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ANALYSIS OF DATA & RESEARCH CONCERNING CCA-TREATED WOOD DISPOSAL AND ECONOMIC IMPACT & PRACTICABILITY ISSUES

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Letter to the Reader:

This White Paper summarizes an analysis of existing scientific data and literature pertinent to the question of whether the disposal of CCA-treated wood waste in unlined landfills is contributing to arsenic levels in groundwater. The analysis summarized herein focused on data and literature from Florida because that State is recognized nationally as representing a "worst case": reported estimates of the quantities of CCA-treated wood waste being disposed in Florida landfills are significantly higher on a percentage basis than those for other states, and Florida has significant rainfall, shallow groundwater, and sandy soils. Thus, if Florida's groundwater is not threatened by disposal of CCA-treated wood in its unlined landfills, it is doubtful that such a situation exists in other states.

Five lines of investigation were followed during this study. Each lead to the same conclusion: ***There is no evidence that the disposal of CCA-treated wood in unlined landfills is contributing to arsenic levels in groundwater.***

The review of the Florida data shows that:
Average arsenic concentrations in upgradient "background" monitoring wells are actually higher than in downgradient "detection" and "compliance" monitoring wells at Florida's 116 unlined construction and demolition debris (C&D) landfills. This is based on quantitative and statistical evaluation performed for this investigation on the available Florida Department of Environmental Protection (FDEP) database of over 12 years of landfill monitoring data (February 1992 through July 2004, representing 4,534 water quality samples). Thus, the Florida data does not demonstrate any contribution to groundwater arsenic levels from unlined C&D landfills.

Results of prior research do not support or justify regulating the disposal of CCA-treated wood. Much of the available literature examined during this study derives from field simulations and laboratory studies performed by academic researchers supported by the Florida Center for Solid and Hazardous Waste Management (Center). However, certain inappropriate, incorrect and flawed techniques uncovered during review of that work leads to questions as to the validity or applicability of the conclusions.

For example:

- Researchers inappropriately imagine a scenario in which all arsenic from CCA-treated wood leachate testing is added to a measured amount of soil, with the resulting calculated soil concentration then compared to standards for direct contact in residential areas.
- In their interpretation of the FDEP database on arsenic concentrations in 832 samples from monitoring wells at 30 C&D landfills, Center researchers

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incorrectly summed arsenic species readings below detection limits (shown as <0.005 mg/L) to create a total arsenic value greater than detection limits, leading to a falsely inflated number of impacted wells.

- Researchers' tests of the leaching of arsenic from CCA-treated wood in lysimeter simulations do not reflect actual landfill conditions. The test results do not simulate field conditions and are flawed by, among other things, failing to account for the highly effective soil attenuation and interactions with other landfill materials that have been demonstrated by landfill monitoring well data, other field studies, and even a similar lysimeter study by researchers in New Zealand.

Even absent these problems, the researchers themselves provide sufficient caveats to the conclusions of their work to indicate that their scientific support for regulation is far from categorical. They acknowledge that:

- The TCLP (used in some of their research) cannot account for all of the physical, chemical, and biological processes occurring within a landfill.
- CCA-treated wood samples of larger size (wood samples were reduced in size to about 3 mm, providing far larger surface area than actually exists in the landfill) leach less arsenic than the referenced 5mg/L Toxicity Characteristic.
- Many factors beyond what can be accounted for using the SPLP will impact actual concentrations in the groundwater; and
- The results are not definitive with respect to groundwater.

Tangential to regulating disposal of CCA-treated wood in landfills, Center researchers examined arsenic concentration in soils below CCA-treated wood decks. The main conclusion was that the impact of leached arsenic is limited to the first 6-8 inches of soil, with a maximum value of 23.66 mg/kg within the first foot, compared to 250 mg/kg in some golf course soils on which pesticides had been applied as reported by the same researchers.

It is critical to understand that laboratory research studies that have been performed do not reflect a true picture of the conditions on which regulatory decisions should be based. Only those studies based on field data from monitoring the actual effects, if any, of CCA-treated wood disposal on groundwater are reliable. Thus monitoring wells placed at landfills provide defensible data that can be used to assess whether regulatory action is needed. Relying solely on laboratory or field simulations to predict what will occur in the natural environment is misleading and inappropriate.

Other Findings:

Measured arsenic levels in several of the Florida landfill monitoring wells are suspect because of high turbidity values in the same samples. This may reflect poor well development and as a result the data may not be useful as indicators of non-compliance with water quality standards.

There is a general lack of agreement among researchers on the quantity of CCA-treated wood that will be disposed of in the future. Furthermore, the impact of the voluntary CCA label changes in 2003 on production volumes has not been incorporated into the disposal models. However, the demonstrated effectiveness of soil attenuation may render the point moot.

The natural occurrence of arsenic in native rock and soil, as well as the arsenic content of fertilizers, pesticides and other materials, have not been evaluated as sources of arsenic in landfill monitoring wells.

Arsenic levels in leachate from California landfills that accept treated wood have been shown to be virtually identical to levels at landfills that do not.

In Maine, data from half the monitoring wells at their unlined C&D landfills showed groundwater impacts other than arsenic that were attributed to disposal of concrete, gypsum wallboard, wood, and ash from brush burn piles.

Regulators in Maine have not found a significant difference in arsenic detection in leachate from landfills that do not receive CCA-treated wood and those that do.

Regulators in Maine determined that disposal of arsenic treated waste wood in unlined C&D landfills should be allowed to continue since data did not suggest an unacceptable environmental risk.

Since a case for prohibiting the disposal of CCA-treated wood in unlined landfills cannot be made even under worst-case conditions in Florida, it is reasonable to conclude that such regulatory action is unwarranted in other states as well.

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PATHWAYS TO LASTING SOLUTIONS

WHITE PAPER:

ANALYSIS OF DATA AND RESEARCH CONCERNING CCA-TREATED WOOD IN FLORIDA C&D LANDFILLS AND RELATED INFORMATION FROM OTHER STATES

INTRODUCTION

Malcolm Pirnie, Inc. (MPI) was retained to assist Wood Preservative Science Council in evaluating technical and scientific issues related to the disposal of chromated copper arsenate (CCA)-treated wood in Florida unlined construction and demolition debris (C&D) landfills. This particular document focuses on whether available data on the quality of potentially impacted groundwater support a requirement to prohibit the disposal of CCA-treated wood in unlined landfills. Central to the question is whether water quality data and results of prior and on-going research demonstrate any groundwater contamination by arsenic attributable to the disposal of CCA-treated wood in these landfills.

This White Paper addresses the overarching question of whether the disposal of CCA-treated wood should be regulated based on five lines of investigation:

1. Quantitative and statistical evaluation of analytical results, representing over 12 years of record, obtained from the Florida Department of Environmental Protection (FDEP), on 4,534 water quality samples collected from February 1992 through July 2004 from background, detection and compliance monitoring wells installed at 116 unlined C&D landfill sites;

2. A rigorous and balanced review of scientific literature and research on the potential impacts of the disposal of CCA-treated wood in unlined landfills, representing academic, regulatory, industrial and other researchers in Florida and elsewhere;

3. Assessment of relevant literature concerning the relationship between arsenic and turbidity in water samples, and the implications of high turbidity observations on the accuracy of groundwater data and the interpretation of these data;

4. Examination of information on the past and projected quantities of CCA-treated wood disposed in landfills as it relates to quantities of arsenic in groundwater; and

5. Evaluation of the literature regarding other sources of arsenic in groundwater, and other contaminants in C&D landfills in Florida and elsewhere, as they may relate to the issue of CCA-treated wood disposal.

Most germane to the regulatory question, of course, is the FDEP database itself. It should be the primary basis for regulatory decisions because, unlike research results based on simulated and potentially unrealistic landfill conditions, it represents what has and is actually occurring in subsurface soils and groundwater beneath Florida's unlined C&D landfills. The database itself is too voluminous to include, but a description of the procedure used to interpret the data can be found in Appendix A.

The key findings of this investigation are as follows:

Florida Database Evaluation

The occurrence of arsenic in groundwater at Florida's unlined C&D landfills may result from natural sources or disposal of arsenic-bearing materials such as arsenical pesticides in cattle dipping solutions, arsenical pesticides used for agricultural and golf course maintenance purposes, phosphate fertilizers, other arsenic-containing fertilizers, biosolids and chicken manure. Irrespective of source, quantitative evaluation of arsenic concentrations in groundwater from the FDEP database for unlined C&D landfills resulted in the following findings:

1. Arsenic was not detectable in over 80% of samples from each of the three well types (background, detection and compliance) in the FDEP database, with compliance wells showing the highest percentage of non-detectable arsenic. Background wells are located hydraulically upgradient from the waste disposal area and are used to evaluate the quality of groundwater before it passes beneath the landfill; detection wells are located hydraulically downgradient from the disposal area and are used to evaluate the quality of groundwater after it passes beneath the landfill; compliance wells are located farther downgradient than the detection wells, generally at the property boundary, to determine whether any constituents that may have been introduced to, or elevated in the groundwater after passing under the disposal area may be migrating offsite. The percentage of wells that have no detectable arsenic is shown below:

Parameter	Background (737 samples)	Detection (857 samples)	Compliance (2940 samples)
Arsenic Below Detection Limits	83.3%	80.5%	86.9%

2. In considering the 116 unlined landfills in the FDEP database, the average arithmetical arsenic concentration from the background wells upgradient of the landfills exceeds the average concentration from both the detection and compliance wells downgradient:

Parameter	Background (737 samples)	Detection (857 samples)	Compliance (2940 samples)
Average Arsenic Value (ug/L)	9.53	5.82	7.31

3. Of the 116 unlined landfills, 70 have data from both background and compliance wells. In considering these 70 landfills, the average arithmetical concentrations of arsenic from background wells exceeds the average concentration from the compliance wells:

Parameter	Background (585 samples)	Compliance (2815 samples)
Average Arsenic Value (ug/L)	10.36	7.17

4. Of the 70 unlined landfills addressed above, 20 have data from all three well types. In considering these 20 landfills, the average concentration of arsenic from background wells exceeds the average concentration from the detection and compliance wells:

Parameter	Background (222 samples)	Detection (411 samples)	Compliance (647 samples)
Average Arsenic Value (ug/L)	6.81	5.73	6.42

These findings appear to indicate that certain attenuation mechanisms in the soils, landfill materials, and aquifers are effective in decreasing the concentration of arsenic, should it migrate through the soil and enter into the landfill leachate to become a potential source to groundwater. Adsorption of arsenic species on soil and aquifer materials has been shown to be an effective mechanism that limits the potential for arsenic species to migrate significant distances in the soil and groundwater. In addition to the small decrease in the average arsenic levels between background and compliance wells, only the average concentration in background wells in the 70-site grouping exceeds the water quality standard of 10ug/L (the Maximum Contaminant Level [MCL] for arsenic in drinking water).

When the data from the 20 sites are examined on an individual site basis, there are six occurrences of average arsenic concentrations in compliance wells exceeding those in background wells, but where that is true, no site shows an average arsenic concentration in compliance wells in excess of 10 ug/L (see Appendix B). Some individual samples from each of the three monitoring well types contained arsenic above the MCL. However, a review of these data does not indicate a correlation between arsenic levels and the landfill as a source. MCL exceedances were observed both upgradient and downgradient of the landfills. Also, an analysis of worst-case conditions for the occurrence of arsenic in groundwater at Florida's individual C&D landfills as found in the FDEP database yielded the following results:

1. Only five of the 116 landfills met criteria for inclusion as worst-case, where the average arsenic concentration in compliance wells is twice or more the average concentration in background wells and the maximum value is greater than 10ug/L.

2. Lack of analytical data from well samples (only one reading) for two of these five landfills precluded further analysis (see Appendix C).

3. Data on samples from the remaining three have high levels of turbidity, measured in Nephelometric Turbitity Units or NTUs, where Nephelometric refers to the way the measuring instrument estimates how light is scattered by suspended particulate material in the water. The average turbidity is greater than 5 NTUs, and the maximum up to 4,980 NTUs. This is probably attributable to inadequate well development and thus the metals concentrations reported are not representative of the actual levels of dissolved arsenic species in the aquifer (see Appendix C). FDEP recognizes various issues related to turbid samples, including high probability that such samples are not representative of the actual concentrations of dissolved metals.[1]

Florida Academic Research Review

A substantial volume of work has been performed by academic researchers at the Universities of Florida and Miami under grants from the Florida Center for Solid and Hazardous Waste Management (Center) to assess the impact of arsenic in CCA-treated wood on soils and groundwater. Although that body of work primarily represents field and laboratory experiments and not actual landfill conditions, it is discussed at length here because some of it is has been partly funded by and received considerable attention from the regulatory community. Our review indicates significant problems with the work:

1. In the only apparent study of actual landfill data[2], a significant error was introduced in the quantitative analysis performed on data provided by the FDEP. Data evaluated included arsenic concentrations in 832 samples from wells at 21 C&D landfills collected between January 1998 and December 2000. The authors incorrectly summed individual species values that were below detection limits at individual wells to create total concentration values for the particular well that are above the detection limit. It is incorrect and thus completely misleading to count any well that had all individual species concentrations <0.005 as anything other than non-detect for total arsenic. Altogether, there are 11 downgradient wells that were incorrectly labeled as "higher than background" even though every one of the 4 individual arsenic species was non-detect or <0.005. Therefore only 11, and not 21 downgradient wells out of 48 analyzed as stated by the researchers, had total concentrations of arsenic higher than the detection limit of 0.005 mg/L. Correction of the summing error significantly alters the conclusions of the work. The authors state that "The average among all of the (detection/compliance) wells (where the below detects were set to 0) was 10 ug/L". This happens to equal the MCL. However, the correct average value when the <0.005 mg/L values **are** set to zero, is 5.65 ug/L, which is below the MCL. More detailed evaluation demonstrates that only one of the 21 landfills studied exhibited arsenic concentrations higher than 10 ug/L in the downgradient (detection/compliance) wells and higher than the background well at the facility during the three-year period of record that was examined.

2. Studies of arsenic concentrations in soil beneath CCA-treated wood decks have little to do with regulating disposal of the material at C&D landfills.

However, the results of such a study[3] were examined and it was found that the main conclusion of the Center researchers is that the impact of leached arsenic is limited to the first 6-8 inches of soil. The average concentration of arsenic in the 0 to 1 foot soil interval below decks was found to be 9.77 mg/kg, with a maximum value of 23.66 mg/kg at the surface. This compares to FDEP soil cleanup target levels (SCTLs) for soil leachability of 29 mg/kg based on groundwater criteria, and 290 mg/kg based on groundwater of low yield/poor quality.[4] Coincidentally, the maximum reported value of 23.66 mg/kg is also an order of magnitude less than reported by the same researchers for some golf course soils (250 mg/kg).[2]

Source	Arsenic concentration (mg/kg)
Soil Under Decks	
Surface - max	23.66
0-1' - average	9.77
Golf Course Soils (Pesticide-Treated)	250

Arsenic Leachability SCTL	
Groundwater	29
Groundwater-low yield/poor quality	290

3. CCA-treated wood leaching tests using lysimeters are simulations[5] that do not reflect actual conditions at Florida's C&D landfills. In addition, results of the experiments are flawed by 1) failing to account for any soil attenuation or other interactions between treated wood and other landfill materials, 2) using wood particle sizes (approximately 3 mm) that are much smaller than the size of wood pieces actually disposed in landfills (note that researchers do acknowledge that CCA-treated wood samples of larger particle size leach less than the referenced 5mg/L Toxicity Characteristic), and 3) conducting tests above ground where temperatures would be higher than underground landfill conditions. Nonetheless, findings include the following:

   a. In these leaching tests, employing the TCLP method on wood treated with five different preservatives, researchers state that results

suggested that all of the treated wood types evaluated might result in elevated leachate concentrations of metals "if disposed in large enough amounts". It is also acknowledged by the researchers that the TCLP cannot account for all of the physical, chemical, and biological processes occurring within a landfill. This further reinforces the importance of using data derived directly from landfill monitoring wells in any consideration of developing regulations to protect them.

b. In leaching tests employing the SPLP, results were qualified by the following statement: "Again, many factors beyond what can be accounted for using the SPLP will impact actual concentrations in the groundwater."[5] The researchers suggest that arsenic-free preservatives are advantageous over CCA with respect to soil contamination issues, but concede that the results are not definitive with respect to groundwater contamination.

c. Researchers state that "One method for assessing the impact on groundwater underneath an unlined landfill is to compare leaching test results (usually SPLP for C&D debris landfills) to groundwater criteria." Such a comparison is highly misleading since all leachate from landfills has levels of constituents that may exceed drinking water standards. No one is proposing that leachate be used for drinking water. Furthermore, the leachate from the laboratory tests has not been compared to the quality of leachate from actual landfills and thus cannot be used to assess the potential impact of leachate from landfills containing disposed CCA-treated wood.

d. Researchers also inappropriately imagine a scenario in which the amount of arsenic leached from CCA-treated wood from the SPLP method is arbitrarily added to $1m^3$ of typical soil, with the resulting arsenic concentration being approximately 75 mg/kg. This misleading value is then compared for some reason to the SCTLs for direct contact with soils in residential areas (0.8 mg/kg) to conclude that arsenic from CCA-treated wood would exceed this irrelevant standard by a factor of 94. In reality, even the maximum concentration of arsenic in soil (23.66 mg/kg), reported in the study of treated decks, does not exceed the groundwater-based SCTL for leachability (29 mg/kg).

In sum, all of the above problems with the Center's work on CCA-treated wood raise significant questions about their findings. The Center's work is seriously flawed and use of these data for purposes of regulatory decisions is not justified on scientific grounds.

Related Research Review

Lysimeter experiments similar to those conducted by the Center researchers were conducted by researchers in New Zealand[6]. Those experiments were established to assess the extent of leaching of CCA, the adsorption of CCA onto soils, the quality of leachate and factors affecting leachate quality when CCA-treated wood was exposed to natural weathering conditions in a simulated land disposal situation. Although leachate was only generated by natural rainfall and lysimeters were buried to simulate natural soil temperature conditions, researchers state that certain "worst case" conditions were imposed such as use of wood chips (rather than larger samples) that would accelerate leaching, and use of wood materials comparable to that from construction sites or materials withdrawn from service. The results do not support the need to regulate CCA-treated wood disposal because:

1. Though the concentration of arsenic in leachate from lysimeters that contained only CCA-treated wood ranged up to 1 mg/L (1000 ug/L), leachate from lysimeters containing wood and soil had arsenic concentrations mostly in the 0.01mg/L (10ug/L) range. Soil was found to markedly adsorb arsenic and reduce concentrations of the components in the leachate by up to 25 times. Further, no statistically significant differences were found for the concentrations of arsenic in leachate between lysimeter treatments that contained CCA-treated wood plus soil, untreated wood plus soil, and sand plus soil.

2. The report concludes that after 18 months of leaching, the lysimeter study indicated that the soil continued to effectively attenuate the concentration of leached arsenic from the CCA-treated wood.

Although this study demonstrates that arsenic content of leachate from CCA-treated wood shows no significant difference than from untreated wood when soil attenuation is allowed, data gathered from simulated conditions do not accurately reflect actual landfill conditions and cannot replace the conclusions based on landfill data. As such, the results of this research should have no more bearing on regulatory decisions than the results of research sponsored by the Center that were also based on simulated conditions.

