volume of residuals sent to landfills, but not likely the stability of the residuals.
- Another question arose regarding how much iron based media will need to be shipped for a small community water supply system? The back of the envelope estimate was about 3000 pounds per year for a small system with 100 people.
- The cost of the iron media was estimated to be about $20 to $40 per ton.
- Given this relatively cheap cost of materials, it was discussed that this might encourage centralized pick up and delivery and better controlled/monitored disposal of the media by vendors. This led to a suggestion (which, in concept, was supported by a number of participants) that utilities have the only real power in the short-term to push for such a system, since they as the purchasers of the technology have the leverage to require the vendors to provide appropriate residuals information and disposal. This type of consumer-driven solution however implies the utilities or their representatives (i.e., consultant engineers, professional organizations) be educated and continuously updated as to the issues regarding residuals assessment and disposal and of the status of on-going research to evaluate residuals from particular technologies.
- There was some discussion of how the States were approaching the January 2006 deadline for implementing the arsenic drinking water standard. There is considerable variability expected. For example, New Mexico is expected to use the exemption process, while Arizona is planning to meet the deadline.
- Titanium dioxide was raised as a potentially preferable alternative to iron and alumina media. Its potential benefits are significant. Compared to iron- or alumina-based sorbents, the titanium-based products are:
    - less sensitive to pH and redox conditions, so less likely to leach
    - cost-competitive
    - easy to “retrofit” to those water systems already designed for iron or alumina media
    - would not “penalize” those water supply systems that have moved ahead in good faith to meet the drinking water deadline
    - are already being applied in some areas of New Jersey

- Another technology that was broached as a potential alternative was the "aging" of iron-based arsenic residuals by exposure to the air to promote "mineralization" of the arsenic. Such aging for about a year could result in the formation of arsenic bound minerals that would slow down the leaching process. Combining mineralization with disposal in separate cells or "lifts" in MSWs could minimize leaching, perhaps enough to significantly reduce the potential exposure to nearby residents dependent on the groundwater.
- It was acknowledged that the "aging/mineralization" process needs more research and pilot testing. The costs and benefits of this process should be quantified. One issue involves being able to get representative residuals that can be used for research. A brief discussion ensued as to what kinds of research/tests would validate this approach? e.g. run column tests to test the material, and then run field verification tests.
- There was considerable discussion of landfills. Are there alternatives to shipping this waste to landfills? Or can separate areas in landfills be identified and used so as to minimize the potential for leaching from them?
- Specifically, could there be separate monofills for arsenic waste? It was felt to be doubtful that there would be enough arsenic waste to merit this, especially since landfills are tending to be consolidated into larger and larger ones to be more economically viable.

Toward an Integrated Framework for Addressing the Issue

A final workshop session focused on integrating the thoughts, conclusions and assessments made in the previous session into workable, short-term paths. There are several factors that must be addressed to move ahead on this issue. The workshop participants laid out the following four steps necessary to develop an integrated framework of new research findings and EPA program actions that would better estimate the impact of and response to this potential threat.

1. Fully assess the likely magnitude of the problem. Identify the volumes and arsenic concentrations of residuals generated; identify volumes likely to go for disposal at local and larger-city landfills; perform groundwater fate and transport modeling to assess the potential for groundwater and drinking water well contamination using IWEM or other models.

2. Define additional short-term research/data needs necessary to understand the seriousness of the problem and support program intervention that reflects this understanding.

   Short-term Research Needed

   - Complete the University of Arizona Algorithm to better quantify the potential impact of this issue – several data sets need to be defined.
   - Use leach testing and other data to run the IWEM Tier 2 model (which considers local conditions) to better understand the magnitude of the problem.

Run two different scenarios discussed by the group: 1) disposal of all local/regional residuals in a single, large-city landfill (assumes vendors change treatment media and dispose of spent materials as part of a service contract with the water supplier); and 2) local disposal of smaller volumes of spent treatment media (assumes water suppliers dispose of their own spent media).

- Assess the potential of residual "aging/mineralization" prior to landfill disposal to reduce the leaching potential of the residuals.
- Assess options for stabilization of ABSRs, such as encapsulation by polymeric or cementatious materials, if such measures are warranted.
- Evaluate titanium dioxide and other non-alumina or non-iron-based media as potential cost-effective drinking water treatment alternatives.
- Assess the potential beneficial impact of disposal of arsenic in separate cells in MSWs.

Comment [GLH1]: Note: Bullet on cost estimation of waste treatment deleted. This analysis was already done by OW, as part of the rulmaking support.

