Gerard Martin, Chief
Brownfields, C&E and Risk Reduction Section
Bureau of Waste Site Cleanup
Massachusetts Department of Environmental Protection
Southeast Regional Office
20 Riverside Drive
Lakeville, Massachusetts 02347

February 22, 2015

Dear Mr. Martin,

We are pleased to have the opportunity to provide comments on the Massachusetts Department of Environmental Protection (MassDEP) document titled: 2014 Public Review Draft, Vapor Intrusion Guidance WSC#-14-435. The comments are prepared by academic scientists and public health professionals, whose contact information is provided in Table 1. We recognize that the draft document represents several years of discussion with many stakeholders, participation of a technical workgroup and incorporates comments on an earlier draft. Of critical importance is that this document is guidance, leaving opportunity for refinement as the science or the practice evolves. This is a well-written document that recognizes the practical difficulties with assessment of vapor intrusion pathways.

The comments are presented in Table 2 and focus on the technical aspects of vapor intrusion (VI) investigations and response, as well as on the communication and outreach components. The table identifies the page number, section, the comment and the initials of the commenter. The comments are not meant to be exhaustive, rather they represent a summary of some key observations by the individuals who reviewed the document. Emphasis is placed on Sections 1, 2, and 5.

The comments on Section 5 are prepared by multiple Board of Health directors (current and former) and are based on their experiences. The general sense of Section 5 is that the approach taken in 2015 should recognize the changing demographics in each city/town, the need for effective communication about the situation and the fact that inclusion of forms placed in a file is insufficient to convey the important that results from the vapor intrusion evaluations.

Please let us know if you have questions or contact the commenter directly.
Sincerely,

Wendy Heiger-Bernays, PhD & Kelly Pennell, PhD, PE
whb@bu.edu kellypennell@uky.edu

Table 1. Commenters' Contact Information

Commenter's Name	Affiliation	Contact Information	Initials Used in Comments
Kelly G. Pennell, PhD, PE	University of Kentucky UK Superfund Research Program	kellypennell@uky.edu http://www.uky.edu/Research/Superfund/index.htm	KP
Wendy Heiger-Bernays, PhD	Boston University School of Public Health BU Superfund Research Program	whb@bu.edu http://www.busrp.org/	WHB
Sigalle Reis, MPH, RS	Superintendent / Director Norwood Health Department	sreiss@norwoodma.gov	SR
Gerard Cody, R.E.H.S./R.S.	Director, Health Division Town of Lexington	gcody@lexingtonma.gov	GC
Ethan Mascoop, MPH, MUA, RS	Consultant, Adjunct BU SPH	emascoop@gmail.com PO Box 320029, West Roxbury MA 02132 617-529-0292	EM
Susan Lumenello	Director, Health Department Town of Burlington	slumenello@burlington.org	SL
C. Max Schlenk	Manager – Environmental Health Services Gloucester Health Department	978-282-8025 (Direct) mschenk@gloucester-ma.gov	MS

Table 2. Comments

Page #	Section	Comments	Commenter's Initials
7	1.1	The first bullet on this page reads as if the pathway must be presently complete, but the likelihood for the pathway to be completed in the future should also be evaluated. See additional comments below related to pages 36 and 38.	KP
7	1.1	The third paragraph uses the term "significant". What is considered a significant impact – Does this mean "measureable?" One could argue that all potentials for vapor intrusion should be considered "significant".	KP, WHB
8	1.3	Last sentence of the first paragraph of this section should be revised to read: "More commonly, the impact is not apparent…"	KP
9	Fig 1-1	Many organizations are generating guidance on VI. How different are the 10X GW-2 Standards with EPA VI screening levels?	KP
9	Fig 1-1	LNAPL exclusion distance of 30 feet should be specified for LNAPLs that are petroleum hydrocarbon in nature. The nature of the LNAPL is clarified on page 13—but this clarification should occur earlier in the document.	KP
10	1.3.3	The first paragraph of Section 1.3.3 does not provide adequate scientific background to support the vertical and lateral distances. Groundwater at depths greater than 15 feet below ground surface does not appear to be conservative. Model simulations by Abreu and Johnson 2005[3], Pennell et al 2009[4] and Bozkurt et a. 2009[5] show the potential for groundwater to serve as a source for vapor intrusion at greater depths. Lateral diffusion appears to occur exponentially, based on analysis of the EPA database and model simulations of Yao et al 2013[6].	KP
11	1.3.3	The extrapolation of groundwater concentrations from a source area to within 30 feet of a building is not protective. Geologic heterogeneities will likely impact the results. Additional field data should be required to verify the potential for vapor intrusion. This field data could include exterior soil gas samples. However, this document excludes those types of samples as being used as a "line of evidence" (last sentence, page 22). One could argue exterior soil gas samples are more reliable than extrapolated groundwater concentration contours.	KP