Review of Regulatory Findings

The State of Maine's Public Law 2003, Chapter 457, "An Act to Protect Public Health by Reducing Human Exposure to Arsenic", required a plan from the Department of Environmental Protection for the safe management of arsenic-treated wood waste by January 1, 2005. The Maine Plan[7] relied heavily on Florida research performed by the Center. Although there are numerous caveats to the conclusions in the Plan, mostly in reference to concerns expressed by Center researchers in that Florida work, the main conclusion in the Plan is that the results of groundwater monitoring at the facilities reviewed do not support a prohibition on the continued disposal of waste CCA-treated wood in unlined C&D landfills. This conclusion was supported by the following arguments:

1. While the presence of arsenic in groundwater may be the result of leaching from man-made sources, such as CCA-treated wood, it is also known to result from the release of arsenic from soil and/or rock due to changing geochemical conditions in an aquifer. Therefore, a landfill that does not contain arsenic-bearing waste (e.g. CCA-treated wood) may contribute to the presence of arsenic in groundwater by mobilizing the bound arsenic. In a landfill setting there is no easy method for distinguishing the source of arsenic that may be detected in groundwater.

2. In general, there did not appear to be a significant difference in arsenic detection and leachate concentrations for landfills not receiving CCA-treated wood vs. landfills that may possibly have included CCA-treated wood in their waste stream.

3. Disposal of arsenic treated waste wood in unlined construction and demolition debris landfills should be allowed to continue at present since the data does not suggest that arsenic at these facilities is posing an unacceptable environmental risk.

The State of California disposes of treated wood wastes in lined non-hazardous landfills. Studies performed for the Western Wood Preservers Institute[8] found that no additional regulatory action was warranted because:

1. The arsenic levels in leachate from landfills accepting treated wood were virtually identical to levels at landfills that do not.

2. The concentrations of arsenic which might result from treated wood products were either below the drinking water standard or below the Leachate Concentration Threshold Value. The Value was calculated for landfills with composite liners (unlike Florida's) using the U.S. Environmental Protection Agency's Tier I Industrial Waste Management Evaluation Model to determine what leachate concentration threshold value would not be expected to produce unacceptable concentrations in groundwater.

Arsenic and Turbidity Considerations

A direct correlation between turbidity and total arsenic concentrations in water has been repeatedly demonstrated.[5, 9] For example, "An almost linear relationship was obtained for the variation of arsenic concentration with residual water turbidity."[9] The relationship is demonstrated graphically in literature from the Center, and was also found in current studies as shown in Appendix E. Higher total arsenic concentrations found in the database may therefore not be valid as indicative of exceeding MCLs because:

1. The analysis conducted for this study on "worst case" individual landfill sites with higher average arsenic concentrations in downgradient wells than background wells demonstrates a correlation with high turbidity values (Appendix C).

2. It has also been shown that there is a strong correlation between poor well development practices and turbidity in groundwater samples. Such samples would not be representative of the dissolved arsenic concentrations in the aquifer.

3. MCL compliance is based on dissolved, not total concentrations of target constituents in groundwater samples. FDEP accepts unfiltered samples, though they clearly state in a technical memo that turbid samples may not reflect dissolved arsenic ("heavy metal") levels.[1]

Information on Quantities of CCA-Treated Wood in Landfills

Insufficient evidence exists to support the theory that groundwater quality is at risk due to projected increases in disposal of CCA-treated wood. There is ongoing controversy among researchers as to the modeling of these projected increases. Researchers at the

Center developed a model that predicted as much CCA-treated wood being disposed between 2003 and 2007 as has been disposed in the previous 50 years. The wood treating industry developed a different model and points out differences between the two: the Florida model uses two product groups, the industry model uses 18; the Florida model uses the same distribution for all products with two different average lifetimes whereas the distribution in the industry model [10] is tri-modal; the Florida model assumed the 1997 production to continue for some 30 years such that the predicted volume comes to a steady state in the model, whereas production of CCA-treated wood for all non-industrial applications ceased as a result of the voluntary label changes by the manufacturers which became effective December 31, 2003. Irrespective of the outcome of this controversy, other relevant findings of this current investigation probably make the volume issue moot.

Information on Other Sources of Arsenic in Groundwater, and Other Contaminants in C&D Landfills

The following information on background concentrations of arsenic in Florida soils is presented to provide further references for comparison. According to recent studies[11], an occurrence of sites with high arsenic concentrations in soils was scattered throughout the state. Limestone concentrations of arsenic have been reported to range from 1.7 to 26 mg/kg in Florida.

Apart from natural occurrences, high concentrations of arsenic in soils have been attributed to such sources as cattle dipping vats, application of pesticides containing MSMA and DSMA which have high concentrations of arsenic, biosolids, and usage of phosphate fertilizer. Center researchers have reported the average concentration of arsenic in phosphate fertilizer applied on Florida soils as 5.78 mg/kg and the average concentration of arsenic in Florida phosphate rock as 7 mg/kg.[2] Therefore, even if the average arsenic concentrations found in compliance monitoring wells at unlined C&D landfills had been elevated relative to background wells, and even when this does occur on an individual site basis, insufficient information exists to demonstrate that they result, even in part, from disposal of CCA-treated wood. Additional comments from the literature include:

1. FROM MAINE: "In a landfill setting there is no easy method for distinguishing the source of arsenic that may be detected in groundwater."[7]

2. FROM CALIFORNIA: "Studies have shown that arsenic is ubiquitous in California soils. Most soil will contain about 1 to 5 mg/Kg of arsenic."[8]

3. NATIONWIDE: An article entitled "Mapping arsenic in groundwater: A real need but a hard problem" presented a map prepared by a U.S. Geological Survey researcher of arsenic levels in groundwater in the U.S.[12] The publication elaborated on the difficulties inherent to accurately identifying the concentrations of arsenic.

While no studies comparing the occurrence of arsenic to the occurrence of other contaminants in groundwater at unlined C&D landfills were encountered during the literature search for this investigation, the Maine Plan comments on this issue:

- "Groundwater monitoring data from more than half of the monitoring wells at eight (8) C&D landfills in the State of Maine showed a recognizable groundwater impact other than arsenic. The sources of these impacts are related to commonly disposed C&D materials including concrete, gypsum wallboard, wood, and ash from brush burn piles."[7]

CONCLUSION

The five lines of inquiry followed in this investigation all lead to the same conclusion: **There is no evidence that the disposal of CCA-treated wood in unlined landfills is causing elevated arsenic concentrations in groundwater.** Results of the evaluation of the FDEP database of arsenic concentrations in background, detection and compliance wells at 116 of Florida's unlined C&D landfills show that, on average, values of arsenic in background wells actually exceed those in detection and compliance wells. Even when examined on a site-specific basis, only three of 116 sites show worst-case conditions where average arsenic concentrations in compliance wells are more than twice those in background wells, and also exceed the conservative drinking water MCL of 10 ug/L. All three also exhibit average turbidity in excess of 5 NTUs, with maximums in the range of 100 to 5,000 NTUs. FDEP states that turbid samples may not reflect dissolved metals (arsenic) levels.

Given these results, there is no support for requiring CCA-treated wood to be disposed of in lined landfills. A similar conclusion was drawn in Maine, where a state study found no basis for banning the disposal of CCA-treated wood in unlined landfills.

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APPENDIX A

Discussion of Quantitative Analysis

The arithmetic average value of all the recorded arsenic concentrations for each particular site and well type was calculated, where all reported numbers with qualifiers designating "ND" (for "Not Detectable" or "Non Detect") and "less than" were assigned a value of ½ the detection limit (e.g., <30 was counted as 15), rather than considering the concentration to be zero. Note that many records that appeared to be detection limits did not contain qualifiers, and were therefore assigned a qualifier to represent a DL value (e.g., in a case where there were multiple <30 and <10 values, a repeating number of values equal to 10 or 30 without any qualifier was each assigned a DL qualifier). A Qualifier Index from FDEP is provided below:

Parameter	Definition	Value Used
<	Less than Detection Limit *	1/2 Value
>	Greater than Detection Limit *	
D	Measurement was made in the field (i.e. on site)	DELETE
DU	No Definition. Assumed to be a combination of "D" and "U"	
I	The reported value is between the laboratory method detection limit and the laboratory practical quantification limit.	1/2 Value
K	Actual value is known to be less than the value given	1/2 Value
L	Actual value is known to be greater than the value given	Value
0	Sampled, but analysis lost or not performed	
Q	Sample held beyond the accepted holding time.	
U	Indicates that the compound was analyzed for but not detected. The value associated with the qualifier is the laboratory method detection limit. Less than the method detection limit values shall not be reported.	1/2 Value
Y	The laboratory analysis was from an improperly preserved sample. The data may not be accurate	
P	Pirnie Defined Detection Limit	1/2 Value
No Value	No qualifier was given. Data was examined to determine obvious detection limit values (i.e. constant values of 10, 50, etc.)	1/2 Value

* No definition given in Data Qualifier Codes Table.

APPENDIX B

Data Comparison from 20 Sites with All Well Types

Facility Name	Well Type	# Of Results	Average (ug/L)
ASTATULA PH I/2A, 2B, 2C (SEE WACS 19819 & 19830)	BACKGROUND	39	9.81
	DETECTION	12	10.21
	COMPLIANCE	147	9.64
BIG WHEEL RECYCLING, INC.	BACKGROUND	3	2.50
	DETECTION	11	2.50
	COMPLIANCE	4	2.50
CENTRAL SANITARY LANDFILL & RECYCLING CENTER	BACKGROUND	6	10.12
	DETECTION	14	5.56
	COMPLIANCE	4	5.45
CROWDER LF	BACKGROUND	8	6.13
	DETECTION	8	4.60
	COMPLIANCE	7	5.00
DIXIE COUNTY CDS	BACKGROUND	5	4.10
	DETECTION	8	6.50
	COMPLIANCE	2	0.50
DREAM BUILDERS-PERSIMMON HOLLOW RD	BACKGROUND	6	2.42
	DETECTION	2	2.50
	COMPLIANCE	6	2.42
FLAGLER COUNTY C & D CDS	BACKGROUND	13	8.62
	DETECTION	18	2.81
	COMPLIANCE	59	7.04
GULF COAST SLF	BACKGROUND	3	2.33
	DETECTION	2	4.00
	COMPLIANCE	3	2.33
JOINER FILL DIRT	BACKGROUND	4	2.50
	DETECTION	4	5.40
	COMPLIANCE	10	2.95
LOWER BRIDGE LANDFILL	BACKGROUND	2	70.05
	DETECTION	4	21.53
	COMPLIANCE	3	25.35
MARTIN COUNTY (PALM CITY II) SLF	BACKGROUND	36	2.21
	DETECTION	117	3.96
	COMPLIANCE	32	7.58

Facility Name	Well Type	# Of Results	Average (ug/L)
MOBILE HIGHWAY LF	BACKGROUND	5	3.40
	DETECTION	5	2.80
	COMPLIANCE	15	2.80
OVIEDO MATERIALS LANDFILL CLASS 3	BACKGROUND	12	5.00
	DETECTION	98	6.78
	COMPLIANCE	90	5.93
PERDIDO LANDFILL	BACKGROUND	17	4.41
	DETECTION	39	3.59
	COMPLIANCE	108	4.20
PIPELINE RD C&D LF-AKA-AGGREGATE TRANSPORTATION	BACKGROUND	5	3.20
	DETECTION	12	4.04
	COMPLIANCE	1	6.00
POINT CENTER INC	BACKGROUND	4	2.50
	DETECTION	5	2.50
	COMPLIANCE	6	4.80
SOLOMON CONSTRUCTION CO OF QUINCY	BACKGROUND	10	5.39
	DETECTION	10	8.00
	COMPLIANCE	14	4.21
ST LUCIE CO SLF	BACKGROUND	8	25.38
	DETECTION	11	31.18
	COMPLIANCE	16	19.13
UNIVERSAL DOOR / DOT LF	BACKGROUND	3	3.67
	DETECTION	7	3.14
	COMPLIANCE	3	5.17
US 27 SOUTH LANDFILL	BACKGROUND	30	6.56
	DETECTION	24	4.77
	COMPLIANCE	104	4.31

APPENDIX C

Worst Case Analysis

In an effort to identify and explore the "worst case" landfills, the data were sorted to locate landfills where the compliance wells satisfy the following two criteria: 1) increase in average arsenic concentration from background wells is in excess of 100 percent, and 2) the maximum arsenic values are higher than 10 ug/L. Five sites satisfied these criteria:

- LAUREL HILL LANDFILL
- ORANGE COUNTY LF
- ORMOND BEACH NOVA ROAD LANDFILL III
- PIPELINE RD C&D LF –AKA- AGGREGATE TRANSPORTATION
- PUTNAM CO CENTRAL LANDFILL LF1

Common for the first three sites are very high turbidity readings (maximums of 119 to 4,980 NTUs) of the sampled groundwater. FDEP recognizes various issues related to turbid samples, including high probability that such samples are not representative of the actual concentrations of dissolved metals – see the FDEP Technical Document entitled "Determining Representative Ground water Samples, Filtered or Unfiltered", Bureau of Drinking Water and Ground Water Resources, Tallahassee, FL, 6p., 1994. In this technical guidance document, FDEP lists various criteria for determining site-specific conditions which warrant collection of filtered groundwater samples and their acceptance by the agency. The turbidity threshold set by FDEP for collecting filtered samples is 5 NTU.

After reviewing the five sites listed above, two were excluded from further analysis for lack of data:

PIPELINE RD C&D LF – AKA - AGGREGATE TRANSPORTATION records contained only one compliance well reading that represented an arsenic detection limit of 12 ug/L. The lack of data excluded the site from further evaluation.

PUTNAM CO CENTRAL LANDFILL LF1 records contained only one background well reading with a minimum arsenic value of 5 ug/L. There were no qualifiers to clarify if this was an actual reading or detection limit. This uncertainty and the lack of data excluded the site from further evaluation.

For the remaining three, a more detailed analysis was conducted on the presence and relationship of turbidity between the background wells and compliance wells:

Turbidity (NTU)	Background			Compliance		
	Average	Min	Max	Average	Min	Max
Laurel Hill Landfill	115.85	1.4	270	517.77	4.7	3900
Orange County LF	11.65	0.45	98	71.47	0.1	4980
Ormond Beach Nova Road Landfill III	16.56	0.51	119	7.07	0.21	109

APPENDIX D

Florida Academic Research Review

Preliminary efforts of Center researcher's 2004 study focused on getting voluntary permission to sample groundwater at the C&D facilities. This was the initial approach that was requested by the Florida Department of Environmental Protection (FDEP). Groundwater data from C&D disposal facilities were obtained through Richard Tedder of the FDEP on March 20, 2001. A spreadsheet was provided by Richard Tedder that included C&D site data collected between January 1998 and December 2000. Out of 832 samples, 125 had arsenic concentrations greater than the detection limit, 593 did not detect arsenic, and the remaining 114 samples were not analyzed for arsenic. The 125 detects were observed at 30 different C&D sites throughout the State. Based on the methodology applied by the researchers, of these 30 facilities, 26 facilities had at least one groundwater sample with an arsenic concentration greater than 10 ug/L, the MCL and were targeted for sampling. Of these, 21 participated in the study.

The total arsenic concentration (calculated by summing the individual arsenic species concentrations obtained by HPLC-ICP-MS) was compared with the results from the commercial laboratories. Results indicate that there were no detectable levels of arsenic in 14 of the 23 background wells. Only 7 samples were above the 5 ug/L detection limit of the HPLC-ICP-MS system. The highest concentration measured for total arsenic was 67 ug/L. Most of the arsenic in this sample was in the form of As(V) with smaller quantities of As(III) and DMAA. The overall average total arsenic concentration computed for the background wells was 7 ug/L (where samples below the detection limit were set to a value of 0 ug/L). For background wells testing positive for arsenic, the majority of the arsenic was present at As(V). Smaller quantities of As(III) and DMAA were detected for some of the positive samples. MMAA was not detected in any of the background samples.

Of the 48 detection/compliance well samples, 21 were found to contain total arsenic concentrations greater than the 5 ug/L detection limit of the HPLC-ICP-MS system. According to the methodology adopted by the authors, the average among all of the wells (where the "below detection limits" were set to 0) was 10 ug/L. The maximum concentration measured by HPLC-ICP-MS was 57 ug/L as observed for well #64.

Text of the Report on pages 84 and 93 states the detection limit of the "HPLC-ICP-MS system" as 5 micrograms per liter, or 0.005 mg/L. However, the results in the tables are

given sometimes as ND and sometimes as <0.005 for the individual arsenic species analyzed by the "HPLC-ICP-MS system". The authors then proceeded to sum individual species values that were shown as <0.005 to create values of, for example, 0.010 (two such species and two NDs) or 0.015 (three such species and one ND) for "total arsenic". The authors then count a particular well as one of those wells having arsenic "above the detection limit of 5 micrograms per liter" even though all of the 4 analyzed species were below detection limits. In addition, in footnote to Table VI.2 in the text, detection limits for commercial labs were given as 0.005 or 0.010 mg/L, but the values in the table were sometimes reported as BDL ("below detection limit"), and sometimes as <0.005 or <0.010. This inconsistency was then apparently used to sum the entries with the "less than" sign (i.e., <0.005), but to exclude the "BDL" entries from such summation. It is also interesting that all non-detect values were set to zero for the analysis of background wells, but not for the analysis of downgradient wells.

It is incorrect and thus completely misleading to count any well that had all individual species concentrations either "BDL" or <0.005 as anything other than non-detect for total arsenic. Altogether, there are 10 wells that were incorrectly labeled as "higher than background" even though every one of the 4 individual arsenic species was either non-detect ("BDL") or <0.005. Therefore only 11, and not 21 wells out of 48 analyzed as stated by the researchers, had total concentrations of arsenic higher than the detection limit of 0.005 mg/L. Interestingly enough, the results of the commercial lab analyses also show, when correctly interpreted, that only 11 wells (instead of 21) had concentrations of arsenic higher than the detection limit.

Out of the 11 wells with the total arsenic higher than 0.005 ppb, seven wells were higher than the MCL of 10 ppb at three C&D facilities. Four of those seven wells were at the same facility which also had the concentration higher than the MCL at the background well: 77 ppb. One facility, which had two downgradient wells with arsenic concentration higher than the MCL, did not have data for a background well.

As a conclusion of our own analysis, only one C&D facility, out of 30 studied, had downgradient monitoring wells with arsenic concentrations higher than the MCL (10 ppb) and higher than the background well at the facility.

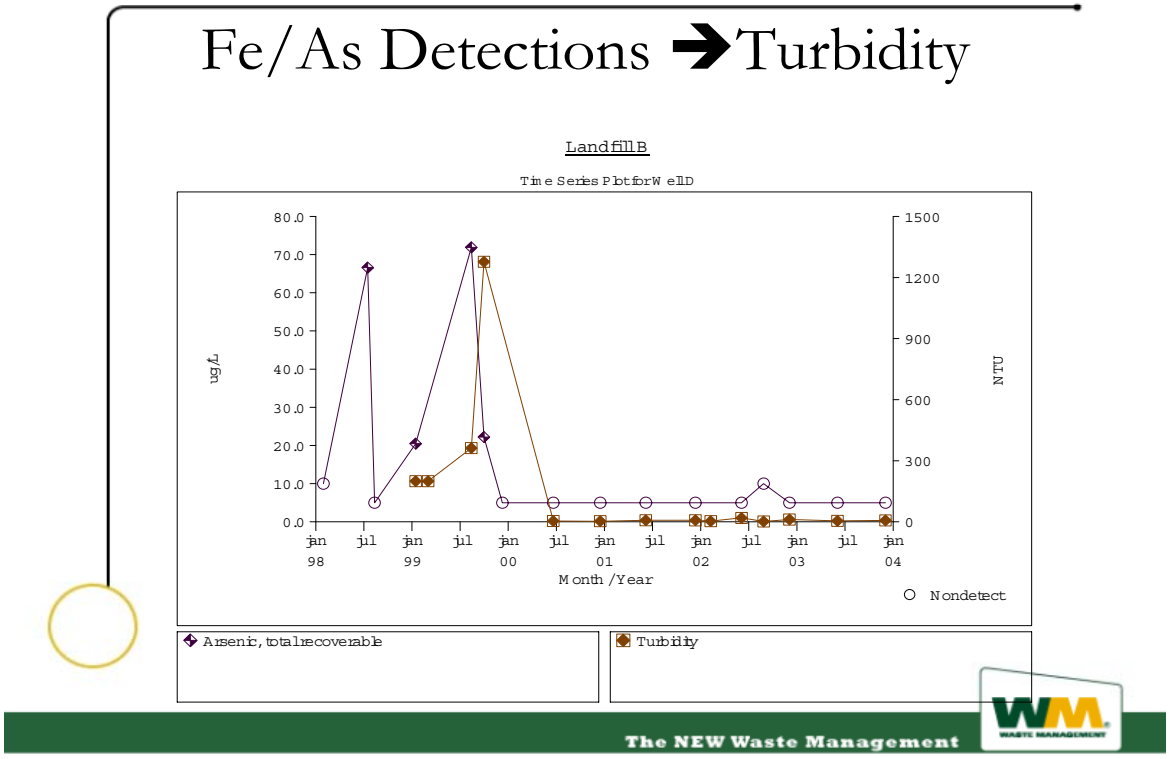
It should also be noted that some important information for more closely evaluating these analytical results, such as sample turbidity, was not discussed in the report.