3. Develop a perspective of and plan for longer-term research needs. Several longer term research needs were identified that could be incorporated into SBRP and EPA ORD's longer term research agenda, depending on competing priorities:

   - Develop additional alternatives to the TCLP for potential use in instances where TCLP is not required by regulation and disposal conditions differ from those anticipated by TCLP. EPA/ORD is developing a suite of leaching tests that encompasses a wide range of physiochemical variables.
   - Determine microbial transformations and leaching of arsenic from ABSRs under e.g. methanogenic conditions. Consider approaches to developing tests to evaluate the effects of microbials on leaching.
   - Evaluate the efficiency of titanium dioxide (Anatase) nanoparticles in arsenic adsorption.
   - Determine if leaching of other oxyanions are also affected in a similar way as arsenic.

After critical portions of the research described in 1-3 above are completed, continue with the activities in 4-6 below. Critical research includes development of a sound assessment of the likelihood that arsenic leaching from landfilled ABSRs will cause or significantly contribute to groundwater contamination, when the ABSRs are managed according to state waste management requirements. This research is critical to the activities below because it will represent the technical support for the central message of the outreach activities.

4. Refine and continue the collaboration initiated in this meeting to guide and evaluate the evolving research, information and thinking regarding ABSR assessment and management. This collaboration must increasingly focus on disseminating appropriate information and guidance to the stakeholders and their representatives.

Chris Ryan reported that the EPA Regional Offices have a pressing need to be able to respond to incoming questions from the States and local communities. The private sector is also looking for guidance on how to deal with this potential issue of arsenic leaching from landfills. Ela has fielded calls from Tribes and local water suppliers as well asking about the research results and the reaction from the Federal and State governments. Workshop participants focused on developing messages for all of the affected parties.

Workshop organizers and participants need to reach out to the American Chemistry Society to start proposing papers and presentations at the ACS Conference. This would be an effective venue to bring this and related issues to the attention of scientists and others in order to promote their involvement in the issue of drinking water treatment residuals assessment and disposal.

This group of EPA, SBRP, ATSDR and academic researchers should continue collaborating; and keep the focus on refining the science and identifying appropriate responses. This could be done through a combination of small working group sessions such as this one and larger more open sessions with other academics and selected, knowledgeable stakeholders to refine an approach and a message to address this issue.

5. Define the key stakeholders affected by this issue. Given the sensitivity and the timeframe, the message(s) that will be conveyed to these stakeholders must be thought through and developed with all the participants. The stakeholders' thoughtful and constructive involvement should be encouraged. It was noted that the community residents are a key stakeholder group.

Key Stakeholders

There is a wide array of stakeholders potentially affected by this issue who were identified in the workshop. The list includes:

- Residents near landfills that may receive these wastes
- Customers of the affected drinking water treatment utilities
- MSW landfill operators
- Drinking water treatment facility owners and operators
- State environmental programs dealing with MSWs and drinking water systems
- Tribal environmental programs dealing with MSWs and drinking water systems
- Regional arsenic MCL coordinators (Chris Ryan's counterparts)/ National Arsenic Work Group – EPA HQ group out of OW
- Regional RCRA MSW experts and leads
- Regional Superfund RPMs/OSCs dealing with arsenic GW treatment
- Adsorbent Media industry representatives
- Other vendors
- Relevant Industry Associations – ASTSWMO, AWWA, ASDWA, WEF
- Academic researchers

6. Develop an outline of a "White Paper" to integrate the science inputs and program options into a cohesive multiparty (Federal, state, local, private) approach to responding to this issue

White Paper on Future Directions

Workshop participants are developing a White Paper to propose a general approach to dealing with this issue. The White Paper should:

- Briefly describe the nature of the issue and its related aspects.
- Lay out the magnitude of the problem.
- Define the stakeholders.
- Develop a workable, strawman timeline for addressing the issue.
- Define short and long term research and science needs.
- Describe the message that is needed.
- Discuss the type of information transfer needed and suggest possible modes to achieve this.
- Lay out an overarching process for addressing the issues of information gathering, evaluation, and follow-on efforts.