11	1.3.3	VOCs concentrations at virtually any depth should trigger 72- hour notification at a school, daycare or child care facility. Without evidence that a pathway is <u>not</u> complete, it is the prudent approach to take. See comments on Section 5 below.	KP
11	1.3.4	The last paragraph on this page states that "… if OHM is likely to migrate at significant concentrations to indoor air, then Method 1…is not applicable." It is not clear what is meant by "significant" impacts. The shorter exclusion distances (15 feet vertical) do not appear scientifically supported. The lateral distance of 30 feet should be supported with literature references.	KP
13	1.3.4	We recognize the revision to the LNAPL guidance, but it should be noted that the presence of LNAPL at any thickness warrants additional assessment, even if it is to determine that it is not a continuing source. The exclusion distances are not conservative.	KP
13	1.3.4	Other factors listed include the presence of utilities; however the factors should also include conduits for vapors such as sanitary sewer[1] and perhaps septic lines which may be considered preferential (structural) pathways into structure[2].	WHB
14	2.0	Adequate number of samples should be more strongly stated – recognizing that the vapor intrusion pathway is probably the most variable and requires focused attention to data.	WHB
18	Fig 2-1	An updated conceptual model was recently proposed by Jacobs *et al* 2014[7] based on the field study findings of Pennell *et al* 2013[1] and Riis *et al* 2008[8], which showed sewer gas as a source of VOCs during vapor intrusion investigations. Figure 2-1 should be revised to account for "alternative exposure pathways". The term alternate exposure pathways commonly refers to trenching and piping for sewer-plumbing systems, land drains, storm drains, abandoned pipelines, cable ducts, steam lines, utility lines, other pipes and other conduits that may provide a connection between subsurface vapors and indoor air spaces.	KP
19	2.2	Other factors that are likely to influence vapor intrusion, but are not specifically termed "lines of evidence" in this document, include soil moisture, building operation & maintenance and air exchange rates. In addition, while modeling may not be considered a "line of evidence," it certainly can provide insight about field observations and guide assessment, as well as mitigation activities.	KP
19	2.2	"Current" site use should be defined, tying back to the MCP. See comments below that relate to current site use definitions and implications.	WHB

19	2.2	The term preferential pathways may warrant revision to "alternate exposure pathways". Commonly, preferential pathways include geologic characteristics of trench backfill or layers of highly permeable subsurface soil that promote vapor transport. As noted in the comment referring to Figure 2-1, the term alternative exposure pathways includes "preferential pathways" but also includes other pathways that might connect subsurface vapors with indoor spaces.	KP
21	2.2.1.1	It is not clear what is meant by composite sampling (last paragraph of this section). Further, it is important to note spatial variation in groundwater concentrations—especially in terms of sample location versus building of interest. It is likely that groundwater concentrations that are located equidistance, but in opposite directions, from a building could have substantially different concentrations. In order to be conservative, the sample location that indicates the greatest potential for vapor intrusion should be used.	KP
21	2.2.2	Current Sentence: "Soil sub-slab soil gas immediately under the slab of a building is the media in direct contact with a building and may best reflect the potential for vapor intrusion." Suggested Revision: "Soil sub-slab soil gas immediately under the slab of a building is the media in direct contact with a building and are good indicators for the potential for vapor intrusion; however due to spatial variations, sub-slab soil gas samples are not necessarily representative of the soil gas concentrations beneath the entire sub-slab."	KP
22	2.2.2.1	Exterior soil gas should be another line of evidence. It is not clear why the paragraph that breaks across page 22 and 23 excludes exterior soil gas for being used to indicate the potential for vapor intrusion. Consider this scenario: Only a single sub-slab location could be installed in a building due to logistical issues. The single sub-slab sample was below screening levels and indoor air was sampled twice and each time was below target concentrations. Exterior soil gas samples were installed within 10 feet of the building and showed elevated concentrations. Only one groundwater well is present near the building (50 feet away) and concentrations are consistently above GW-2. In this case, there appears to be a potential for vapor intrusion to occur, even though the current indoor air	KP