APPENDIX E

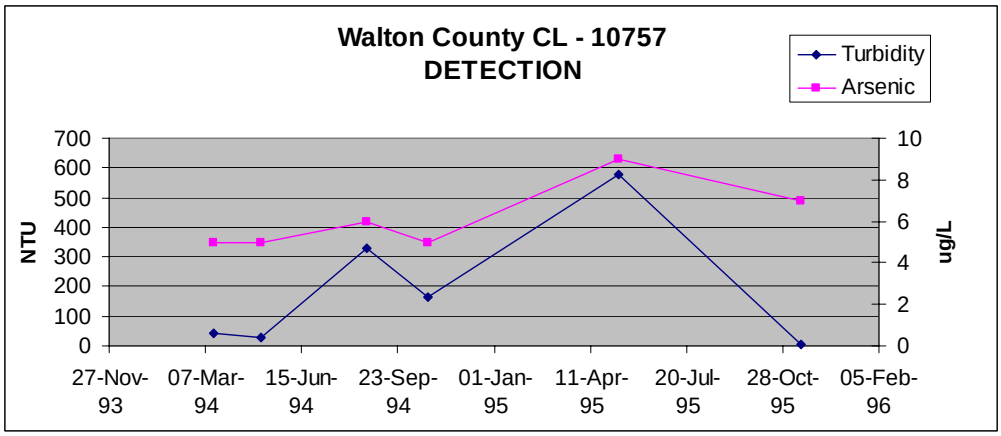
Graphical Arsenic and Turbidity Correlations

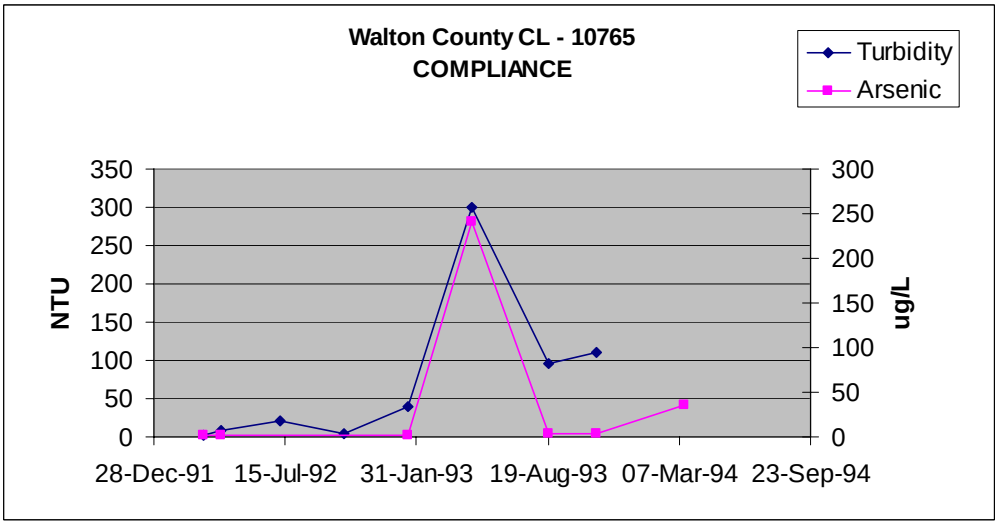
Example of Arsenic/Turbidity Relationship
Arsenic Detections in Groundwater at C&D Facilities, Florida Center for Solid and Hazardous Waste Management, PowerPoint Presentation found at:

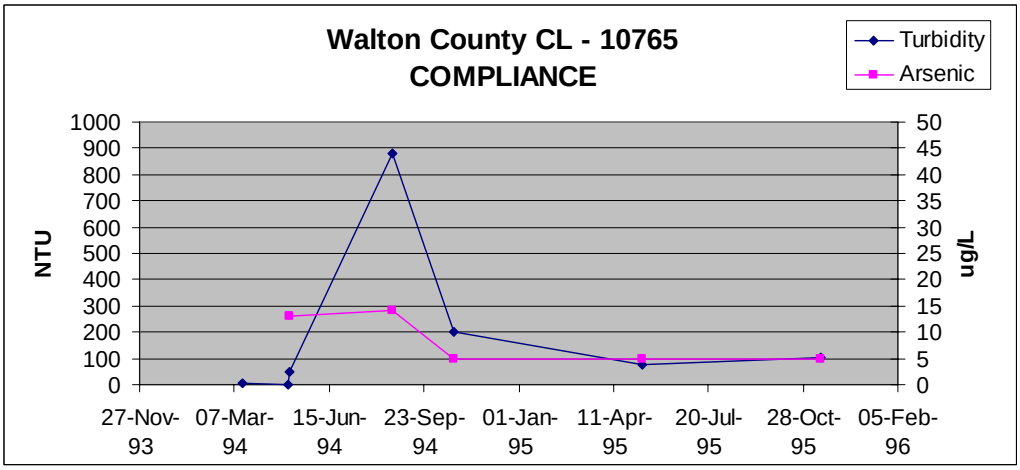
http://www.dep.state.fl.us/waste/quick_topics/publications/shw/solid_waste/051304-GWTAGArsenicDetectsinGW.ppt



Examples of Arsenic/Turbidity Relationship from FDEP Database: Walton County Central Landfill (no background well data available)







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PATHWAYS TO LASTING SOLUTIONS

ADDENDUM I

ECONOMIC IMPACTS AND PRACTICABILITY ISSUES ASSOCIATED WITH FURTHER REGULATION OF LANDFILL DISPOSAL OF CCA-TREATED WOOD

INTRODUCTION

This aspect of study entailed two tasks: one to evaluate readily available information on the nationwide costs associated with disposal of CCA-treated wood waste in Construction & Demolition Debris (C&D) landfills vs. hazardous waste landfills nationwide. The second task was to examine the non-quantitative, practical issues attendant to segregation of CCA-treated wood wastes from the waste stream.

APPROACH

Task 1

Based on a search of literature and data, unit costs of disposal in the two types of landfills were collected and evaluated. The unit cost figures were then applied to existing estimates of the quantity of C&D wastes disposed annually, and estimates of the CCA-wood waste portion of those wastes disposed. A summary of the information and the results of the assessment are provided herein.

Task 2

The methods available for segregation of CCA-treated wood in the landfill waste streams were evaluated, and an assessment of their practicality was performed. This included consideration of new techniques being researched for segregation at the landfill as well as curbside segregation. A discussion of regulatory enforcement issues is also provided in a subsequent section.

TASK 1: DISPOSAL QUANTITIES AND COSTS

Various studies have been performed during the past decade to estimate both the quantities and the costs of disposal of C&D and hazardous wastes in landfills around the country. Most of these studies focus on a single state or locality, or several case studies, and are primarily based on survey data that may now be many years old. The most timely and comprehensive information located during this study was drawn upon for making the cost estimates provided.

C&D Landfills - Waste Quantities

It is important to note that the definition of C&D wastes varies from state to state, as do regulations for landfills, property values, and many other socio-economic and environmental factors that impact disposal quantities and costs. Consequently, information presented here has the shortcomings inherent to the studies upon which it is based, coupled with assumptions made and extrapolation techniques applied, as later discussed.

Some states regulate C&D wastes in accordance with municipal solid waste (MSW) requirements, while others provide for disposal in onsite and/or offsite C&D landfills. Available information indicates that most states do not require C&D wastes to be regulated as MSW. A 1998 study by EPA[1] provides the most current information identified on the regulatory framework in each state. A summary of the EPA categorization showing states either in the MSW or C&D regulatory column is provided in Table 1, which reflects 1996 information. Note that California was shown in the "C&D" column in the original report; however, California now regulates C&D wastes as MSW, thus the designation was changed. In order to further characterize the framework of C&D disposal in the U.S., Table 1 also includes the number of C&D landfill disposal facilities in each state, as reported in the 1998 EPA study. That information was based on a 1994 survey and may no longer be accurate. For example, as of July 2004, the Florida Department of Environmental Protection (FDEP) maintained data on 116 licensed C&D landfills, thus many of the 277 reported by EPA for Florida may now be closed. This may be true for other states as well.

Table 1: State Regulatory Schemes & Number of C&D Landfills

(Adapted from U.S. EPA, June 1998)

State	Regulations*			State	Regulations*		
	MSW	C&D	# C&Ds		MSW	C&D	# C&Ds
Alabama		X	32	Montana		X	27
Alaska	X		21	Nebraska	X		6
Arizona	X		6	Nevada	X		6
Arkansas		X	22	New Hampshire		X	0
California	X		16	New Jersey		X	3
Colorado		X	5	New York		X	4
Connecticut	X		21	New Mexico		X	19
Delaware		X	1	North Carolina	X		153
Florida		X	277	North Dakota		X	39
Georgia		X	44	Ohio		X	148

State	Regulations*			State	Regulations*		
	MSW	C&D	# C&Ds		MSW	C&D	# C&Ds
Hawaii		X	1	Oklahoma	X		6
Idaho	X		7	Oregon		X	2
Illinois		X	3	Pennsylvania		X	4
Indiana		X	11	Rhode Island	X		1
Iowa	X		1	South Carolina		X	53
Kansas		X	78	South Dakota		X	103
Kentucky		X	143	Tennessee		X	32
Louisiana		X	167	Texas		X	24
Maine		X	57	Utah		X	9
Maryland		X	14	Vermont		X	2
Massachusetts	X		18	Virginia		X	32
Michigan		X	5	Washington		X	22
Minnesota		X	79	West Virginia		X	2
Mississippi		X	111	Wisconsin		X	39
Missouri		X	9	Wyoming		X	4
						TOTAL	1,889
*MSW: must meet MSW requirements							
C&D: separate regulations for C&D (may differ if onsite or offsite)							

In total, about 1,900 active C&D landfills in the United States were tallied by EPA. They also provided the following information: "A recent survey of 850 randomly selected C&D landfills in the United States found that on average, C&D landfills received 29,300 tons of material in 1995[2]. Assuming that average holds true for the 1,900 active landfills, 55.6 million tons per year are disposed of in permitted C&D landfills."

As a result of a separate analysis provided in the same study, EPA estimated that in 1996, C&D debris generation from the construction, demolition, and renovation of residential and nonresidential buildings in the United States totaled almost 136 million tons. Of that, 43 percent represented residential sources and 57 percent nonresidential sources. They further state the following: "The estimate of 136 million tons per year is equal to 2.8 pounds per capita per day (pcd). This compares to 4.3 pcd of MSW generation. Note that the 2.8 pcd does not include C&D debris from roadway and bridge construction and demolition or from land clearing projects." The estimates made by the researchers largely derive from such sources as Census Bureau records of the number of demolitions per year, or National Association of Home Builders Research Center data and case studies of waste generation rates from various types of residential projects, with extrapolations of those rates on a cost basis to nonresidential projects. As a result, the figures are not location-based. The method thus employed herein to

estimate C&D waste generation by state was to apply the 2.8 pcd value to 1996 population data.

Literature was reviewed to establish the amount of wood that could be expected in C&D waste. A number of sources estimated that this faction constituted about 25% of the waste[3, 4, 5, 6, 7, 8]. This percentage was applied to the numbers derived for quantities of C&D wastes. Similarly, literature was examined to determine the amount of CCA-treated wood that could be expected in the wood waste stream. Numbers ranged from a low of less than 2% in Maine, to a high of 6% in Florida, with an average of 3% considered reasonable[9]. This percentage was also applied to the C&D waste figures to derive estimates of CCA-treated wood waste. It is recognized that this method of calculating waste quantities will result in overestimates in some states and underestimates in others; however the overall figures should provide a reasonable baseline for use in estimating national disposal costs of CCA-treated wood in C&D landfills. The results are provided below in Table 2.

Table 2: 1996 State Population & Quantities of C&D and CCA-Treated Wood Waste

(Source of population data – U.S. Census Bureau)

State	POP.*	Mil T C&D*	T CCA Wood*	State	POP.	Mil T C&D	T CCA Wood
Alabama	4,273	2.184	16,376	Montana	879	0.449	3,369
Alaska	607	0.310	2,326	Nebraska	1,652	0.844	6,331
Arizona	4,428	2.263	16,970	Nevada	1,603	0.819	6,143
Arkansas	2,510	1.283	9,620	New Hampshire	1,162	0.594	4,453
California	31,878	16.290	122,172	New Jersey	7,988	4.082	30,614
Colorado	3,823	1.954	14,652	New York	18,185	9.293	69,694
Connecticut	3,274	1.673	12,548	New Mexico	1,713	0.875	6,565
Delaware	725	0.370	2,779	North Carolina	7,323	3.742	28,065
Florida	14,400	7.358	55,188	North Dakota	644	0.329	2,468
Georgia	7,353	3.757	28,180	Ohio	11,173	5.709	42,821
Hawaii	1,184	0.605	4,538	Oklahoma	3,301	1.687	12,651
Idaho	1,189	0.608	4,557	Oregon	3,204	1.637	12,279
Illinois	11,847	6.054	45,404	Pennsylvania	12,056	6.161	46,205
Indiana	5,841	2.985	22,386	Rhode Island	990	0.506	3,794
Iowa	2,852	1.457	10,930	South Carolina	3,699	1.890	14,176

State	POP.*	Mil T C&D*	T CCA Wood*	State	POP.	Mil T C&D	T CCA Wood
Kansas	**2,572**	**1.314**	**9,857**	South Dakota	**732**	**0.374**	**2,805**
Kentucky	**3,884**	**1.985**	**14,885**	Tennessee	**5,320**	**2.719**	**20,389**
Louisiana	**4,351**	**2.223**	**16,675**	Texas	**19,128**	**9.774**	**73,308**
Maine	**1,243**	**0.635**	**4,764**	Utah	**2,000**	**1.022**	**7,665**
Maryland	**5,072**	**2.592**	**19,438**	Vermont	**589**	**0.301**	**2,257**
Massachusetts	**6,092**	**3.113**	**23,348**	Virginia	**6,675**	**3.411**	**25,582**
Michigan	**9,594**	**4.903**	**36,769**	Washington	**5,533**	**2.827**	**21,205**
Minnesota	**4,658**	**2.380**	**17,852**	West Virginia	**1,826**	**0.933**	**6,998**
Mississippi	**2,716**	**1.388**	**10,409**	Wisconsin	**5,160**	**2.637**	**19,776**
Missouri	**5,359**	**2.738**	**20,538**	Wyoming	**481**	**0.246**	**1,843**
				TOTALS	**264,741**	**135.000**	**1,014,000**

***POP.** is population in thousands; **Mil T C&D** is million tons of C&D waste; **T CCA Wood** is tons of CCA-treated wood

By this method of estimation, just over 1 million tons of CCA-treated wood was disposed in 1996. In order to assess the validity of these numbers, a comparison was made with other available literature reporting quantities of C&D and/or CCA-treated wood waste on a state basis: In North Carolina, approximately 2.5 million tons of building-related C&D debris were generated during 1997[6]. This compares with 3.7 million tons calculated above, or 68% of the value. In developing their estimate, North Carolina had maintained that application of a per capita figure in their state would significantly overestimate the amount of C&D generated. Conversely, applying EPA's average C&D disposal rate of 19,000 tons per year per landfill to North Carolina's 153 landfills results in 4.5 million tons of C&D waste – an even greater overestimation.

The FDEP[10] reported that 5.4 million metric tons (6 million tons) of C&D waste were disposed in 1998 which is 81% of the 7.4 million tons shown in Table 2. On a tons per year per landfill basis, the number would be 8.1 million tons. The State of Maine estimated that approximately 323,000 tons of C&D waste is disposed each year, based on 2001 data[9]. This represents 51% of the 635,000 tons calculated for 1998. Again, the ton per year per landfill estimate is a more significant overestimation at 1.67 million tons. Maine also estimated that 2,600 tons of CCA-treated wood wastes were generated in the state each year. This is 55% of the 4,764 tons in Table 2.

It can be seen that the pcd figures probably result in an overestimate of the quantity of C&D wastes (and thus CCA-treated wood wastes) that are disposed. In fact, EPA's estimate of 55.4 million tons of C&D waste disposed in 1997, based on average disposal

rates in landfills, is only 41% of the 136 million tons estimated nationally on the basis of pcd waste generation figures. Yet when compared to the quantities reported for North Carolina, Florida and Maine, the disposal rate method more substantially overestimates the quantity of C&D/CCA-treated wood waste disposed. Obviously, the tons per year per landfill calculations even more substantially underestimate disposal quantities in other states. In view of the fact that EPA abandoned the disposal rate method in favor of the per capita rate method, the same was done for this report. However, the state figures were adjusted to 65% of the pcd estimates in order to accommodate the apparent overestimation in the original application.

In order to further adjust the disposal figures to year 2005, an annual increase of 1.5% per year for 1996 through 2001 was applied, based on data from the Southern Forest Products Association[3] and level production was assumed from 2001 forward. Results showing the adjusted estimated volume of CCA-treated wood waste are provided in Table 3. As shown, the estimated national total for 2005 is about 710,000 tons.

Table 3: Adjusted Estimates of CCA-Treated Waste

(Disposed in 2005 [tons])

State	Adjusted Tons	State	Adjusted Tons
Alabama	**11,467**	Montana	**2,359**
Alaska	**1,629**	Nebraska	**4,433**
Arizona	**11,883**	Nevada	**4,302**
Arkansas	**6,736**	New Hampshire	**3,118**
California	**85,549**	New Jersey	**21,437**
Colorado	**10,260**	New York	**48,802**
Connecticut	**8,786**	New Mexico	**4,597**
Delaware	**1,946**	North Carolina	**19,652**
Florida	**38,644**	North Dakota	**1,728**
Georgia	**19,733**	Ohio	**29,984**
Hawaii	**3,177**	Oklahoma	**8,859**
Idaho	**3,191**	Oregon	**8,598**
Illinois	**31,793**	Pennsylvania	**32,354**
Indiana	**15,675**	Rhode Island	**2,657**
Iowa	**7,654**	South Carolina	**9,927**
Kansas	**6,902**	South Dakota	**1,964**
Kentucky	**10,423**	Tennessee	**14,277**
Louisiana	**11,677**	Texas	**51,333**

State	Adjusted Tons	State	Adjusted Tons
Maine	**3,336**	Utah	**5,367**
Maryland	**13,611**	Vermont	**1,581**
Massachusetts	**16,349**	Virginia	**17,913**
Michigan	**25,747**	Washington	**14,849**
Minnesota	**12,500**	West Virginia	**4,900**
Mississippi	**7,289**	Wisconsin	**13,848**
Missouri	**14,382**	Wyoming	**1,291**
		TOTAL	**710,000**

C&D Landfills – Disposal Costs

The costs of disposal identified here are highly variable and reflect of the stringency of C&D landfill disposal regulations, and various socio-economic factors. In North Carolina, where the Department of Environment and Natural Resources state that their landfills are "abundant and relatively inexpensive", average tipping fees at C&D landfills are $23.66/ton.[1] In Florida, the average cost of disposal for C&D is $32.06/ton, and ranges anywhere from $5.00/ton in Okaloosa County to $92.00/ton in Monroe County (the Florida Keys area).[2] Authors note that the cost of disposal for C&D as reported by counties appears high and in many cases most likely does not include the disposal costs at private C&D disposal facilities which are significantly lower.