Appendix A—List of Workshop Participants

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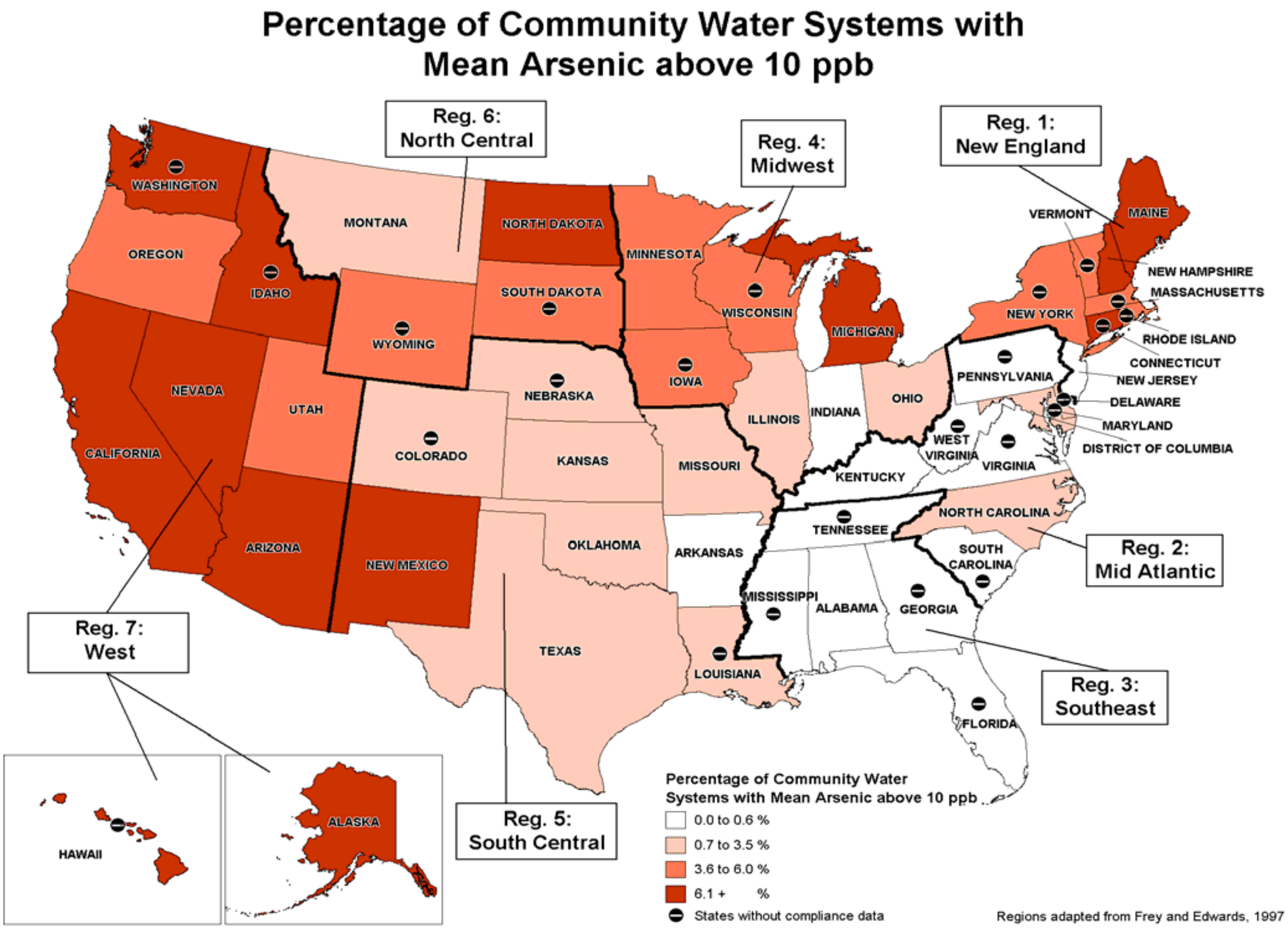
Appendix B – Ela paper from Environmental Science and Technology (2004)

Comment [mcp2]: I'm guessing this will be added in this section

TCLP Underestimates Leaching of Arsenic from Solid Residuals Under Landfill Conditions (Environmental Science and Technology, 2004)

Appendix C



Percentage of Community Water Systems with
Mean Arsenic above 10 ppb
Reg. 1: New England
Reg. 2: Mid Atlantic
Reg. 3: Southeast
Reg. 4: Midwest
Reg. 5: South Central
Reg. 6: North Central
Reg. 7: West
WASHINGTON
OREGON
IDAHO
MONTANA
WYOMING
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
WISCONSIN
MICHIGAN
IOWA
NEBRASKA
NEVADA
UTAH
CALIFORNIA
COLORADO
KANSAS
MISSOURI
ILLINOIS
INDIANA
OHIO
KENTUCKY
WEST VIRGINIA
VIRGINIA
PENNSYLVANIA
NEW YORK
VERMONT
MAINE
NEW HAMPSHIRE
MASSACHUSETTS
RHODE ISLAND
CONNECTICUT
NEW JERSEY
DELAWARE
MARYLAND
DISTRICT OF COLUMBIA
NORTH CAROLINA
SOUTH CAROLINA
TENNESSEE
ARIZONA
NEW MEXICO
OKLAHOMA
ARKANSAS
MISSISSIPPI
ALABAMA
GEORGIA
TEXAS
LOUISIANA
FLORIDA
HAWAII
ALASKA
Percentage of Community Water Systems with Mean Arsenic above 10 ppb
0.0 to 0.6 %
0.7 to 3.5 %
3.6 to 6.0 %
6.1 + %
States without compliance data
Regions adapted from Frey and Edwards, 1997