		concentrations are not above target concentrations. Exterior soil gas samples can help identify situations where vapor intrusion potentials exist.	
31	2.2.4.1	Para 3. Refers to 8 hour sample collection at Commercial Buildings, but if the building is shared with the sensitive receptors, it is reasonable to sample the working space for 8 hours, but other rooms may be used for other purposes (day care facilities on site), requiring clear distinction as MassDEP does make in the	
31	Table 2-1	The information provided in this table is perhaps based on logic, rather than scientific basis. There is a community-based study by Johnston and Gibson 2013[9] that provides some information about these factors, and it is likely that this study provided context for Table 2-1. While the work by Johnston and Gibson[9] is important and provides extremely interesting insights, it is not clear that the study's findings should be generalized for all vapor intrusion investigations. Below is some rationale for why there is currently insufficient information to support some of the claims in Table 2-1. Season: There is nothing inherently related to the "time of year" (i.e. season) that would alter vapor intrusion rates, rather it is the way in which buildings are typically managed, during those seasons that influences vapor intrusion. Soil: There is little information to support that sampling during or shortly after a rain event is most conservative. In fact, Shen et al 2012[10] report that temporal fluctuations in soil gas concentrations due to saturated soil are not instantaneous. Further, if a heavy rain event took place, it is possible that a clean water lens may be present atop the groundwater table and would be LEAST conservative—which is in disagreement with the Table. Wind: The wind direction may be important, not only speed. Wind can cause asymmetrical pressure gradients around and near a building. This gradients can then result in asymmetrical contaminant mass flow rate. Therefore, it is not obvious that a calm day would necessarily be more conservative than a windy day. Windy days can increase air exchange rates, but it is not clear if this would happen in ALL buildings and it is not certain that it would compensate for increases in wind-induced vapor intrusion fluxes due to changes in subsurface vapor mass flow rates.	KP

		Groundwater Table Depth: It is not always the case that a high groundwater table would be conservative—especially if the groundwater is being diluted by rain water infiltration or snow melt. Barometric Pressure: It is not clear why the conditions in Table 2-1 are shown as most and/or less conservative.	
31	2.2.4.1	The discussion of sensitive buildings (schools and day cares) that is provided throughout the document is notable and extremely important. One thing to consider is timing. Waiting for 2-4 sampling events may not be acceptable to building inhabitants of schools, and other sensitive settings. Further, in these cases the "total" exposure will likely be of most interest to the inhabitants, rather than only the portion of exposure that is attributable to vapor intrusion. Even though it is typically outside the scope of most vapor intrusion guidance, practitioners and regulators will likely have to address and respond to concerns about total exposure during a vapor intrusion assessment at these types of sites. Recent cases in sensitive settings suggest that care in parsing indoor/ambient contributions from VI sources requires fast-tracked efforts. Development of the equivalent of TIACs for schools may be viewed as an academic exercise, but is a necessary element in a data-driven response to a difficult situation. The guidance suggests that assessment be conducted while people are using the building for its intended purposes. Again, may not be possible for sensitive settings and this should be acknowledged. In lieu of sampling when occupied, the building should be kept as close to occupied conditions as possible. In our experience, sampling of indoor air typically occurs on weekends and school vacations.	KP, WHB
31	2.2.4.1	The existence of 2-4 air samples being required before determining that the vapor intrusion pathway does not exist, only addresses the current building situation. Further, no single line of evidence should be used to establish whether vapor intrusion is or is not likely. Even after 2-4 air samples below the regulatory level, vapor intrusion might still occur in the future when the building operation changes or the foundation settles and cracks. Therefore, subsurface sampling is required to evaluate the potential for vapor	KP