A 1997 study of C&D landfills[2] provided the average 1995 costs of disposal based on responses from 374 facilities nationwide. In order to update these estimates to 2005 dollars, a 3% annual increase was applied, based on the increase to the CPI. These costs, and the states within each region, are provided in Table 4 below.

Table 4: C&D Landfill Disposal Costs

(Source: Bush, 1997)

Region	States	1995 cost/ton	2005 cost/ton
Midwest	CO, IL, IN, IA, KS, MI, MN, MO, MT, NE, ND, OH, SD, WI, WY	$19.70	$26.48
Northeast	CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT	$46.00	$61.82
West	AZ, CA, ID, NV, OR, UT, WA	$42.60	$57.25
South	AL, AK, FL, GA, KY, LA, MS, NM, NC, OK, SC, TN, TX, VA, WV	$27.10	$36.42
	Weighted Average	**$33.85**	**$45.49**

The calculated 2005 cost was applied to the estimated amount of CCA-treated wood waste disposed in 2005 by state, in order to calculate the overall cost of disposal nationally. That amount is about $31 million, as shown in Table 5 below.

Table 5: Estimated Costs of CCA-Treated Wood Disposal in C&D Landfills - 2005

State	$/ton	tons	$ cost	State	$/ton	tons	$ cost
Alabama	36.42	11,467	417,628	Montana	26.48	2,359	62,466
Alaska*	33.85	1,629	55,142	Nebraska	26.48	4,433	117,386
Arizona	57.25	11,883	680,302	Nevada	57.25	4,302	246,290
Arkansas	36.42	6,736	245,325	New Hampshire	61.82	3,118	192,755
California	57.25	85,549	4,897,680	New Jersey	61.82	21,437	1,325,235
Colorado	26.48	10,260	271,685	New York	61.82	48,802	3,016,940
Connecticut	61.82	8,786	543,151	New Mexico	36.42	4,597	167,423
Delaware	61.82	1,946	120,302	North Carolina	36.42	19,652	715,726
Florida	36.42	38,644	1,407,414	North Dakota	26.48	1,728	45,757
Georgia	36.42	19,733	718,676	Ohio	26.48	29,984	793,976
Hawaii**	57.25	3,177	181,883	Oklahoma	36.42	8,859	322,645
Idaho	57.25	3,191	182,685	Oregon	57.25	8,598	492,236
Illinois	26.48	31,793	841,879	Pennsylvania	61.82	32,354	2,000,124
Indiana	26.48	15,675	415,074	Rhode Island	61.82	2,657	164,256
Iowa	26.48	7,654	202,678	South Carolina	36.42	9,927	361,541
Kansas	26.48	6,902	182,765	South Dakota	26.48	1,964	52,007
Kentucky	36.42	10,423	379,606	Tennessee	36.42	14,277	519,968
Louisiana	36.42	11,677	425,276	Texas	36.42	51,333	1,869,548
Maine	61.82	3,336	206,232	Utah	57.25	5,367	307,261
Maryland	61.82	13,611	841,432	Vermont	61.82	1,581	97,737
Massachusetts	61.82	16,349	1,010,695	Virginia	36.42	17,913	652,391
Michigan	26.48	25,747	681,781	Washington	57.25	14,849	850,105
Minnesota	26.48	12,500	331,000	West Virginia	36.42	4,900	178,458
Mississippi	36.42	7,289	265,465	Wisconsin	26.48	13,848	366,695
Missouri	26.48	14,382	380,835	Wyoming	26.48	1,291	34,186
				TOTALS		710,000	31,000,000

* not included in original study; national average applied
** not included in original study; value for West applied

Hazardous Waste Landfills

No studies were identified that provided unit costs of disposal of hazardous waste on a state or regional basis. A 1999 report by EPA[11] presented disposal costs on a case study basis. These generally approximated $275 per ton. This cost is consistent with various other case studies and estimates found in the literature.

In addition to the cost of disposal, there is generally a significant additional cost associated with the transportation of wastes to hazardous waste landfills. Another 1999 EPA economic assessment[12] identifies transportation cost differences between disposal at non-hazardous (assumed for C&D) and hazardous waste landfills that average about $65/ton. This brings the costs of disposal of CCA-treated wood as a hazardous waste to $340/ton in 1999 dollars, or $406 in 2005 dollars at 3% annual escalation. Applying this to the 710,000 tons of CCA-treated wood waste generated in 2005 results in a total hazardous waste landfill disposal cost of $288 million. This is nine times greater than disposal at C&D landfills.

Conclusion

Estimates made in this study result in a nationwide cost of $31 million for disposing CCA-treated wood in C&D landfills. The estimate for disposal of CCA-treated wood in hazardous waste landfills, plus the cost differential for transportation to such facilities results in a nationwide cost of $288 million.

TASK 2: PRACTICABILITY OF WASTE SEGREGATION AND RELATED ISSUES

In order to dispose CCA-treated wood wastes separately from other C&D wastes, it would be necessary to segregate it from the waste stream. Theoretically, this could be performed at the landfill or at curbside. With mulching and other recycling opportunities foreclosed, the segregation issue becomes more significant in considering the practicability and enforceability of any potential regulatory scheme.

Visually identifying CCA-treated wood is not simple. While it often takes on a greenish tint after processing, it tends to weather to grayish colors and thus becomes indistinguishable from untreated wood. Recognizing this dilemma to any potential further regulation, researchers have been investigating potential methods for segregating the wood at the landfill, where it would presumably be disposed in separate, more stringently controlled cells than other C&D debris, or turned away.

The Florida Center for Solid and Hazardous Waste (Center) has been funded for a number of years to continue its research on various aspects of CCA-treated wood, including sorting. In reporting on recent field studies[13], the researchers concluded that "The identification and removal of treated wood is **VERY** difficult." (emphasis is original) They further elaborate that sorting of treated wood is difficult when it is painted or when it is in mixed wood debris. Manual sorting of mixed loads at the landfill would obviously be labor intensive and costly. They also point out the difficulty of finding treated wood in waste loads, as it may be hidden in landscaping and yard wastes. Another problem is determining whether wood wastes were treated with CCA or other preservative compounds. Finally, the researchers state that "Once wood is processed, separation of CCA-treated wood is not a realistic possibility."

Some visual identification can be made based on greenish hue for newer treated wood. Also, presence of treated wood can be deduced if the wastes are recognizable as being derived from fences, decks, or docks. Some treated wood waste still bears end tags which can be examined to determine whether the wood is CCA-treated. It is apparent that sorting and segregation by these methods would be very labor intensive, lack reliability in many instances, and thus not be practicable.

In view of the failure of these methods, the Center received funding to develop and evaluate alternate sorting techniques[14]. One project entailed efforts to develop a stain testing technique to visually identify CCA-treated wood in order to exclude it from being sent to or disposed at C&D landfills if new regulations so required. While there were some positive results reported, none of the staining tests was overwhelmingly

reliable. Investigators did not consider the staining techniques to be practicable at the current stage of development. As part of the research effort, 43 test stain packets were sent to study participants; however, concerns over the costs of the packets were expressed. With reliability, practicality and costs a concern, staining techniques do not appear to be a feasible sorting technique.

Additional research has been done in "augmented sorting" entailing the use of instrumentation to detect the presence of CCA-treated wood. The technologies being evaluated include laser induced breakdown spectroscopy (LIBS) and x-ray (XRF). Recent work by the Center examined the use of these technologies with hand-held instruments. Results thus far indicate that LIBS requires additional R&D before being commercially feasible, while XRF is ready now. During a field experiment with XRF, an instrument was mounted on a conveyor belt in Sarasota County, Florida where it was found to allow easy identification of CCA wood at a certain threshold point. However, it was judged to be impractical for use in a hand-held mode for a person to sort materials passing on a conveyor belt, due to the volume of materials handled in a commercial operation. As well, landfill personnel would require training in the proper operation and maintenance of the instruments. Also, because these instruments are about $30,000 per unit, the costs may be prohibitive for wide-scale use. They may be feasible for spot-testing; however there is no long-term experience with them. At present, it appears that neither LIBS nor XRF represent practicable solutions to the sorting problem.

With no feasible alternatives to manual sorting by visual observation at the landfill, this labor-intensive and unreliable method would be necessitated if CCA-treated wood disposal at C&D landfills were prohibited. Landfills may post signage declining to accept treated wood; however, compliance would largely depend on the honor system.

The efficacy of curbside sorting by residential waste generators is also doubtful. The extent to which residents (or contractors) would understand how, or make the effort to sort CCA-treated wood from other wood and yard wastes is unknown. It seems unlikely that even with public awareness programs, curbside sorting of wastes after a remodeling, renovation or demolition project would be entirely successful, especially absent recycling incentives.

Another potential disincentive in curbside sorting is the issue of how, when, where, and at what cost haulers would remove and dispose CCA-treated wood waste, assuming it could even be identified and segregated. Calling for special curbside removal could be considered an unnecessary nuisance, cost, and delay in having wastes removed and disposed. This could thus incentivize home owners to commingle the small quantities of CCA-treated wood wastes with other larger volume wastes for pickup as C&D

debris. Alternatively, commingled C&D wastes may be disposed as MSW, thus adding substantial volumes of innocuous wastes to the MSW waste stream and posing further capacity problems to MSW landfills. This in turn would pose a loss of revenue to C&D landfills and haulers.

Municipalities and private haulers and landfill owners/operators would likely need to make adjustments to pickup and routing schedules. Undoubtedly, some C&D landfills that do not have lined cells, or that now operate marginally could be forced to close. Also, with resources for regulatory enforcement already inadequate in many areas, and the difficulty inherent to identifying CCA-treated wood waste in a landfill setting, compliance monitoring of any new regulations may be very limited in scope and success.

Conclusion

The practicability issues and other potential impacts discussed here require more serious investigation to weigh and quantify the consequences of further regulation. Costly additional requirements for CCA-treated wood wastes lack practicability in both the implementation and enforcement phases, in addition to having highly doubtful potential benefits.

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ADDENDUM II

RESUMES OF AUTHORS

Michael C. Kavanaugh

Dr. Kavanaugh is Vice President and the National Science and Technology Leader for Malcolm Pirnie, Inc. He is a chemical and environmental engineer with over 33 years of consulting experience, providing a broad range of environmental and chemical engineering services to private and public sector clients. His areas of expertise include hazardous waste management, site remediation with particular focus on groundwater remediation, risk and decision analysis, water quality, water treatment, potable and non-potable water reuse, fate and transport of contaminants in the environment, industrial and municipal wastewater treatment, strategic environmental management, and technology evaluations including patent reviews on environmental technologies. Dr. Kavanaugh has extensive litigation experience, both as a testifying expert and a fact witness on engineering and hydrogeologic issues related to hazardous waste sites as well as on other issues related to his areas of expertise. He also has participated on several mediation and arbitration panels as a neutral technical expert as well as serving as a mediator or arbitrator directly. Dr. Kavanaugh has been project engineer, project manager, principal-in-charge, technical director or technical reviewer on over 200 projects covering a broad range of environmental problems. Dr. Kavanaugh has prepared over 30 peer reviewed technical publications, two books, and has made over 130 presentations to technical audiences as well as public groups including testimony before congressional and state legislative committees. Dr. Kavanaugh was elected into the National Academy of Engineering in 1998.

Title/Firm:
Vice President
Red Oak Consulting

Years of Experience
33

Education
BS Chemical Engineering Stanford University 1962
MS Chemical Engineering University of California, Berkeley 1964
PhD Civil Engineering University of California, Berkeley 1974

Licenses and Certifications
Professional Engineer
Diplomate, American Academy of Environmental Engineers

Special Recognition
Member, National Academy of Engineering (NAE), 1998;
AAEE Kappe Lecturer, 1993;
Engineering News Record (ENR), Top 25 Newsmakers in 1994.

Societies
National Academy of Engineering

Employment History
Malcolm Pirnie, Inc. 1997 to present
ENVIRON Corporation 1994 to 1997
Montgomery Watson 1977 to 1994
Swiss Federal Institute for Water Research 1972 to 1977

DETAILED EXPERIENCE

Litigation Support/Expert Witness

- Testifying expert for the State of California (plaintiff) in a dispute with insurance companies over recovery of past and future costs associated with the remediation of the Stringfellow Acid Pits Superfund Site in Riverside County, CA. Prepared expert report on past and future costs, consistency of past actions with the National Contingency Plan, appropriateness and reasonableness of past and future actions. Testified at jury trial in 2005.
- Testifying expert for plaintiff in Illinois in a cost allocation dispute involving chlorinated solvent contamination. Evaluated fate and transport of chlorinated solvents in municipal waste water treatment plant to estimate sewer ex-filtration as possible source of solvent contamination and prepared expert report.
- Testifying expert for the defense in a cost allocation dispute involving chlorinated solvents in soil and groundwater at a site in Palo Alto, CA. Testified on fate and transport issues, reasonableness of costs ex-

pended, and allocation of remediation costs based on the results of a groundwater transport model. Case settled during trial.

- Testifying expert for an insurance company (defendant) in insurance cost recovery dispute involving multiple carriers and Dow Chemical Company. Trial testimony on fate and transport of contaminants of concern at ten (10) Dow facilities and estimated timing of release(s).
- Dr. Kavanaugh was retained by a major oil company to provide expert opinions on the likely sources of petroleum hydrocarbon contamination at a former bulk oil terminal in Stockton, CA currently being developed for other land uses. Case settled prior to deposition discovery.
- Defense expert for the U.S. Department of Justice, in defense of former government contractors regarding alleged contamination of aquifer in Albuquerque, NM with chlorinated solvents. Prepared expert report in rebuttal to natural source damage claim by State of New Mexico.
- Testifying expert for the defense in a multiparty dispute on the need for and estimated costs of soil and groundwater remediation at the site of a former sugar plantation in Oahu, Hawaii. Scientific issues in dispute included sources of organic (PAHs, chlorinated solvents) and metal contaminants in the soil and groundwater, adequacy of the site characterization as a basis for estimating remediation costs, and probability estimates for future remediation costs.
- Testifying expert for Alabama Department of Transportation in a dispute over the adequacy of a proposed site investigation plan to characterize the extent of a PCE and TCE problem at a site near Birmingham, AL.
- Technical support to Emerson Electric Company at a multi-party PRP site in Florida. Key issues included cost allocation based on treatment costs for specific compounds and value engineering of remedial action plan at former chemical recycling facility.
- Expert witness for plaintiff in case involving a dispute between Kaiser Steel Resources (Plaintiff) and several defendants. Case involved basis for net worth valuation of company prior to leveraged buyout of a former steel manufacturing facility in California. Prepared expert report, and deposition testimony on whether reasonable estimates of environmental liabilities could have been made with limited field data. Case settled in plaintiff's favor.
- Expert witness for defense regarding alleged property contamination from former wood treating facility at a site in Alameda, California bordering the San Francisco Bay. Case settled in favor of defendant.
- Expert testimony on sources and impacts of contaminants found in a municipal landfill, at a NPL site in California.
- Designated expert for the defendant (privately held chemical company) in a property damage claim involving alleged damages from operations of a former chemical manufacturing facility in Santa Fe Springs, CA.
- Designated expert for plaintiff in litigation involving CERCLA cost recovery for costs incurred to complete an RI/FS at a site in California owned by a large bank. Case settled in plaintiff's favor.
- Provided litigation support for defendant (Napa Sanitation District, California) in property damage case involving alleged contamination of property owned by gasoline retailer caused by alleged migration of petroleum products from off-site sources via abandoned sewers. Testified before federal judge on fate and transport issues.
- Expert witness on behalf of defendant in a case involving claims that defendant's site investigation activities caused subsurface contamination (1, 2-DCA) to spread. Prepared expert report rebutting fate and transport claims, and providing alternative estimate of remedial costs for remediation of DNAPL contamination. Case settled in favor of defendant.
- Designated expert in patent dispute over "prior art" issues related to the use of steam injection for remediation of organic contaminants in saturated and unsaturated soils.
- Expert witness representing a property owner in the Bay Area in a dispute over the need for remediation of gasoline spills at a gas station leased on the property. Continued migration of MTBE was one of the concerns raised by the property owner. Case settled prior to trial.

- Designated expert representing a major oil company in a dispute with another oil company over responsibility for cleanup of a commingled BETX plume caused by gasoline releases at gas stations in close proximity to one another. Assisted counsel in preparing a technical report on fate and transport of BETX, free product, and MTBE, which was submitted to the California State Water Resources Control Board.

Alternative Dispute Resolution (Mediation, Arbitration, Facilitation)

- Member of three-person arbitration panel established to arbitrate a dispute between Inyo County, CA, and the Los Angeles Department of Water and Power on the operation of the McNally Canals in California.
- Served as private arbitrator for two oil companies to arbitrate a dispute over past and future costs of cleanup at two gas stations involving soil and groundwater contamination by gasoline containing MTBE.
- Member of a three-person mediation panel mediating a dispute between the Los Angeles Unified School District and a law firm in Los Angeles. Technical issues including potential or actual risks from methane and hydrogen sulfide gases emanating from oil fields beneath a high school in downtown Los Angeles.
- Member of a two-person mediation panel to settle dispute between a golf course developer, State Water Resources Control Board, Regional Water Resources Control Board, the effected city, and the interested citizen groups. Met with each group to facilitate constructive dialogue between parties to resolve areas of disagreement or uncertainty.
- Member of two person panel working with JAMS to resolve a cost allocation dispute between the City of San Francisco and several oil companies regarding costs for soil and groundwater cleanup at the San Francisco International Airport.
- Member of three person mediation team organized by JAMS to settle dispute over damage claims between the City of Fresno, CA, and three chemical companies who manufactured fungicides (DBCP and EDB) used on crops in the Central Valley, CA. Case settled based on technical approach proposed by mediation team.
- Directed technical evaluation of alternative closure plans for the ACME Landfill as basis for mediation settlement of cost allocation issues between owner/operator and waste generators.
- Mediator to settle dispute between City of Livermore, CA and Dublin/San Ramon Sanitation District over water rights issues.
- Independent technical mediator to resolve cost allocation dispute at the Gould Superfund site near Portland, Oregon. Issues included cost allocation between PRPs, resolution of sources/contributions of PAHs/dioxins to soil and groundwater.
- Served as an independent expert preparing arbitration decision on dispute between responsible parties at Gould Superfund Site in Portland, Oregon, on cost liabilities for failed remedy and cost liabilities for subsequent remedial costs.
- Technical expert for FMC Corporation during mediation process to settle dispute over cost allocation for commingled TCE and hexavalent chromium plumes at a site in Fresno, CA.
- Court designated expert to advise Federal Judge F. Damrell on technical issues related to a dispute between the City of Lodi, CA, and potential responsible parties regarding PCE contamination originating from several sources including dry cleaners.

Site Investigations

- Project Manager and Principal-In-Charge on a major remedial investigation (RI) of four NPL sites in the San Fernando Valley of Southern California. The project included extensive soil gas testing to locate multi-piezometer monitoring wells, preparation of a three-dimensional ground water flow model, and the definition of the nature and extent of contamination in the ground water at the four NPL sites. RI showed that several million pounds of TCE and PCE render the aquifer unusable without treatment.
- Provided technical review and oversight on soil and ground water investigations of ground water contamination at U.S. Navy Moffett Field, California. Key problems included allocation of financial responsibility for remediation of TCE plume caused by

releases from U.S. Navy facility and releases from upgradient industrial sources.