		intrusion in occur in the future. Emphasis should be placed on the potential for vapor intrusion to occur, not only whether or not vapor intrusion is currently a concern.	
36	2.2.8	The document uses the term "current site use," which can be interpreted many ways. For instance, it could mean the building use for which the property is currently zoned. Perhaps it could even be interpreted as the building use that occurs given the current physical structure. Therefore, if the building was modified or renovated, than that would be a different site use. Either way, it is not entirely clear. Additional clarification is needed. On a related note, an important and significant terminology change occurs on page 36 (last paragraph). Here, the term "current condition" is introduced. This could be interpreted much more narrowly. Importantly, the last sentence on page 36 states "…if it is concluded that the vapor intrusion pathway is not likely to be a concern under current conditions and use, then generally no additional evaluation is necessary," provides no assurance that the vapor intrusion assessment approach will protect against future exposures—even if the building continues to operated exactly as it did when the assessment was completed. This is a concern and should be addressed. Multiple lines of evidence should be used to evaluate the potential for vapor intrusion, not just the present risk.	KP
38	Tables 2-2 and 2-3	The term "current condition" continues to be used. The "potential" for vapor intrusion to occur, even if a building's use and structure is not altered, does not appear to be included in the assessment, which is very concerning. There is virtually no school, day care or home where the occupants should only be protected against vapor intrusion exposures that were occurring at the time of assessment. If this terminology is selected in the final draft, than long-term assessment plans for assessing future vapor intrusion exposures should be included.	KP
40	Table 2-4	For the "undeveloped" property category, the future use is not shown. If an undeveloped property is being considered for development, then vapor intrusion should be assessed. This is especially important for school sites, but other future uses as well. A more limited assessment of potentially impacted media is sufficient, but necessary. Also, undeveloped properties are an excellent example of when vapor intrusion modeling could be used to	KP, WHB

		inform site uses and interpret site data, even before a building a constructed.	
42	2.3.3	The use of the average concentration, and more specifically the 95% UCL on the mean requires a sufficient numbers of data points, often not available for the indoor air measurements, particularly when samplers are placed in multiple rooms and not as multiples in the same room. A minimum number of samples results should be either defined or suggested. Alternatively, a range of concentrations might be used, presenting a range of EPCs. This would recognize the variability in the VI pathway measurements and provides information for decision-making in regard to additional sampling.	WHB
41	2.3.3	No Significant Hazard and Substantial Hazard is referred to, but not defined, and should be. The OHM that are examined in the VI situation are, by definition, hazards – does measurement above a set concentration make them Significant? If necessary, refer the reader to the MCP with a definition provided (since the MCP does not provide a user-friendly description).	WHB
43	2.3.3.2	Option 1. This option limits the property owners' use of the property. Unless the property owner is the Responsible Party, this does not seem a viable option. The nature of the on-going monitoring is not clear and establishing the exact nature of monitoring is critical.	KP, WHB
44	2.3.3.2	Option 2. While this is somewhat vague, it seems robust. Caution is recommended because this option suggests relying too heavily on subslab samples because they are hard to install in preferred locations. Additional weight should be given to exterior soil gas, to help establish the potential for vapor intrusion. Together, subslab and exterior soil gas could be informative. The inclusion of modeling to interpret the data would also be valuable.	KP
45	2.3.3.2	Option 3 seems viable nly when the building does not influence the potential for vapor intrusion exposures. The only situation this seems likely for is petroleum hydrocarbon, as long as the building is not influencing biodegradation by somehow increasing oxygen transport.	KP
50	3	The American National Standards Institute (ANSI) is currently developing guidance for vapor intrusion mitigation systems. Once finalized (which will not be for several months), the ANSI standards would provide additional guidance for mitigation and O&M.	KP
74	4.1	A description of the unique situation is made with TCE, however, it is not known now how many additional VOCs may have similar "unique" situations associated with their short-	WHB