- Project Manager for investigation of ground water contamination at a former steel mill in Southern California located above sole-source aquifer (Chino Basin). Studies showed extensive degradation from TDS discharges and major non-toxic organic plume that could impact municipal wells used to extract ground water for potable use. Evaluated reuse of extracted water by local industries.
- Provided technical oversight for a large RI of a former oil refinery near New Orleans. The site was directly in the path of a new freeway. Extensive testing and analysis of soil and ground water were required. Innovative on-site analytic protocols were developed to accelerate the site investigation.
- Principal-In-Charge for site investigations being carried out at two operating chemical facilities owned by a major U.S. Chemical Company in the Netherlands and Belgium. Both sites have soil and ground water contamination including the presence of dense non-aqueous phase liquids (DNAPLS). Project includes RI/FS and human heath risk assessment. Soils contaminated with molybdenum and synthetic organic chemicals.

Site Remediation / Feasibility Studies

- Project Manager and Principal-In-Charge for remedial actions at a pipe manufacturing facility in Napa, California. Soil and ground water contaminated with total petroleum hydrocarbons, solvents, and metal wastes. Remedial actions have included on-site bioremediation for TPH reduction, on-site stabilization, and solidification of metal wastes, permitting for on-site storage of wastes, and pump and treat for control of a VOC plume.
- Project Manager for remedial actions to recover JP-4 jet fuel found beneath former fire fighting facility at the China Lake Naval Weapons Center, California. A dual pump recovery system with air stripping of the extracted water was installed.
- Project Manager for major site investigation, feasibility study, remedial action plan, and implementation of remedial actions for control of contaminated ground water at the Crazy Horse Landfill, a NPL site in Salinas, California. Remediation system included an innovative passive air stripping system for removal of VOCs with off gas treatment by GAC.
- Project Manager overseeing a pump-and-treat remedial action program at an industrial facility in southwest Florida. Ground water contamination caused by release of 1,1,1-trichloroethane and abiotic degradation product of 1,1-dichloroethylene. Project included negotiations with FDER in Florida. A four-year extraction program to demonstrate compliance with clean up levels (MCLs) at the property boundary was successful.
- Project Manager and Principal-In-Charge, RI/FS/Remediation Design at a former chemical facility in Santa Fe Springs, California. A Remedial Action Plan has been approved by the lead regulatory agency which includes capping of site, and hydraulic containment of impacted groundwater using a pump and treat system. Currently overseeing optimization of remedial system and assessment of natural attenuation remedial option.
- Provide technical review for innovative technologies being tested at Hill Air Force Base in Utah. Technologies to be evaluated include surfactant flushing and co-solvent flushing for removal of DNAPLs, the use of gate "and funnel" technology with iron filing reactors for a reductive dehalogenation of solvents, bioventing, and in situ bioremediation of chlorinated solvents.
- For ARCO, provided technical review of a technical impracticability (TI) report prepared for EPA at a Superfund site in Montana.
- Project Manager, feasibility analysis of alternatives to manage acid mine drainage from Penn Mine in California, an abandoned copper mine, located on property owned by East Bay Municipal Utilities District.
- Project Director, analysis of technical feasibility of Superfund mandated remedy at the J.H. Baxter Superfund site in Weed, CA. Key issues involved assessment of technical feasibility of ground water restoration in the presence creosote of DNAPL below water table, and strong adsorption of arsenic to specific soils. Based on analysis, EPA agreed to assess alternative strategies for site.

- Technical expert for a major U.S. Chemical Company on site remediation issues at U.S. and European facilities.
- Project officer, review of pump-and-treat system at a semi-conductor manufacturing facility on Long Island, NY. Contaminants include TCE, PCE, and 1,1,1-TCA. Assisted client in negotiating an agreement to terminate remediation system.

Audits / Due Diligence

- Project officer, due diligence evaluation for major airline company considering purchase of a fueling company in the U.S.
- Principal-In-Charge, due diligence study for a Fortune 200 U.S. electronics company as part of a purchase of manufacturing facility in the United Kingdom. Project involved soil and ground water sampling, risk assessment, and analysis of costs for potential remedial measures. Successfully negotiated the sale of property despite finding contamination in soil and ground water.
- Project Manager for due diligence evaluation of the soil and ground water contamination at a former pipe manufacturing facility in Northern California. Investigations uncovered a number of potential problems on the site. Cost estimates of possible remediation made to provide a basis for sale of company.
- Project Manager, environmental audit of a Silicon Valley manufacturing facility that was foreclosed by a California bank. Site found to be contaminated with volatile organic chemicals and metals caused by leaking sewer system and from spills within buildings. Estimated environmental liabilities exceeded value of loan on the property.
- Principal-In-Charge for site audits at three operating facilities owned by HB Fuller Company in Germany and Austria. Activities included soil and ground water sampling and preparation of summary reports.
- Principal-In-Charge, preliminary assessment/site inspection to assess potential contamination at former steel mill in Southern California. Site encompasses 1,000 acres and included 28 waste management units with potential soil contamination. The sites were prioritized and a program implemented for a RCRA RFI and CMS.
- Project Manager for due diligence audit of an auto shredding facility in Southern California. Sampling included soil, auto shredding waste, and ground water to determine extent of soil and ground water contamination, and evaluate disposal options for shredder waste.

Engineering Design

- Provided technical review of process design and specifications for a pump and treat system at Castle Air Force Base, California. System included extraction wells, filtration for particulate removal, air stripping with low profile air strippers and vapor control GAC.
- Provided technical review and analysis of plans and specifications for a soil vapor extraction system at the Davis Monthan Air Force Base, Arizona.
- Provided technical review of plans and specifications for a 2,000 gpm air stripper, with vapor phase GAC system, installed by the Los Angeles Department of Water and Power to treat ground water. Also evaluated the use of UV/Ozone for off-gas treatment.
- Provided process engineering and review of plans for leachate treatment systems to remove volatile organic chemicals, nonvolatile organic chemicals, and metals at the Stringfellow Superfund site, and the BKK landfill.

Industrial Waste Treatment

- Provided technical review of engineering options for treatment of ballast water at the Valdez refinery, Alaska. Ballast water treatment plant upgrade required to meet new NPDES requirements for BTEX. Participated in design of an innovative enhanced biological treatment system with post treatment using an air stripping system installed within existing structure.
- Project Manager, lab scale and pilot testing of physical chemical methods for moving metals and toxic organics from wastewater at the Vallejo Wastewater Treatment Plant, Vallejo, California. This POTW treats a high fraction of industrial wastewater.

- Principal-In-Charge of an industrial waste treatment evaluation for treatment of wastewater from an aluminum anodizing facility in Arizona. Waste streams characterized by low and high pH, high metals content.
- Part of a team of experts evaluating wastewater treatment options for removal of toxics in the Niagara Falls Wastewater Treatment Plant, New York. Previous treatment facility was predominantly physical chemical plant. High level of biodegradable organic matter rendered the GAC system dangerous due to production of hydrogen sulfide.
- Technical review of proposed industrial waste treatment facilities to be installed by Eastman Chemical Company in Tennessee to meet the Clean Water Act requirements for control of toxic organics and suspended solids.
- Principal-In-Charge and technical review of project to improve performance of industrial waste treatment plant, treating paint wastes from spray booths at a major auto manufacturing plant in Fremont, California.

Engineering Feasibility Evaluations

- Project Manager, assessment of hazardous waste treatment technologies for handling contaminated soils under contract to SITA, a French waste management company. Project involved estimate of quantities of hazardous wastes generated in France and other European countries and an assessment of applicable stabilization/solidification technologies. Information used by SITA to license appropriate technologies for stabilization/solidification facilities in France.
- Program Manager and Technical Director for investigation of alternative technologies to control synthetic organic chemicals in potable reuse plant. Technologies evaluated included GAC, air stripping in packed towers, ion exchange, electrodialysis, low pressure reverse osmosis membranes, and UV/Ozone oxidation.
- Project Manager for a state-wide assessment of VOC removal options for utilities in the state of New Jersey. Prepared a report, which was widely distributed, assessing the magnitude of the VOC removal problem in New Jersey, and estimating costs for compliance of new facilities.
- Technical Reviewer, advanced water treatment project for control of synthetic organic chemicals found in the Great Lakes. Assessed impact to water treatment plants in Canada. Project completed for Ministry of the Environment, Toronto, Canada.
- Provided evaluation of technologies proposed for remediation of portions of the Stringfellow hazardous waste site. Assessed suitability of soil vapor extraction and other technologies for removing volatiles from major waste zone at the site.
- Provided technical support to major U.S. tire manufacturer on strategies for ground water remediation. Technologies reviewed included in situ bioremediation, in well aeration systems, funnel and gate technologies, air sparging, and bioventing in addition to pump and treat.

Waste Minimization / Pollution Prevention

- Principal-In-Charge, study evaluating waste minimization options at six U.S. operating Air Force Bases in Germany, UK, Italy, and Turkey. Project involved development of a database to prepare mass balance audit of hazardous materials used and wastes generated at the facilities. Alternatives for reducing wastes were evaluated and recommendations made to meet the Air Force goals of 25% reduction in hazardous wastes by 1996.
- Provided technical review for an assessment of water minimization options at a fabric manufacturing facility in UK.
- Principal-In-Charge, technical consulting to the Santa Clara County Manufacturing Association for assessment of options to reduce copper and nickel discharges from local industries. Waste minimization options as well as end-of-pipe treatment to be assessed.

Water Quality and Water Reuse

- Principal Investigator for the Water Reuse Foundation directing a study on the formation, fate and transport, and treatment for removal of n-nitrosodiethylamine (NDMA) in chlorinated municipal wastewater effluents. Participating utilities

include several Bay Area discharges, West Basin Water District, and the City of Scottsdale.

- Project Officer, directing study on control of total cyanide levels in effluent from the Sacramento Regional County Sanitation District (SRCSD) Wastewater Treatment Plant.
- Chair of Project Advisory Committee, National Water Research Institute funded project evaluating Title 22 Design Criteria for wastewater filtration; laboratory and pilot studies to assess impacts of increasing filtration rate above current requirement of 5 gallons per minute/square foot.
- Project Manager, evaluation of appropriate statistical models to determine total maximum daily loads for dioxin-equivalents in wastewater discharges from petroleum refineries in the San Francisco Bay Area.
- Principal-in-Charge, directed three-year project on cyanide species in municipal wastewaters under contract to the Water Environment Research Foundation (WERF). Project involved assessment of alternative analytical techniques to measure cyanide species, modeling of cyanide fate and transport in wastewater treatment systems and evaluation of alternative management strategies to maintain compliance with total cyanide discharge standards between 5 and 50 ppb.
- Project Manager, confidential client. Evaluation of fate and transport of ferrocyanide in surface waters, groundwater, and in sanitary sewers.
- Project Manager, operation and evaluation of 1 MGD advanced water treatment plant to test the use of the contaminated Potomac River as a potable source under drought conditions. Water quality issues included estimate of water quality levels under drought conditions in the Potomac River estuary, and evaluation of water quality requirements for potable reuse. Testing program included evaluation of the efficiency of advanced water treatment processes for removing or reducing the levels of 220 compounds. Project included extensive toxicological and microbiological tests on treated water from pilot plant and three local water treatment plants. Report submitted to Congress assessing the water quality aspects of potable reuse under conditions tested.
- Project Manager, investigation of causes, and control options for total cyanide in wastewater effluent from City of Sunnyvale, CA wastewater treatment plant, and East Bay Municipal Utilities District (EBMUD) wastewater plant.
- Expert witness for Delta Wetlands Properties on water quality issues, particularly impact of proposed Delta islands water storage project on Delta export water quality. Prepared expert testimony as part of water rights permit hearings before the State Water Resources Control Board, California. Issues included estimate of dissolved carbon (DOC) releases from sediments of a reservoir.
- Project Engineer, Water Quality 2000 project in Switzerland. Study involved projections of population density, industrial production, unit waste production, and evaluation of transformations of chemicals in receiving waters. Report provided basis for long-term strategy to protect water quality in Swiss surface waters.
- Provided technical analysis of "how-clean-is-clean" issue, remediation of drilling mud sites on the North Slope, Alaska. Several hundred drill pits must be remediated. Assessment of water quality impacts of small quantities of organics (petroleum hydrocarbons, PAHs) and metals present in the drilling muds to determine extent of excavation required. Assisted ARCO Alaska in negotiating less stringent cleanup levels, leading to significant savings in overall costs of closure of the drill pits.
- Technical review of water quality issues surrounding reuse of contaminated ground water through blending into municipal supply after treatment. Client was Santa Clara Valley Water District.
- Project Engineer, optimization study of coagulation options for Vallejo Wastewater Treatment Plant for control of phosphorous, heavy metals.
- Research Director, directed two-year study of direct filtration of secondary effluent for phosphorous removal, City of Zurich, Switzerland.
- Ph.D. Thesis, investigation of kinetics of granular media filtration; mechanisms and performance models.

Peer Review / Strategic Consulting

- Retained by Ideascope as an expert on environmental monitoring. Participated in a strategic planning process for Hewlett-Packard's Analytical Products Division.
- Member of an Independent Review Team under contract to Sandia National Lab to review groundwater program planned for UMTRA (Uranium Mill Tailings) sites, and to review environmental restoration program for the Lawrence Livermore National Laboratory.
- Retained by Golder Associates as an expert to review proposed corrective actions at a TSDF owned and operated by a major waste management company.
- Retained by Lawrence Livermore National Laboratory as member of an expert committee reviewing closure plans for petroleum release sites at ten military bases in California. Committee prepared evaluation of each site for closure under a risk-based corrective action (RBCA) approach. Also a member of the Working Task Force conducting an assessment of natural attenuation of chlorinated solvents at sites throughout the U.S. Work funded by DOD and DOE.
- Retained by ARCO Chemical and Oxygenated Fuels Association as an expert on water treatment and remediation issues associated with MTBE in surface and ground waters. Providing on-going technical outreach to impacted parties, public agencies, and general public. Technical reports have been prepared on the following subjects: 1) Effectiveness and Costs of Soil and Ground Water Remediation Systems for MTBE; 2) Review of Technologies for Removing MTBE from Drinking Water; 3) Taste and Odor Study for Setting Secondary Drinking Water Standards for MTBE; 4) Impact of Small Gasoline Spills on MTBE in Ground Water; 5) Volatilization of MTBE from Surface Waters.
- One of eight members of the Hanford groundwater/vadose zone expert panel advising Bechtel Hanford and the Department of Energy on integrating and optimizing remedial efforts at Hanford site (1997 – 2001).
- Member, Science Advisory Board for Department of Defense Strategic Environmental Research and Development Program (SERDP) (2002 – present).

Policy Issues

- Member, Board of Scientific Councilors, advising the Office of Research and Development, EPA on peer review issues related to research priorities and research management at EPA's research labs. Participating in peer review of several of the EPA laboratories.
- Dr. Kavanaugh was Chairman of National Research Council Committee to evaluate alternatives for ground water cleanup. The 1994 report provides a definitive statement on the capabilities and limitations of pump and treat, as well as other ground water remediation alternatives. Numerous policy recommendations were made in the report to improve the regulatory approach to ground water contamination sites. Dr. Kavanaugh provided briefing to industrial, environmental, and governmental groups, including testimony before the House of Representatives Committee on Public Works and Transportation, as part of Superfund reauthorization.
- Dr. Kavanaugh was the Chairman of the Water Science and Technology Board from 1989 to 1991. During this time, the Board managed or developed over 15 projects related to all aspects of water resources management. From 1995 to 1998, he chaired the Board on Radioactive Waste Management, a Board responsible for evaluating the nation's strategies for management of radioactive waste.
- Dr. Kavanaugh is a member of the Scientific Advisory Board for the Strategic Environmental Research & Development program (SERDP), a DOD program providing funds for R&D projects in support for DOD's efforts to meet environmental requirements at operating military facilities.
- Dr. Kavanaugh served on the editorial advisory board for the largest circulation environmental journal, Environmental Science & Technology, published by the American Chemical Society (ACS) (1999-2003).
- Dr. Kavanaugh recently co-chaired an Expert Panel advising EPA on the issue of whether source remediation at DNAPL sites is justified given difficulties

of characterizing and remediating DNAPL impacted sites. The Panel's report was published in 2004.

SELECTED PUBLICATIONS

Hawley, E., Deeb R., Jacobs, J. and Kavanaugh, M. 2004. **Treatment Technologies for Hexavalent Chromium. Chapter 8.** Hexavalent Chromium Handbook. CRC Press.

Kavanaugh, M. 2003. **Emerging and Unregulated Chemical Contaminants: Technical and Institutional Issues. Proceedings,** WEFTEC. Los Angeles, CA. October.

Deeb, R., Chu, K., Shih, T., Linder, S., Suffet, I., Kavanaugh, M. and Alvarez-Cohen, L. 2003. **MTBE and Other Oxygenates: Environmental Sources, Analysis, Occurrence and Treatment.** Environmental Engineering Science 20(5):433-447.

Deeb, R., Dzombak, D., Theis, T., Ellgas, W. and Kavanaugh, M. 2003. **The cyanide challenge WERF Researchers Discuss Strategies for Managing this Disinfection Byproduct.** Water Environment and Technology 15(2):34-38.

Stroo, H. F., M. Unger, C. H. Ward, M. C. Kavanaugh, C. Vogel, A. Leeson, J. A. Marqusee, and B. P. Smith. 2003. **Remediating Chlorinated Solvent Source Zones.** Environ. Sci. & Technology. June 1, 2003 37: 223A-230A.

Deeb, R.A., Dzombak, D., Theis, T., Ellgas, W., and Kavanaugh, M. 2003. **The Cyanide Challenge WERF researchers discuss strategies for managing this disinfection byproduct.** Journal of Water Environment and Technology.

Deeb, R.A., Sharp, J., Stocking, A., McDonald, S., West, K., Laugier, M., Alvarez, P., Kavanaugh, M., and Alvarez-Cohen, L. 2002. **Impact of Ethanol on Benzene Plume Lengths: Microbial and Modeling Studies.** Journal of Environmental Engineering-ASCE. In Press.

Deeb, R. A., Stocking, A., Alvarez-Cohen, L. and Kavanaugh, M. 2001. Biodegradation of MTBE and TBA: A Current Review. Chapter 16. In Diaz, A. and Drogos, D. (Eds.), **Exploring the Environmental Issues of Mobile, Recalcitrant Compounds in Gasoline,** American Chemical Society Books and Oxford University Press, pp. 228-242.

Deeb, R. A., Flores, A. and Kavanaugh, M. 2001. **Overview of MTBE Remediation and Treatment Strategies.** Chapter 14. In Diaz, A. and Drogos, D. (Eds.), Exploring the Environmental Issues of Mobile, Recalcitrant Compounds in Gasoline, American Chemical Society Books and Oxford University Press, pp. 190-207.

Deeb, R.A., McMillan, B., Kavanaugh, M. 2001. **Environmental Fate and Transport of Fuels Oxygenates. In Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Ground Water:** Prevention, Detection, and Remediation, Houston, Texas, pp. 90-99.

Stocking, A.J., Suffet, I.H., McGuire, M., Kavanaugh, M. 2001 **Implications of an MTBE Order Study for Setting Drinking Water Standards.** J.AWWA March, pp. 95-105.

Stocking, A.J. and Kavanaugh, M. 2000. **Modeling Volatilization of MTBE from Standing Surface Waters,** J. Environmental Engineering, ASCE, December.

Kavanaugh, M.C., Weinstein, D. 2000. **Alternative Dispute Resolution Techniques in Practical Environmental Forensics:** Process & Case Studies, by T.J., Sullivan, F.A. Agardy, R.K. Traub, J. Willey & Son. December. In Press.

Stocking, A.J., Deeb, R.A., Flores, A.E., Stringfellow, W., Talley, J., Brownell, R., Kavanaugh, M.C. 2000. **Bioremediation of MTBE: A Review from a Practical Perspective.** Biodegradation 11(2-3):187-201.

Flores, A.E., Stocking, A.J., Ivery, J.J., Thoma, S.M., Kavanaugh, M.C. 2000. **Impact of Small Gasoline Spills and the Treatment of Water Supply from Private Drinking Water Wells. Soil, Sediment, and Groundwater:** MTBE Special Issue. March, pp. 15-20.

Stocking, A.J., McDonald, S., Woll, B., Kavanaugh, M.C. 1999. **Evaluation of the Fate and Transport of Methyl Tertiary Butyl Ether (MTBE) in Gasoline Following a Small Spill.** October.

Stocking, A.J., Kavanaugh, M.C. 1999. **Modeling the Volatilization of MTBE from Standing Surface Waters,** Journal of Environmental Engineering. December.

Stocking, A.J., Carroll, P., Keegan, E., Kavanaugh, M.C. 1999. **Potential Impact of the UST Upgrade Program on MTBE Plume Lengths.** Malcolm Pirnie, Inc. 180 Grand Ave. 1000; Oakland California, 94612. July.

Stocking, A.J., Koenigsberg, S., Kavanaugh, M.C. 1999. **Remediation and Treatment of MTBE, Environmental Protection** (A Stevens Publication), pp. 36 41. April.

Stocking, A.J., Keegan, E., Kavanaugh, M.C. 1999. **Literature Review of the Air Quality Benefits Resulting from the Use of Oxygenated Fuels.** March.

Stocking, A.J., Pappas, K.J., Kavanaugh, M.C. 1999. **Evaluation of the Fate and Transport of Methanol in the Environment.** January.

Stocking, A.J., Petersen, S.F., Kavanaugh, M.C. 1998. **Remediation Technologies: Design, Selection, and Optimization of Recovery Systems for Methyl Tert-Butyl Ether,** presented at the Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection, and Remediation, November.

Stocking, A.J., Deeb, R.A., Kavanaugh, M.C. 1998. **Evaluation of the Fate and Transport of Ethanol in the Environment.** October.

Stocking, A.J., McGuire, M., Suffet, M., Kavanaugh, M.C. 1998. **Taste and Odor Properties of Methyl Tertiary-Butyl Ether and Implications for Setting a Secondary Maximum Contaminant Level.** June.

Kavanaugh, M. 1998. **In-Situ Treatment Technologies: New Challenges.** Invited Keynote address, 1st International Conference on Chlorinated and Recalcitrant Compounds, Monterey, CA.

Kavanaugh, M. 1997. **In-Situ Treatment Technologies: Promises and Limitations.** Keynote address, ASCE Annual Conference, Minneapolis, MN.

Kavanaugh, M. 1997. **An Overview of NAPL Remediation.** Presented at the Workshop on Scientific and Engineering Challenges in Remediation of Contaminated Soil and Groundwater. University of Washington. May.

Kavanaugh, M. 1996. **An Overview of the Management of Contaminated Sites in the U.S.; Conflict between Technology and Public Policy.** Water Science and Technology, 34 (7-8), 275-283.

Boller, M.A., and Kavanaugh, M.C. 1995. **Particle Characteristics and Headloss Increase in Granular Media Filtration,** Water Research, 29, 4, 11-39-1149.

MacDonald, J., and Kavanaugh, M. 1994. **Restoring Contaminated Groundwater: An Achievable Goal?** ES&T., 28(8), 362a.

Kavanaugh, M. 1993, In-Situ Remediation: **Research Needs,** Keynote Speaker. Association of Environmental Engineering Professors Symposium, Ann Arbor, Michigan.

Olsen, R., Kavanaugh, M. 1993. **Can Groundwater Restoration be Achieved?** Water Environment & Technology, 5 (3). March.

Rogers, Jean, Telaldi, D, Kavanaugh, M. 1993. **A Screening Protocol for Bioremediation of Contaminated Soil, Environmental Progress**, 12 (2), 146.

Amin, H., Ozbilgin, M., LeClaire, J., Kavanaugh, M., et al. 1991. **Ground Water Remediation; Risks and Alternatives,** Water Environment & Technology, 3 (8). August.

Kavanaugh, M.C., Sullivan, M., and Findley, P. 1991. **Importance of Water Reuse in Water Resource Planning; Water Quality and Economic Issues.** Proceedings, Symposium on Management Strategies for Surface Water Resources, Istanbul. November.

Kellums, B., Gulas, V., Rogers, J., and Kavanaugh, M. 1991. **A Screening Protocol for Bioremediation of Contaminated Soil.** Presented at AIChE Meeting, Los Angeles, CA. November.

Melton, L.Y., and Kavanaugh, M.C. 1989. **An Innovative Air Stripping System for Removal of Volatiles from Groundwater at a Municipal Landfill Proposed Superfund Site.** Paper presented at Hazmacon, San Jose, CA. April.

Appleton, A.R., Kavanaugh, M.C., Tekippe, R.J., Westendorf. 1988. **Operation and Performance of Granular Activated Carbon Adsorption at the City of Niagara Falls Wastewater Treatment Plant.** Presented at WPCF Conference, Dallas. October.

Bouwer, E., Mercer, J., Kavanaugh, M., DiGiano, F. 1988. **Coping with Groundwater Contamination,** J. WPCF. September.

Gleason, P.J., Kavanaugh, M.C., et al. 1988. **Remediation Cost Reduction through Risk Assessment and Development of Alternative Cleanup Levels.** Paper presented at Ninth Annual Conference, Superfund '88, Washington, D.C. November.

Ozbilgin, M.M., Bond, L.D., Gleason, P.J., Kavanaugh, M.C., Bartel, T.J. 1988. **Applications of Solute Transport Modeling for Evaluation of Remediation Alternatives and Setting of Groundwater Cleanup Levels.** Paper presented at Ninth Annual Conference, Superfund '88, Washington, D.C. November.

Appleton, A.R. and Kavanaugh, M. 1984. **Treatment Alternatives for Groundwater Contamination, Proceedings,** 16th Mid-Atlantic Industrial Waste Conference.

Ball, W., Jones, M., and Kavanaugh, M. 1984. **Mass Transfer of Volatile Organic Compounds in Packed Tower Aeration,** J. WPCF, 56, 127.

Kavanaugh, M., et al. 1981. **The Potomac Estuary Experimental Water Treatment Plant: A Case Study of Treating Heavily Polluted Source.** Proceedings of Second AWWA Water Reuse Symposium.

Kavanaugh, M. and Trussell, R. 1981. **Air Stripping as a Treatment Process. Proceedings of Seminar on Organic Chemical Contaminants in Groundwater, Transport and Removal,** AWWA.

Kavanaugh, M.C. and Leckie, J.O., Eds. 1980. **Particulates in Water.** American Chemical Society, Advances in Chemistry Series, Vol. 189.

Kavanaugh, M., Tate, C., Trussell, A., Treweek, G. 1980. **Use of Particle Size Measurements for Water Treatment Plant Process Selection and Control, in Particulates in Water.** Edited by Kavanaugh, M., and Leckie, J., Advanced in Chemistry Series, 189.

Kavanaugh, M., Trussell, A., Cromer, J., and Trussell, R. 1980. **Empirical Kinetic Model of Trihalomethane Formation:** Applications to Meet the Proposed THM Standard, J. AWWA, 72, 578.

Kavanaugh, M., and Trussell, R. 1980. **Design of Aeration Towers to Strip Volatile Contaminants from Drinking Water,** J. AWWA, 72, 684.

Kavanaugh, M. 1978. **Modified Coagulation for Improved Removal of Trihalomethane Precursors,** J. AWWA, 70, 613.

Kavanaugh, M., et al. 1978. **Phosphorus Removal by Post-Precipitation with Iron** (III), J, WPCF, 50 (2), 216.

Kavanaugh, M., Toregas, G., Chung, M., and Pearson, E.A. 1978. P**articulates and Trace Pollutant Removal by Depth Filtration.** Progress in Water Technology, 10, (5/6), 197-215.

Kavanaugh, M., Eugster, J., Weber, T., Boller, J. 1977. **Contact Filtration for Phosphorus Removal,** J. WPCF, 49, (10), 2157.

Neven Kresic

Dr. Kresic has over 20 years of groundwater and surface water-related consulting, research and teaching experience. He is a professional hydrogeologist working with U.S. and international clients including federal, state and local agencies, and industries such as water, transportation and power utilities; and oil, petrochemical, chemical, construction, and mining companies. Dr. Kresic, a Fulbright Scholar, has extensive experience on major projects in the United States, Eastern Europe, the Middle East and North Africa. His areas of expertise include groundwater modeling, groundwater engineering, development and remediation, karst hydrogeology, water resources planning and mapping using GIS and remote sensing applications, and expert witness testimony. Dr. Kresic is the author of more than 50 papers, three books (including his latest Quantitative Solutions in Hydrogeology and Groundwater Modeling) and one monograph. Dr. Kresic was a professor at Belgrade University, Yugoslavia and Texas Christian University, Fort Worth, Texas where he taught courses in Hydrogeology, Hydrology, Groundwater Modeling, Groundwater Development and Groundwater Remediation. He also taught courses in Advanced Quantitative Hydrogeology at Georgia State University and teaches short professional courses in GIS, Groundwater Modeling and Groundwater Remediation for the National Ground Water Association. Dr. Kresic is a founding member of the Ground Water Modeling Interest Group sponsored by the National Ground Water Association, and an active member of the Karst Commission of the International Association of Hydrogeologists. He was leading modeler for numerous flow, and fate and transport models for various clients, including expert reviews of groundwater models for regulatory and litigation purposes.

Title/Firm:

Associate
Red Oak Consulting

Years of Experience

25

Education

BS Hydrogeologic Engineering University of Belgrade 1981
MS Hydrogeology University of Belgrade 1984
PhD Geology/Hydrogeology University of Belgrade 1987

Licenses and Certifications

Professional Geologist
Certified Ground Water Professional

Special Recognition

Fulbright Scholar

Societies

American Institute of Hydrology, Member
International Association of Hydrogeologists, Member, Karst Commission
National Ground Water Association, Member

Employment History

Malcolm Pirnie, Inc. 2001 to present
GeoSyntec Consultants 2000 to 2001
Law Engineering 1996 to 2000
Texas Christian University 1993 to 1996
Ebasco Environmental (Foster-Wheeler) 1992 to 1993
USGS National Center and George Washington University 1991 to 1992
Center of Urban Planning and Development, Belgrade 1988 to 1992
Energoprojekt Holding Corporation, Belgrade 1982 to 1991
Belgrade University 1982 to 1992

DETAILED EXPERIENCE

- **AFCEE, Bergstrom Air Force Base: Groundwater Modeling / Austin TX.** Groundwater modeling of fate and transport of chlorinated solvents, remedial investigation and remedial design.
- **ARCO and Multiple Clients: Expert Witness and Litigation Support / CA.** Expert witness and litigation support on potential impacts of MTBE releases on public water supply wells, Lake Tahoe, CA. Issues included groundwater characterization, fate and transport characterization, review of groundwater remediation systems and groundwater models.
- **Atlantic Steel Industries, Inc.: Brownfield Development / Atlanta GA.** Groundwater characteriza-

tion, remedial investigation and design of a groundwater extraction system for brownfield development.

- **Chemical Insecticide Corporation: Superfund Site / Edison NJ.** Groundwater modeling for design of a groundwater remediation system.
- **Confidential Client: Groundwater Withdrawal Permitting / GA.** Successful permit application for groundwater withdrawal for a Gas Powered Electric Power Plant in a sensitive, drought affected portion of Southwestern Georgia. Hydrogeologic characterization, quantitative assessment of withdrawal effects from various aquifers, and well design were key factors for the approval.
- **Confidential Clients: Spring Water Sources for Bottled Drinking Water (GA, CA, PA).** Hydrogeologic investigations and testing for bottled water operations.
- **Costa Serena Ocean Front Development: Environmental Investigation / San Juan PR.** Environmental impact statement; storm water infiltration and sea water and fresh groundwater interactions.
- **Cytec Corporation: Piney River Superfund Site / Piney River VA.** Enhanced remediation; groundwater characterization and modeling.
- **Douglas County: Cedar Mountain Road Landfill / Douglasville GA.** Groundwater Modeling in support of natural attenuation remedial alternative.
- **Energoprojekt: Engineering Studies / Various Foreign Countries.** Hydrogeologic and water resources engineering studies for strategic electric power, water supply and irrigation projects conducted by Energoprojekt, Belgrade.
- **Georgia Environmental Protection Division: Expert Reviewer of USGS Groundwater Models / Atlanta GA.** Project included evaluation and analysis of six regional and embedded models of coastal Georgia for all stages of individual model design and application, including changing model parameters and boundary conditions to perform sensitivity analysis and re-run the models for various groundwater management and salt water intrusion scenarios provided by EPD. The project goal was to help EPD understand the applicability, usefulness, and reliability of the models for groundwater resources management along the coast of Georgia, and included numerous technical meetings with EPD and USGS, and public meetings with stakeholders (industry, municipalities, environmental groups, citizens).
- **Inland Steel: Groundwater Characterization / East Chicago IN.** Evaluated extent of groundwater contamination with organic and inorganic chemicals, performed groundwater flow, and fate and transport analyses including modeling for remediation and construction dewatering purposes; designed GIS for the overall characterization and remediation program.
- **Kemira Pigments: HSRA Program / Savannah GA.** Characterization of soil, sediment, surface water and groundwater contamination with metals, SVOCs and VOCs; surface water and groundwater characterization in the Savannah river tidal basin, white paper on potential impacts of the contamination on shallow and deep aquifers, study of the subsurface brackish water-fresh water relationship.
- **Mattiace Petrochemical: Superfund Site / Glencove NY.** Aquifer characterization and remedial investigation.
- **Olin Chemicals: Groundwater Modeling and Characterization in Support of Monitored Natural Attenuation of Chlorinated Solvents / Kingsville OH.** The effort at this Superfund site (Big D Campground) resulted in one of the first applications of MNA approved by the US EPA, Region V and groundwater remedy change from the existing pump-and-treat system.
- **Olin Corporation: Saltville Superfund Site / Saltville VA.** For Waste Disposal Ponds 5 and 6, remedial design for groundwater interceptor system, and modeling of fate and transport of mercury in groundwater.

- **PFZ Properties: Environmental Impact Statement / San Juan PR.** Environmental impact statement; storm water infiltration and sea water-fresh groundwater interactions; Costa Serena ocean front development.
- **Pall Corporation: Surface Water-Groundwater Interactions; Fate and Transport Characterization / Ann Arbor MI.** Expert witness and consultant for Pall Corporation on issues related to 1,4-Dioxane contamination. Designed investigations, evaluated data, and performed numeric groundwater flow modeling and geochemical modeling to determine losing and gaining reaches of surface streams and potential impact of 1,4-Dioxane treatment effluent in the surface streams on groundwater resources. Evaluated site characterization results and in-situ innovative groundwater remediation technologies.
- **Puerto Rico Aqueduct and Sewer Authority (PRASA): North Coast Super Aqueduct Project / PR.** Karst aquifer characterization, analysis of aquifer recharge with storm water and water storage tanks emergency overflow, groundwater modeling and groundwater engineering design.
- **U.S. Army Corps of Engineers and Alamo Council of Governments: Groundwater Flow Model / TX.** Groundwater flow model for water resources planning in Atascosa, Frio, Karnes, and Wilson Counties, South Texas; consulting for the U.S. Army Corps of Engineers and Alamo Council of Governments, Texas. In addition to modeling, the activities included development of a GIS database, maps and layers for the groundwater flow model, and analysis of land cover / land use from satellite imagery.
- **US Army Corps of Engineers: Superfund Sites - Technical Oversight.** Saltville, VA Olin Chemicals site and Vineland, NJ; hydrogeologic characterization, groundwater modeling and remedial design.
- **USEPA, Region 2: Hudson River Dredging Project.** Removal of sediments contaminated with PCBs. Task leader for developing dredging residuals standard guidance document.
- **Various Industrial and Governmental Clients: Remedial Design, Groundwater Flow and Fate and Transport Modeling, Construction and Litigation Support/.** AFCEE, Olin, Cytec, EPA, Walt Disney Studios, Shell, Exxon, Mobil, Atlantic Steel Industries, Velsicol, Honeywell, etc. Groundwater characterization, remedial design implementation, lead groundwater modeling and expert model reviewer for various groundwater models and applications. Groundwater contaminants include chlorinated solvents, BTEX, MTBE, metals, inorganic chemicals and others; sites include numerous RCRA, Superfund, State Superfund (e.g., HSRA in GA) and other industrial and non-industrial facilities.
- **Vineland Chemical Company, Inc.: Superfund Site / Vineland NJ.** Groundwater modeling for design of an extraction system for remediation of groundwater contaminated with arsenic.
- **Walt Disney Studios: Groundwater Services / Los Angeles CA.** Groundwater analysis and modeling for construction dewatering for Walt Disney Studios at Los Angeles and Alameda Transportation Corridor.
- **Confidential Client: Yarnell Project / Peeples Valley AZ.** Assessment of water resources.
- **Groundwater Modeling / Teterboro NJ.** Groundwater modeling for design of a groundwater extraction treatment system.
- **RI/FS / Moundsville WV.** Groundwater modeling and characterization in support of RI/FS and remedial design.

PUBLICATIONS

Schladweiler, C.N., Alter, S.R., Kresic, N., Lang, D.C., **"Long-Term Monitoring Network Optimization,"** *Proceedings*, Conference of the Southern Arizona Environmental Management Society, Tucson AZ, July 28, 2004.

Schladweiler, C.N., Alter, S.R., Kresic, N., Lang, D.C., **"Optimization of a Long-Term Monitoring Program at an Arizona Superfund Site,"** *Proceedings*, Conference on Accelerating Site Closeout through Optimization, Dallas TX, June 15-17, 2004.

Deeb, R.A., Kresic, N., Laugier, M., Kavanaugh, M.C., **"Emerging Chemical Contaminants: Technical, Legal and Policy**

Challenges," presented at the Fall Meeting of the American Geophysical Union, San Francisco CA, December 6-10, 2002.

Kresic, N., Laugier, M., Deeb, R.A., Kavanaugh, M.C., **"Evaluating the Success of Groundwater and Soil Cleanup at Sites Impacted by Fuel Oxygenates,"** presented at the Annual Conference on Contaminated Soils, Sediments and Water, University of Massachusetts, Amherst MA, October 21-24, 2002.

Kresic, N., Booth, E., **"Environmental Aspects of Surface Water-Groundwater Interactions,"** presented for the National Ground Water Education Foundation Course sponsored by the National Ground Water Association (Westerville OH), Miami FL, January 20-21, 2000.

Kresic, N., Rumbaugh, J., **"GIS and Data Management for Ground Water Modeling,"** presented for the National Ground Water Education Foundation Course sponsored by the National Ground Water Association (Westerville OH), San Diego CA, June 26-28, 2000.

Kresic, N., Golubovic, R., Papic, P., **"Chapter V. Industrial and Urban Produced Impacts, Effects of Air Pollution,"** in *Karst Hydrogeology and Human Activities; International Contributions to Hydrogeology*, Vol. 20, D. Drew and H. Hoetzl, eds., 1999. International Association of Hydrogeologists: A.A. Balkema Publishers, Rotterdam, The Netherlands.

Kresic, N., Smith, M., **"Predicting Fate and Transport of Chlorinated Solvents in Groundwater,"** in *State Bar of Georgia, Environmental Law Section*, pp. 1-8, T.R. Silliman, Ed., 1999.