		term exposure. We suggest rewriting the text to identify TCE, but to recognize that as more is known about fetal exposure to toxicants, there may be other chemicals that require minimizing short-term exposures to pregnant women.	
115	5.1	In the first paragraph, it states [in part] that " MassDEP's experience confirms that providing information to the public in a timely and straight forward manner is a key element of a successful project and building trust with the public. **Information that is made understandable for a non technical audience** and anticipates likely questions can be an effective in addressing concerns and fostering cooperation during the response action process". Who will help create the message, (Mass DEP, LSP, MDPH, Local Health or other resource)? Will local health be informed of the information before it is distributed to here be resources available to help translate the message / information the public? Will t to languages other than English?	GC
115	5.1	Samplers are foreign objects and often "scary" to residents and building occupants. In our experience, people have asked us "what are we putting into the air?" An explanation of a canister how the sampling is conducted should be included in materials provided to the Boards of Health and the building owners and occupants.	WHB
115	5.2	Provide ongoing statewide training programs and educational tools to local BOH and other local officials. Vapor intrusion is a complex topic. There is significant misunderstanding among well-intentioned officials and departments.	EM
116	5.2.1	Notice of Environmental Sampling Form (BWSC123) http://www.mass.gov/eea/docs/dep/cleanup/approvals/bwsc-123.pdf Is there any requirement for the property owner to notify residents/employees of any elevated results once the property owner is notified of the sampling results? Notice Related Immediate Response Actions (Form BWSC 124)) - http://www.mass.gov/eea/docs/dep/cleanup/approvals/bwsc-124.pdf	GC
116	5.2.2	Include the following statement with the required Form BWSC124 – "This is an important document. This information may affect your health. You should have it translated." The statement should be translated into any non-English language that is spoken as a primary language by greater than 1% of the population of that community.	EM

117	5.2.2	MassDEP should enter into a discussion with the Massachusetts Department of Public Health regarding amending the State Sanitary Code, Chapter 2: 105CMR410.000 to include a requirement that property owners inform occupants of impacted dwellings of vapor intrusion conditions. The Sanitary Code details obligations and responsibilities of both occupants and owners "to protect the health, safety and well-being of the occupants of housing." Current MassDEP regulations (310CMR40.1403(11) (d) "requires the person conducting the IRA to *request* the owners and/or operators of the buildings post the notice where it will be visible…" A property owner of a rented residential dwelling or unit is very unlikely to post a notice unless required by regulation. As vapor intrusion is a serious health issue, occupants have the right to be informed. The "request" to disseminate this information should become an enforceable regulatory requirement to inform occupants of impacted dwellings.	EM
117	5.2.2.1	In addition to being notified verbally by the LSP, a visit to the impacted building is warranted. This way, the board of health can understand the type of communication (see below) and can more efficiently answer questions by the public, if they arise.	EM
117	5.2.2.1	In the case of 72 hour notifications, for example with TCE, the local board of health should be verbally notified. This will start a dialog with the LSP and lay the groundwork for effective public communication.	SR
117	5.2.2.1	Notice Related Immediate Response Actions Where TCE in Indoor Air Poses an Imminent Hazard (p.117)- mentions that fact sheets will be provided along with the written notice of TCE levels posing an imminent hazard- Are there further steps, guidelines or recommendations that can be taken to ensure that fact sheets are distributed to those at risk? Will the fact sheets be available in languages other than English appropriate for the municipalities' s demographics or will this burden be placed on the local health department?	GC
118	5.3	General Public Notification and Involvement- link to factsheet does not work. (http://www.mass.gov/dep/cleanup/factpi2.pdf	GC
118	5.3	Encourage the publication of notifications in minority run media – newspapers, radio, etc. The MCP general public notice (newspapers) requirements are useful and important. However, a general newspaper notice is typically not read or recognized in an	EM

		Environmental Justice neighborhood. The LSP should ask the local BOH for additional appropriate contacts and resources to post notices.	
119	5.4	Optional Public Involvement Activities- MassDEP strongly encourages parties conducting response actions to work directly with the School Department personnel and the school principal or daycare director to develop a risk communication strategy for informing staff, parents and students about the investigation, remedial actions, and potential risk. It is recommended that the parties also involve the local health department, especially with this vulnerable population.	GC
116 – 118	5.2	Submit at least one printed (hard-copy) of each required document to the local Public Library. These documents are currently submitted to the local Board of Health and/or the Chief Municipal Officer in an electronic form. The most vulnerable residents of a community are least likely to be aware of the correspondence/documents and are unlikely to visit the BOH office or research documents on-line. The local library is a neutral place that residents can feel safe and are not questioned why they are looking for information. In addition, most municipal offices no longer keep printed copies of documents and charge a fee for printing. Particularly for larger documents (and when the resident is not sure as to what may be important or what to ask for) a fee for copying can be substantial and prohibitive. The local library provides equitable access for all residents.	EM
121	5.3.3	"The MCP provides community members and local officials with an opportunity, through the filing of a petition signed by ten or more residents, to designate ..." This sentence gives the impression that a petition is always needed, however, a local official does not need a petition. The MCP actually reads "Local officials or ten or more residents of a community(ies) in which a disposal site is located or in any other communities which are, or are likely to be, affected . . . may request an opportunity for Public Involvement Activities"	SL
120	5.4	Translate MassDEP fact sheets into other common languages such as Spanish, Portuguese and Creole. The link to the fact sheets is useful. However, the fact sheets are only in English. The concepts are difficult to understand in English and, therefore, it is very unlikely that a non-English speaker would find the fact sheets easy to comprehend.	EM