Kresic, N., **"Quantitative Solutions in Hydrogeology and Groundwater Modeling"** CRC/Lewis Publishers, New York, Boca Raton, 461 pp. (ISBN 1-56670-219-4), 1997.

Stephen C. Schwarz

Mr. Schwarz has been involved in the professional practice of engineering for more than 30 years. His experience has included all phases of project development, including planning, design, and construction. In addition, he has served as an expert witness in several cases involving technical and contractual issues involving solid waste projects.

Title/Firm:
Vice President
Red Oak Consulting

Years of Experience
37

Education
BCE Civil Engineering City College of New York 1967
MSE Sanitary Engineering Manhattan College 1968

Licenses and Certifications
Professional Engineer
Diplomate, American Academy of Environmental Engineers

Societies
American Academy of Environmental Engineers
Fellow, American Society of Civil Engineers
Solid Waste Association of North America

Employment History
Malcolm Pirnie, Inc. 1968 to present

DETAILED EXPERIENCE

- **ACT Consultants Co., Ltd.: Nakhon Si Thammarat Landfill / Nakhon Si Thammarat NY Thailand.** Siting and preliminary design for a lined sanitary landfill for municipal, commercial, and industrial solid waste.
- **Broward County Office of Resource Recovery: Solid Waste Management Program / Broward County FL.** Responsible for the initial planning and development of a countywide solid waste management program, including two waste-to-energy facilities totaling 4,500 tpd in capacity. Both facilities have been in operation since 1991. This program is believed to be the largest of its kind ever undertaken in North America, with a total cost exceeding $700 million, and in 1991 was the recipient of the Grand Conceptor Award from the Florida Chapter of the ACEC.
- **Chadbourne & Parke, LLP: BCH Facility Assessment and Litigation Support / Rocky Mount NC.** Served as an expert witness in litigation concerning the failed BCH facility in Rocky Mount. Key issues in this $100 million plus lawsuit included the performance of various processing and handling systems, the expected standards of performance in the solid waste industry, interpretations of various contractual requirements, and the responsibilities of the contractor under a design/ build contract approach.
- **Chung-Hsin Electric Machinery Manufacturing Corporation (CHEM): Hsin-Chu and Pali Waste Incineration Projects / Hsin-Chu and Pali NY.** As Project Officer, responsible for the design and construction of two waste incineration and electric power generation plants located in the northern portion of Taiwan. Nominal capacities are 900 tonnes per day for Hsin-Chu and 1,350 tonnes per day for Pali. Activities included review of the contractor project pricing, negotiations of the schedule of deliverables, overall project planning, and O&M training assistance.
- **City of Bangkok: Solid Waste Master Plan / Bangkok Thailand.** Responsible for the development of a Solid Waste Master Plan for a metropolitan area with a population of 6,500,000, including collection, recycling, and disposal. This program included the development of a 1,000-tpd MSW composting facility and two new landfills (350 and 150 acres). A major goal of the program was the replacement of scavenging operations at the face of the landfill with an enclosed recycling facility.
- **City of Charlotte: Privatization of Solid Waste Collection / NC.** Assisted the City in its first solid waste collection privatization effort. One third of the City's routes were privatized in the effort at substantial cost savings.

- **City of Coconut Creek: Water and Wastewater Master Plan / Coconut Creek FL.** Principal-in-Charge for the ongoing development of a water and wastewater master plan.
- **Confidential Client: Emergency Planning Services / FL.** Principal-in-Charge responsible for the development of an Emergency Response Plan in accordance with the Bioterrorism Act of 2002 and U.S. EPA Guidance. Responsibilities included reviewing Water System Vulnerability Assessment report, Emergency Action Plan, Emergency Response Plan, Risk Management Plan, Hurricane Preparedness Plans, and other related plans; conducting workshops; developing draft emergency response information; and preparing Emergency Response Plan.
- **City of Miramar: Funding Review / Miramar FL.** Principal-in-Charge responsible for assessing the city's monetary needs, evaluating various funding vehicles, and providing recommendations.
- **City of New Haven Water Pollution Control Authority: Contract Operations Monitoring / New Haven CT.** Directed oversight of transition to contract operation services for a 15-year operations and maintenance agreement. Reviewed all submittals required by contract, conducted physical assessment of plant and pumping stations, reviewed monthly operating logs, and evaluated operating data to determine compliance with contract documents.
- **City of New Haven: Middletown Avenue Landfill / New Haven CT.** Directed all aspects of permitting, design and construction phases for the closure of the Middletown Avenue Landfill. The unique design solutions to minimize the closure costs of the site included regrading areas at the site exceeding a 2H:1V slope, and 2.5H:1V slope for the maturity of the site. Interactive discussion and meetings with the state regulatory agencies resulted in expediting the project and ensuring compliance with consent order deadlines.
- **City of North Miami Beach: Implementation of a Capital Improvement Program / North Miami Beach FL.** Principal-in-Charge for ongoing efforts in support of the city's five-year capital improvement program, which includes a new membrane softening treatment plant.
- **City of North Miami Beach: Improvements at the Norwood Water Treatment Plant / North Miami Beach FL.** Principal-in-Charge responsible for review and analysis of color data from both the Norwood and Miami Dade Water and Sewer Department water treatment plants. Also responsible for development of numerous recommendations to improve the current finished water color.
- **City of Norwalk: Wastewater Privatization Services / Norwalk CT.** Principal-in-Charge for assisting the city's finance department with procurement of a contract operator for its 16-mgd wastewater treatment facility. The city's objectives were to:
  - Retain a qualified private firm to operate the wastewater treatment plant and collection system.
  - Provide the city and the customers of the system with cost-effective and reliable operation and management services at stabilized rates and charges for a 20-year term.
  - Preserve the city's capital investment at the facility, including the significant capital upgrades currently under construction.
  - Require that the selected private company successfully negotiate with the existing union(s) and provide employment and career development opportunities to all current and fully employed personnel.
  - Meet all regulatory requirements on an ongoing basis.
- **City of Pompano Beach: Grant Preparation / Pompano Beach FL.** Principal-in-Charge responsible for overseeing the preparation of one South Florida Water Management District (SFWMD) grant application for alternative sources of water. The installation of reclaimed water mains in residential areas would decrease potable water utilization. The application resulted in the city being awarded $300,000.
- **City of Richmond: Privatization of Solid Waste Disposal / Richmond VA.** Assisted the City in RFP

preparation and bid evaluation for transfer station rehabilitation and operations, and solid waste disposal.

- **City of Springfield: Privatization of Wastewater Facilities / Springfield MA.** Assisted the commission in an "Organizational Evaluation and Assessment" in an effort to improve organization efficiency and reduce costs at the Springfield Wastewater Treatment Plant. Currently assisting in an RFP process to solicit bids to privatize facility operations. These bids will be compared with the optimized employer operations and a final decision made on privatization.
- **City of Tampa: McKay Bay Resource Recovery Facility Retrofit/Reconstruction Project / Tampa FL.** As project officer, oversees development of procurement documents; directs process, including selection of qualified vendors, conducting vendor meetings, and serving as technical resource.
- **Coastal Regional Solid Waste Management Authority: Regional Landfill / Palmico County NC.** Responsible for the planning, financing, design, and construction of various solid waste projects, including a 20-acre regional Subtitle D landfill with composite liners, leachate collection, leachate recirculation, and a transfer station system to serve the three-county partnership. Those systems are fully permitted and in operation.
- **Confidential Clients: Water System Vulnerability Assessments.** Principal-in-Charge responsible for overseeing the development of several water system vulnerability assessments that met U.S. EPA requirements. Duties included review and documentation of available information; performing facility prioritization, threat assessment, fault tree analysis, consequence assessment, risk reduction, and mitigation workshops; site characterization; security system effectiveness; and risk analysis and development of a vulnerability assessment report, which included recommendations and costs.
- **Connecticut Resources Recovery Authority: Various Projects / CT.** Project Officer responsible for coordination and management of over a dozen project assignments from the CRRA, including construction oversight of solid waste site closure projects at the Ellington and Hartford landfills.
- **Escambia County Utilities Authority: Management Audit / Pensacola FL.** Serving as Principal-in-Charge for performing a management audit to assess the operational and functional strengths and weaknesses of the Escambia County Utilities Authority. The study is evaluating staffing levels, work processes, and organizational structure. Work elements included outlining business objectives, assessing departmental needs, conducting a functional analysis of the organization, and making recommendations for focused change. This assessment will lay the foundation for continuous, sustainable improvement.
- **Fairfax County Division of Solid Waste Disposal: Technical Support and Assistance for Resource Recovery Facility / Fairfax County VA.** As project officer, provides overall technical oversight of operations monitoring and system revenue review reporting.
- **Florida Governmental Utility Authority: Water Transmission Pipeline / FL.** Principal-in-Charge responsible for overseeing the design of a 24-in-diam reclaimed-water transmission pipeline measuring approximately 53,000 lin ft in length including trenchless technology crossings of roadways and railroad. Other services included design and permitting of 4 miles of 10-in-, 12-in- and 16-in-diam potable water transmission main in Poinciana along Marigold Parkway and Poinciana Parkway, and design and permitting of 4 miles of 16-in-diam water transmission main to serve as an interconnect pipeline between Poinciana WTP No. 6 and WTP No. 1.
- **India Ministry of Environment & Forests: Hazardous Waste Facility Siting and Design / India.** Providing assistance to Engineers India Limited, New Delhi, in support of their efforts to identify sites for

the development of centralized hazardous waste treatment and disposal facilities for the government of India. Services include evaluation of treatment technology, site selection, project planning, and scheduling. The project is funded by the World Bank.

- **Lee County Department of Utilities: Resource Recovery Project / Lee County FL.** As project officer, overall responsibility for Malcolm Pirnie's final permitting, construction monitoring, and administrative services performed for the County's 1,200-tpd resource recovery project. Provided expert assistance during Florida Power Plant Site Certification Review Process.
- **Lee County: Engineer-of-Record / Ft. Myers FL.** Principal-in-Charge for Engineer-of-Record services for Lee County's water and wastewater systems. Work includes conducting annual inspections of the facilities to evaluate the current practices and performance of the contract operator, reviewing operations for conformance with regulations, reviewing insurance coverage, evaluating rates and charges for compliance with bond covenants, and preparing a comprehensive annual report.
- **Maharashtra Industrial Development Corp.: Kurkumbh Industrial Estate / Maharashtra India.** Privatization of waste management facilities for a 483-hectare industrial estate near Pune, India. Approximately 109 industries are planned for the estate, including chemical, pharmaceutical, and paper. Both solid and liquid waste will be handled.
- **Miami-Dade County Water and Sewer Department: Bond Consulting Engineer / Miami FL.** Served as Principal-in-Charge for the development of the Miami-Dade Water and Sewer Department's annual report for fiscal years 2001, 2002, and 2003, and the engineer's feasibility report for the Series 2003 Bonds. In the capacity of Bond Consulting Engineer, Malcolm Pirnie's review has included the following:
  - Characterization of major water and wastewater utilities system assets through site inspections, review of information furnished by department, and staff interviews.
  - Review and approval of the Capital Improvement Program.
  - Identification of noteworthy accomplishments of previous year and future challenges in the areas of water and wastewater systems.
  - An overview of the WASD's organization and management.
  - Review and documentation of status of trends/agreements associated with service and sales to retail and wholesale customers.
- **Miami-Dade County: Financial and Operating Issues/Action Plan / Miami FL.** Principal-in-Charge for development of an action plan to establish realistic and sustainable performance measures in support of the county's gain-sharing program. Convened a workshop and a series of breakout sessions with key staff (Assistant Director Group) and other county stakeholders. The goal of building agreement on suitable performance measures for each Assistant Director Group within the department was achieved. Through this process the following was accomplished:
  - Identified and clarified important performance milestones and issues impacting the department's business and its ability to achieve its mission.
  - Evaluated and established the relationships among the issues of concern and constraining factors with the objective of prioritizing their relative significance.
  - Characterized performance measures that are appropriate for the department and each Assistant Director Group.
  - Identified opportunities to improve alignment with the departments' mission.
- The findings of this assignment comprise the Action Plan. Malcolm Pirnie will continue to provide strategic assistance throughout the implementation of the Action Plan.
- **New York City Department of Sanitation: Progressive Closure of Fresh Kills Landfill / Staten Island NY.** Project Officer for the closure and restoration of a 2,430-acre landfill that is the largest in the U.S. The

work includes redesign of the landfill cap, gas and storm water management, and planning for end-use activities which may include passive and active recreation facilities.

- **R-II Builders, Inc.: Green Island Off-Shore Disposal Facility / Manila PH.** Responsible for the conception and planning of a 500-hectare dredge fill island to be constructed in Manila Bay. The island is to be home to a lined sanitary landfill which will receive all the solid waste generated in the Metro Manila area.
- **R-II Builders, Inc.: Smokey Mountain Landfill / Manila NY Philippine.** Project Officer for the closure and redevelopment of a 30-hectare former burning dump in downtown Manila.
- **R-II Builders, Inc.: Smokey Mountain Redevelopment / Manila NY Philippine.** Technical advisor for the engineering, economic, and environmental integrity of the conceptual engineering plans for excavation of an urban landfill for redevelopment as high-rise housing.
- **St. Johns River Water Management District: GIS Data Mapping and Data Management / Palatka FL.** Malcolm Pirnie is subconsultant to provide engineering and GIS data mapping and data management support to Robert Reiss, PE of Reiss Environmental Inc., for a Concentrate management planning study for the St. Johns River Water Management District. This report has become necessary as the District seeks ways to identify alternative water sources to relieve the demands on the groundwater supplies within the District. In the SJRWMD's 2020 plan for water supply there is predicted shortfall in continued reliance on groundwater supplies and the District is encouraging utilities to develop surface water and brackish ground waters as alternatives to the Floridian aquifer supply. These alternatives are likely more highly mineralized and will require membrane treatment systems such as reverse osmosis or nanofiltration.
- The District is seeking alternatives to disposal of concentrate and areas of the district where the alternatives are feasible and exclusionary zones where they are not. The purpose of the report will be to assist utilities in their planning and evaluation of the membrane processes for water supply by providing information about the feasibility of handling concentrate disposal in their area.
- **Tompkins County: Solid Waste and Recycling Center / Tompkins County NY.** Directed the development of a 350-tpd recycling and solid waste center. The facility combines a transfer station and a materials recovery facility into a single operation. This facility is one of the first municipally sponsored projects where extraction of recyclables from the mixed waste stream is accomplished. Also directed the closure of a 32-acre landfill pursuant to the New York State 6 NYCRR Park 360 requirements.
- **Town of Islip: Blydenburgh Road Landfill Expansion / Islip NY.** Responsible for design and construction of a vertical "piggy-back" expansion of the 23-ac landfill for interim refuse disposal, and a short-term ash disposal monofill. The project received awards for engineering excellence from the New York Association of Consulting Engineers and the American Academy of Environmental Engineers.
- **Town of Jupiter: Operational Productivity Study / Jupiter FL.** Principal-in-Charge for conducting an operational productivity study for the Town of Jupiter's Utility Department. The study, which consists of staff interviews, desktop benchmarking, and operations and maintenance review, will focus on identifying how to enhance the department's performance effectiveness and efficiency.
- **Town of Southampton: North Sea Landfill / Southampton NY.** Directed the permitting, design, and construction monitoring of a new landfill (Cell No. 3) and the closure of two landfills (Cell Nos. 1 and 2). The new landfill is the only remaining permitted landfill on Long Island for mixed solid waste. Because Long Island depends on a single, sole-source aquifer for virtually all its drinking water, successful

permitting of the new landfill was a significant accomplishment.

- **U.S. Army Corps of Engineers, Fort Worth District: Air Force Materiel Command Privatization Services / Nationwide UT.** Project Officer to five utility and housing privatization projects for AFMC (Los Angeles, Brooks, Tinker, Wright Patterson, and Hill AFB). Managing the first prototype within the DOD where creative sale of Air Force real estate will be used to supplement MILCON budgets to meeting base modernization plans at LAAFB. Each of these projects includes multiple environmental and privatization consulting services.
- **University of North Carolina at Chapel Hill: Landfill Gas Demonstration Project / Bangkok NY Thailand.** The Group 79 landfill is one of two landfills serving the metropolitan Bangkok area. It is located adjacent to Kasetsart University. The University wished to develop a project to extract methane gas from the landfill and use it to generate electric power. We assisted by performing a feasibility analysis, developing the overall concept, and devising and implementing a field program to determine the amount and composition of the landfill gas available.
- **Westchester County: Solid Waste Management System / Westchester County NY.** Planning and development of a countywide solid waste management system. The centerpiece of this program, the 2,250-ton per day (tpd) Peekskill refuse-to-power facility went into operation in 1984, and was at that time the largest such facility in the U.S. A second major component, the Sprout Brook residue disposal facility (the first lined leachate collection residue landfill in the U.S.), went into operation in 1985. The system also includes transfer stations and a materials recovery facility (MRF), designed by Malcolm Pirnie, to process and beneficiate 350 tpd of source-separated materials.
- **York County Solid Waste Authority: Refuse-to-Energy Facility / York County PA.** Directed the planning, development, and construction of a 1,350-tpd refuse-to-energy facility. This facility began commercial operation in 1990 and was, at the time, the largest O'Connor Rotary Combustor type facility in the world. In 1992, this program was awarded the Consulting Engineers Council of Pennsylvania 1992 Honor Award for Engineering Excellence in Consulting Services, Research and Studies. Work for this client also included closure and capping of two cells of the Hopewell Township Landfill, preparation of a permit application to PADER and, after regulatory approval, directed the detailed design and construction observation of the 23-acre capping project. Also directed the preparation of the construction certification report for submission to PADER.

PUBLICATIONS

Schwarz, S.C., Dietch, D.E., **"Lessons Learned from a Failed Design-Build Project,"** *MSW Management*, November/December 2003.

Anderson, R.B., Schwarz, S.C., Dietch, D.E., **"Gasification in Collier County, Florida,"** *Proceedings*, Annual Conference of the Solid Waste Association of North America (WASTECON 2003), St. Louis MO, October 14-16, 2003.

Schwarz, S. C., Dietch, D. E., **"Collier County, Florida - Consideration of Gasification as a Long-Term Waste Management Solution,"** *Proceedings*, North American Waste-to-Energy Conference, Tampa FL, April 21-30, 2003.

Schwarz, S.C., Richter, L.K., **"Brightstar Solid Waste and Energy Recycling Facility: An Innovative Waste to Energy Technology,"** *Proceedings*, 10th North American Waste to Energy Conference (NAWTEC 10), American Society of Mechanical Engineers, Philadelphia PA, May 6-8, 2002.

Schwarz, S. C., Dietch, D. E., **"BCH Energy -- Lessons Learned from A Failed Design/Build Project,"** presented at the 4th Annual Planning and Management Symposium of the Solid Waste Association of North America, August 2000.

Schwarz, S. C., **"Wastewater Privatization Experience Worldwide,"** presented at Wastewater '98, Bangkok, Thailand, October 1998.

Schwarz, S. C., **"Wastewater Privatization Experience Worldwide,"** presented at the 'Wastewater 98' Conference, Bangkok, Thailand, 1998.

Schwarz, S. C., Frillici, P. W., **"BACT, MACT, and the ACT: What's Going On?"** *Waste Age*, November 1991.

Schwarz, S. C., **"A Discussion of Technical Options for Managing Solid Waste in New York,"** presented at the Fundamen-

tals of New York Environmental Law Compliance Course, Albany NY, March 1991.

Schwarz, S. C., **"Incineration: A Burning Issue,"** presented at the 27th Annual Public Affairs Symposium at Dickinson College, February 1990.

Schwarz, S. C., Bhatt, H. G., Hess, S. K., Clayton, J. K., Starobin, N. I., **"Recycling: The State of the Art,"** *Recycling Today*, July/August, October 1988.

Kapner, M. M., Schwarz, S. C., **"A Guide to Air Pollution Control Equipment,"** *Waste Alternatives*, September 1988.

Schwarz, S. C., **"Recycling: State of the Art,"** *Recycling Today,* May 1988.

Schwarz, S. C., Shelstad, M. J., **"Waste Disposal Issues Surveyed,"** *American City & County*, pp. 42-48, February 1987.

Macy, M. S., Schwarz, S. C., **"Solid Waste Management: A Focus on Resource Recovery,"** presented at the Winter Conference of the Ohio County Commissioners & Engineers, November 1985.

Schwarz, S. C., **"Fast-Track Resource Recovery Procurement - Bergen County, New Jersey - A Case History,"** presented at the 7th National Conference on Waste Management, Canada, November 1985.

Miller, J. P., Mills, R. J., Schwarz, S. C., Krishnaswami, S. K., **"Resource Recovery Applications to Solid Waste Management in India,"** presented at Envirotech '84 Exhibition and Conference, Bombay, India, February 1984.

Schwarz, S. C., "*Recovery of Energy from Solid Waste*," Noyes Data Corporation, 1983.

Schwarz, S. C., Bolton, R. E., **"An Analysis of Resource Recovery Facility Costs,"** presented at the National Conference on Environmental Engineering of the American Society of Civil Engineers, Minneapolis MN, July.

Schwarz, S. C., **"Resource Recovery and Solid Waste Management,"** presented at the Solid Waste Seminar, University of Alabama, March 1981.

Alexandra P. (Sandy) Wright

Ms. Wright, a hydrogeologist, has extensive experience as a vice president/officer/operations manager for both small and multinational environmental and engineering consulting firms. She has directed multimillion-dollar contracts for federal and private-sector clients throughout the United States and overseas. In performing this work, she has directed staffs of up to 150 scientists, engineers, and support personnel on a broad range of environmental and engineering projects. Areas of special expertise include hazardous and solid waste management; landfill planning, assessment, monitoring and remediation; groundwater and soils contamination assessments and remediation; groundwater and surface water resource management; siting and permitting; environmental compliance; water quality; and expert witness testimony. Major clients have included the federal government (EPA, DOE, DOD, BLM, OSM, BoR, U.S. Forest Service, U.S. Postal Service), state and local governments, and numerous industrial/private-sector clients including many Fortune 500 companies. Ms. Wright has directed RCRA and Superfund programs involving more than 300 sites in 32 states and successfully negotiated the scope of major cleanup programs with EPA, states, and other regulatory entities. She has also managed major water supply projects and EISs. Ms.Wright has published several dozen technical articles for various scientific journals. She was awarded an honorarium by the U.S. Congressional Research Service for her expert testimony regarding costs of cleanup as part of Superfund legislation and funding. She has also testified as an expert witness before Federal District Court, the Securities and Exchange Commission, and other entities.

Title/Firm:
Senior Project Scientist
Red Oak Consulting

Years of Experience
37

Education
BA Geology University of South Florida 1967
MA Geology University of South Florida 1972

Special Recognition
Honorarium from U.S. Congressional Research Service, Washington, DC, for expert testimony regarding costs of groundwater cleanup as part of Superfund Legislation and funding
Who's Who: American Women Scientists
Certificate of Appreciation: Plant Engineering and Maintenance Conference, Boston, MA
Transportation Scientists & Engineers Symposium, NY: Panel Chair
Women's Forum at the National Association of Hazardous Waste Management Annual Meeting, Washington, DC: Panel Chair
RCRA Compliance for Industry, Executive Enterprises: Training Program Chair
National Speaker: numerous public hearings, professional conferences and symposia

Employment History
Malcolm Pirnie, Inc. 2004 to present
Wright Consultants International, Inc. 1997 to 2004
ICF Kaiser Engineers 1995 to 1997
Wright Consultants, Inc. 1990 to 1995
ICF Kaiser Engineers 1988 to 1990
Jacobs Engineering Group, Inc. 1983 to 1988
Fred C. Hart Associates, Inc. 1974 to 1983
Woodward Clyde Consultants 1972 to 1974
Florida Bureau of Geology 1970 to 1972
U.S. Geological Survey 1968 to 1970

DETAILED EXPERIENCE

- **U.S. Department of Energy: Environmental Restoration/ Los Alamos National Laboratory NM.** Managed and executed $50M multi-task Environmental Restoration (ER) Program. Also responsible for multi-task AE Services contract, Audits and Assessments contract, NEPA Support contract, and Health and Safety/Risk Assessment contract for LANL.

  For the ER Program, conducted hydrogeologic investigations, Voluntary Cleanup Actions, Expedited Cleanups; prepared and reviewed Standard Operating Procedures, Sampling and Analysis Plans, RFI reports, RCRA closure plans; directed database management, pilot projects, and development and implementation of innovative testing and remedial technologies (e.g., laser induced breakdown spec-

troscopy [LIBS], segregated gate soil sorting system); oversaw geophysical surveys, waste management and remedial operations, drilling and installation of boreholes and monitoring wells; performed QA/QC, cost and schedule control. Received six letters of commendation from the client.

Sites addressed for groundwater, surface water, soils, and waste investigations included borrow pits, drum storage areas, landfill and surface disposal areas, septic system outfall, firing sites, waste container storage areas, septic tanks, a lagoon site, and a massive debris ball. Contaminants included VOCs, metals, PAHs, PCBs, low-level radiation, HE by-products, asbestos, etc. Received six letters of commendation from client.

- **Solid Waste Authority of Puerto Rico.** Conducted detailed technical review of 30 Landfill Design Reports for Puerto Rico's existing Municipal Solid Waste Landfill system to assess environmental and capacity issues.

  Work considered all aspects of the landfill system including landfill siting and design, O&M, closure and post-closure. Local hydrogeology, monitoring systems, leachate collection, and environmental controls were of particular importance. Also prepared a White Paper to address the issues inherent to landfills sited in areas of karst topography.

- **U.S. Bureau of Land Management: Preliminary Assessments & Site Investigations, Landfill Sites / Western States & Alaska.** Served as Program Manager for this year-long field evaluation of 26 Subtitle D landfills on BLM-owned lands in the western states and Alaska. Work involved field assessments including sampling and analysis at selected sites, and preparation of PA reports on all sites, and SI reports on selected sites, with recommendations for continued operation, closure or post-closure care.

- **UTC Corporation: Groundwater Investigations and Remediation / San Jose CA.** In an area of complex hydrogeologic conditions, conducted groundwater investigations and remedial planning and design for an aerospace facility covering many square miles. Work entailed hydrogeologic mapping, location, design, and supervision of the construction of shallow (alluvial aquifer) and deep monitoring wells, selection of water quality monitoring parameters, and interpretation of water quality data. This three-year effort focused on delineating the extent of soil and groundwater contamination by organics, metals, and other chemicals; and designing remedies for dozens of separate cleanup areas. Work was conducted in accordance with a detailed Consent Decree issued by the Regional Water Quality Authority, an EPA order, and State Regulatory Guidelines. Worked to streamline activities in order to avoid duplication of effort in the sometimes contradictory language of the various orders. Participated in negotiations with regulators on behalf of the client.

- **UTC Corporation: Hydrogeological Modeling, Extraction and Injection Well Design / San Jose CA.** Conducted modeling to design optimum placement of withdrawal and injection wells, optimum pumping rates, and treatment system design. Various durations were considered, along with associated capital and O&M costs. Conducted feasibility studies for both pump and treat systems and bioremediation.

- **Goodyear Tire & Rubber Company: Hydrogeological Studies and Groundwater Quality Mitigation / Phoenix AZ.** Designed deep monitoring wells for a complex aquifer system contaminated with jet fuels and other chemicals associated with the aeronautical industry. Based on pumping test data and water quality results, assisted in the modeling and design of a pump-and-treat system, and oversaw the drilling program for withdrawal and injection wells. Also participated extensively in negotiations with the state and EPA during the one-year course of the work. Prepared modeling and flow calculations considering dispersion, dilution, retardation, and other factors.

- **U.S. Environmental Protection Agency Headquarters: RCRA/CERCLA Studies Nationwide.** Under multiple successive contracts, performed a full range

of RCRA/CERCLA studies and related work nationwide.

- Performed evaluations of over 100 solid and hazardous waste landfills to determine compliance with RCRA Subtitles C and D. Review and oversight of RI/FSs, RCRA landfill closure and post-closure plans; technical review of RODs; direction of RFAs, RFIs, CMEs, human health and ecological risk assessments; remedial action planning and implementation; removal actions, community relations, and development and implementation of complex multimedia testing and monitoring programs (nationwide) on behalf of EPA.
- In conjunction with the assessment of groundwater contamination, designed and supervised the installation, sampling, and monitoring of innumerable boreholes, test wells, pumping wells, and monitoring wells throughout the U.S. This work was conducted in diverse hydrogeologic settings, including all rock groups, multiple aquifer systems, the vadose zone, and unconfined and confined aquifers.
- Designed and supervised tests and analyzed data from many aquifer pumping tests. Also designed, supervised the installation of, and analyzed the results of physical and chemical testing of innumerable monitoring well systems to examine interactions between water bearing units, and the transport and fate of a host of water quality contaminants.
- Managed RCRA/CERCLA Support programs for EPA's Regions V through X, entailing management of over 400 assignments (up to 42 simultaneously); supervision of a litigation team of four attorneys and attendant paralegal staff; extensive work with EPA regulators and the regulated community.
- Served as Project Manager for the preparation of EPA's RCRA Inspectors' Manual and provided training to both EPA and state personnel in methodology for field inspections of RCRA-regulated sites.
- Oversaw the management of the operation of the NEIC high-hazard laboratory, providing contractor-staffed analytical laboratory services, including RAS and SAS. In a subsequent contract, managed contractor-provided lab support at EPA's Denver Technical Center facility.
- Served as Project Manager for development of the Programmatic EIS for EPA's RCRA Subtitle D guidelines for landfill disposal of solid waste
- Managed the provision of program and policy support to EPA HQ in developing industrial effluent standards for 21 industrial categories and pretreatment standards for industries discharging to POTWs
- Directed groundwater-monitoring inspections of TSD facilities (including federal); preparation of training materials/programs; review of endangerment assessments; development of a focused feasibility study and trial exhibits; preparation for expert witness testimony; reviews, compliance monitoring, and comments on behalf of EPA.
- Managed the development and implementation of extensive hydrogeologic investigations involving the collection and analysis of 2,000 multimedia samples from 6 dioxin-contaminated horse arena sites in Missouri.

✦ **Confidential Chemical Manufacturing Client: Expedited Environmental Audits / Worldwide**

Conducted expedited environmental audits at 22 chemical manufacturing facilities nationwide and 10 facilities in Canada, Europe, Asia, Australia, and South America; identified hazardous waste management problems including Superfund liability, and performed assessments of the magnitude of the problems and potential remedial costs; facilities were the subject of an $800 million acquisition.

✦ **US Department of Energy: Facility Assessments / Western States & Missouri.** Served as senior scientist/hydrogeologist during major cleanup programs for DOE.

Design and direction of groundwater investigations at DOE's Uranium Mill Tailings Remedial Action (UMTRA) Program sites, and performance of senior review of various reports and documents produced under the UMTRA program

Coordination of remedial studies for DOE's Weldon Spring Site Remedial Action Project; design of

groundwater investigation programs; and provision of senior support on risk assessment, data validation, and applicable technologies for remedial action

- **Confidential Food Manufacturing Client: Environmental and Groundwater Supply Studies / American Samoa and Puerto Rico.** Managed groundwater investigations, water supply and water quality evaluations for a Fortune 100 food-processing corporation.

  Performed investigations of alternatives sources for water supply, water quality investigations, assessment of disposal areas for oily wastes, and other environmental investigations.

- **Public Service of Colorado: Environmental Audits and Assessments / Denver, Colorado** Served as Project Manager for environmental investigations of over 50 sites for a major utilities client in preparation for property transfers; design and implementation of cleanup measures to mitigate problems caused by hazardous waste, petroleum products, USTs, lead-based paint and asbestos; presentations to, and negotiations with, various regulatory entities.

- **Counsel to Confidential Paper Manufacturing Client: Evaluation of Hazardous Waste Problems / New York & Michigan.** Managed contamination evaluations for a law firm serving as counsel to a major manufacturing company during an unfriendly $300M takeover attempt; development of a case establishing undisclosed financial liabilities for hazardous waste problems attributable to the acquiring entity; provision of testimony before the Securities and Exchange Commission as an expert witness

- **Counsel to a Confidential Private Sector Client: Contaminated Groundwater Study / Baltimore, Maryland.** Served as Project Manager for technical evaluation of substantial damages due to a leaking UST and consequent contamination of a drinking water supply aquifer, conducted for a law firm during negotiations with a national oil company; negotiations were successfully concluded out of court.

- **Allegheny County: Hazardous Waste Contamination Study / Pittsburgh, Pennsylvania.** Served as Project Manager for a multimedia field study and endangerment assessment of a proposed park site in Pittsburgh where hazardous wastes had been discovered onsite during park development on property donated by a major industry; extensive groundwater studies and toxicological assessments were performed and expert testimony provided.

- **Macon County: Groundwater Availability and Reliability Studies / Macon County NC.** Performed groundwater supply and demand studies and construction of water balance in western North Carolina, and provided grant-writing assistance. Received follow-on contract to develop a watershed management plan for future water use in the county.

- **New York State Department of Transportation: Environmental Impact Statement / Rochester, New York.** Served as Project Manager for an EIS prepared in conjunction with the expansion of the New York State Interstate highway – outer loop in Rochester, New York.

- **PNM/EPE: Hydrogeological Study and Groundwater Evaluation / NM.** Performed a year-long statewide aquifer mapping and water supply evaluation for a New Mexico utility's site selection project. Conducted studies of hydraulic properties of all deep (fresh, brackish, and saline) aquifer systems and integrated information to assess capacity of these systems to yield sufficient sustained supply for power plant usage without impacting the quantity and quality of water in shallower aquifers or intermediate aquifer zones producing drinking water supplies.

- **Pinellas County: Groundwater Modeling for Water Supply Planning / Pinellas County FL.** Modeled optimum well locations, depths, and pumping scenarios for public water supply to avoid saltwater intrusion in Pinellas County.

- **City and County of Denver: Underground Storage Tank Management Program / Denver, Colorado.** Managed the groundwater and soils contamination assessments for the City of Denver's UST program
- **South Florida Regional Planning Council, National Estuary Program: Comprehensive Conservation Management Plan / Six Florida Counties.** Consolidated over 100 action plans for groundwater and surface water quality improvements including marine, estuarine, freshwater, upland, and wetland resource conservation in the six-county drainage basin of Charlotte Harbor, Florida.
- **North American Coal Corporation: Environmental Impact Statement / Beulah area, North Dakota** Served as manager of groundwater and surface water studies on an EIS for a coal mine and gasification complex
- **U.S. Bureau of Reclamation: Groundwater Injection / High Plains States.** Managed a major assignment for the High Plains States Groundwater Recharge Demonstration Program, implemented by the Bureau of Reclamation. Developed a QA program plan and data management plan with data quality objectives, and supervised the development and implementation of a training program for the Bureau of Reclamation staff and others.
- **U.S. Department of Energy: Evaluation of Regulatory Impacts on Water Supply / Nationwide.** Evaluated regulatory impacts on groundwater and surface water supply associated with energy development technologies nationwide. Conducted assessments of the Safe Drinking Water Act, Clean Water Act, and other legislation, including deep well injection (UIC) regulations as they impact the development of energy resources.
- **U.S. Environmental Protection Agency: Assessment of Hazardous Waste Impacts on Groundwater / Nationwide.** Managed first EPA-funded technical assessments of groundwater contamination at Love Canal, New York and Woburn, Massachusetts ("A Civil Action").
- **Various Clients: Multi-client Permitting Acquisition / Nationwide.** Prepared and negotiated terms for a variety of environmental permits issued by all levels of government (numerous private-sector clients nationwide).
- **Withlacoochee Regional Planning Council: Groundwater Supply and Quality Impact Evaluations / Ocala FL.** Served as an expert consultant in conducting Development of Regional Impact (DRI) reviews. Reviewed multivolume documents and provided comments addressing critical groundwater supply and water quality issues on three controversial DRIs.
- **Charlotte Harbor National Estuary Program (CHNEP): Compilation of Comprehensive Conservation Management and Development Plan (CCMP).** Program Manager under contract to the CHNEP/Southwest Florida Regional Planning Council directed a year-long program for action plan development, evaluation, and public comment. Consolidated over 100 action plans for groundwater and surface water quality improvements in marine, estuarine, freshwater, upland, and wetland environments for resource conservation in the six-county drainage basin of Charlotte Harbor, Florida.
- **Confidential Furniture Manufacturer: Hazardous Waste Investigation & Remediation / Michigan & Ohio.** Direction of compliance and remediation work conducted for a confidential client at hazardous waste disposal sites in Michigan and Iowa (metals and organics): screened remedial alternatives, developed and costed selected alternatives, and performed detailed feasibility assessments.

PUBLICATIONS

Wright, A.P., **"Water Resources Study of the Upper Cullasaja Watershed,"** *Second Publication of the Upper Cullasaja Watershed Association, Inc.*, Highlands NC, January 2003.

Wright, A.P., **"Preliminary Water Resource Inventory and Water Balance Study -- Upper Cullasaja River Watershed,"** *First Publication of the Upper Cullasaja Watershed Association, Inc.*, Highlands NC, March 2000.

Wright, A.P., **"Establishing a Small, Woman-Owned Business -- One Person's Experience,"** presented at the Annual Conference of the Hazardous Materials Control Research Institute, Washington DC, November 1995.

Wright, A.P., **"Limiting Financial Liability through the Environmental Audit Process,"** presented at the Summer National Meeting of the American Institute of Chemical Engineers, Denver CO, August 1988.

Wright, A.P., et al., **"The Tightening Regulations for Hazardous Waste Management: Mandates and Compliance Strategies -- a Case History,"** *Chemical Engineering Progress*, March 1985. American Institute of Chemical Engineers, New York NY.

Wright, A.P., et al., **"Site Risk Assessment Procedures,"** presented at the National Conference on Environmental Engineering, Minneapolis MN, July 1982.

Wright, A.P., **"Practical Problems in Complying with RCRA,"** delivered training course for industry sponsored by Executive Enterprises, Inc., March 1982.

Wright, A.P., **"National Hazardous Waste Problems and Implications to Industry,"** presented at the Plant Engineering and Maintenance Conference, East Boston MA, December 1979.

Wright, A.P., et al., **"National Survey of Hazardous Waste Problems and Associated Cleanup Costs,"** presented at the National Conference on Hazardous Material Risk Assessment, Disposal and Management, Miami FL, April 25-27, 1979.

Wright, A.P., et al., **"Legislative Initiatives for Stabilization/Solidification of Hazardous Waste,"** *Stabilization/Solidification Options for Hazardous Waste Disposal*, September 1978. Ann Arbor Science Publishers.

Wright, A.P., et al., **"The National Strategy for Pretreatment of Toxic Industrial Effluents: Issues and Implications,"** *Proceedings*, 33rd Annual Purdue Industrial Waste Conference, Purdue University, West Lafayette IN, May 1978.

Wright, A.P., et al., **"Status of the U.S. Environmental Protection Agency Program to Control Toxic Industrial Wastes,"** *Proceedings*, 32nd Annual Purdue Industrial Waste Conference, Purdue University, West Lafayette IN, May 1977.

Wright, A.P., **"Design of a System for Monitoring Hydrologic Effects of a Proposed Coal Surface Mine in Southwest North Dakota,"** presented at the Fall Meeting of the Society of Mining Engineers of AIME, Salt Lake City UT, September 1975. Preparing No. 75-F-339.