120	5.4	Rewrite the New York State Department of Health fact sheets to include links, resources and contacts specific to Massachusetts. The NY Department of Health link in the guidance document is specific to New York with various phone numbers and websites imbedded in the documents. It is doubtful that an LSP will modify the fact sheets to make them useful for a local resident looking for appropriate information.	EM
121	6.0	Obtaining Access to Adjacent Properties. As with the potentially impacted properties, contact with the property owner may not result in proper notification to tenants, if the property is a rental property. Same comments apply – language barrier, understanding about vapor intrusion, chemical hazards and sampling. By conversation with the local health departments, information about mechanisms for information transfer can be facilitated. In addition, the Massachusetts Housing Code (105 CMR 410.000) requires that occupant be notified before the property accesses the renter's space. The notification should also go to the occupant as well as the property owner.	WHB
Minor Edits		Data are plural and the document should use the word correctly (datum is singular)	

Citations

[1] Pennell, K. Kangsen Scammell, M., McClean, M., Ames, J., Weldon, B., Friguglietti, L., Suuberg, E., Shen, R., Heiger-Bernays, W. (2013). Sewer Gas: An Indoor Air Source of VOCs to Consider During Vapor Intrusion Investigations. Ground Water Monitoring & Remediation. 33:119-126. DOI:10.1111/gwmr.12021

[2] Izzo, V. J. 1992. Drycleaners – A Major Source of PCE in Ground Water. Sacramento: State of California Regional Water Quality Control Board Central Valley Region. http://www.swrcb.ca.gov/rwqcb5/water_issues/site_cleanup/dry_cleaner_rpt.pdf

[3]Abreu, L.D., Johnson, P.C. Effect of Vapor source --Building Separation and Building Construction on Soil Vapor Intrusion as Studied with a Three-Dimensional Numerical Model. *Environmental Science and Technology*. 2005. 39, 4550-4561.

[4]Pennell, K. G., Bozkurt, O., Suuberg, E. M. Development and Application of a Three-Dimensional Finite Element Vapor Intrusion Model. *Journal of Air and Waste Management Association*. 2009. 59: 447-460.

[5]Bozkurt, O., Pennell, K. G., Suuberg, E. M. Simulation of the Vapor Intrusion Process for Nonhomogeneous Soils Using a Three-Dimensional Numerical Model. *Ground Water Monitoring and Remediation*. 2009. 29 (1): 92-104.

[6]Yao, Y., Shen, R., Pennell, K. G., Suuberg, E. M. (2013) "Examination of the Influence of Environmental Factors in Contaminant Vapor Concentration Attenuation Factor with the U.S. EPA's Vapor Intrusion Database." Environmental Science and Technology. 47(2): 906-913.

[7]Jacobs, J.A., Jacobs, O.P., and K.G. Pennell. 2014. Geologists and Site Conceptual Models: VOCs and Sewer Gas in Indoor Air Resulting from Migration from Breached Sewer Conveyance Systems, American Institute of Professional Geologists National Meeting, Abstracts, p. 73-74.

[8]Riis, C.E., A.G. Christensen, M.H. Hansen, and H. Husum. 2010. Vapor Intrusion through sewer systems: Migration pathways of chlorinated solvents from groundwater to indoor air. Presented at the Seventh Battelle International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey. http://indoorairproject.files.wordpress.com/2011/03/ sgs-attachment-1.pdf

[9]Johnston, J. E.; Gibson, J. M. Spatiotemporal variability of tetrachloroethylene in residential indoor air due to vapor intrusion: A longitudinal, community-based study. Journal of Exposure Science and Environmental Epidemiology, 2013, DOI: 10.1038/jes.2013.13

[10]Shen, R., Pennell, K. G., Suuberg, E. M. A Numerical Investigation of Vapor Intrusion--The Dynamic Response of Contaminant Vapors to Rainfall Events. *Science of the Total Environment.* 2012. 437:110-120.