COSTS ASSOCIATED WITH A POTABLE WATER SYSTEM TO SUPPLY THE AFFECTED POPULATION OF THE CONCESSION AREA OF ECUADOR

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I prepared this report at the request of plaintiffs' counsel.

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1.0 Cost of Developing a Potable Water System

1.1 Introduction and Overview

This evaluation examines alternatives for the provision of potable water to residents within the Concession area where Texaco carried out oil exploration and production activities. Consistent with the noble goals specified by the World Health Organization (WHO) and UNICEF (WHO/UNICEF, 2010), the availability and consistent supply of a safe, potable water to all, including those within the Concession area, should be a priority.

1.2 Considering Contamination of Source Waters in the Concession Area

As shown in the Cabrera (2008) Expert Opinion Technical Summary Report and Appendices, Fugro-McClelland (1992), HBT Agra (1993), Woodward-Clyde (2000), and elsewhere in this report, Texaco oil exploration and production activities have adversely affected the quality of soil, sediment, groundwater, and surface water in the Concession area in terms of environmental degradation due to the release of total petroleum hydrocarbons, metals, and other substances associated with Texaco's activities. As a result, various water sources within the Concession area could be classified as compromised or unsuitable at present without significant remediation for use as a drinking water source due to unacceptable levels of anthropogenic hazards or toxins related to the aforementioned Texaco oil activities.

For example benzene, one harmful constituent of oil, is classified by the United States Environmental Protection Agency (US EPA) as a known carcinogen (USEPA-1). The US EPA has established a maximum contaminant level (MCL) for benzene in drinking water at 0.005 mg/L via the Safe Drinking Water Act (USEPA-2). Benzene also has a rather high water solubility and soil mobility for an organic compound (USEPA-2). Using average data sourced from the US EPA, 1 liter of discharged or spilled crude oil (2178 μg benzene/g oil: averaged from USEPA-3) would contaminate approximately 375,000 L of water with respect to benzene at the MCL level set by the US EPA (0.005 mg/L).

From materials available for review, it appears that environmental contamination has been most thoroughly characterized in areas closest to known sources such as production wells, storage pits, surface water outfalls, and documented spills. However, given the inherent mobility of contaminants, much less information appears to be available for review to characterize the movement of environmental contaminants away from known release locations. Although contaminants related to oil production activities are likely to move away from their release areas in groundwater, surface runoff, sediment, and surface water, the extent and concentrations of these substances more distant from source locations does not appear to be well-characterized. Furthermore, the potential for future migration of oil-production contaminants in the environment over time does not appear to be well understood or described in litigation-related documents available for review for either surface water or groundwater.

Due to all of the aforementioned justifications, utilization of any possible water source within the Concession area for drinking water applications would need to be extensively evaluated and sampled for all possible contaminants associated with oil drilling and production activities. Furthermore, even sources initially found to be free of contamination would still need to receive very frequent sampling, given the fact that contaminant mobility could eventually render a source unusable.

1.3 Characterization of Affected Population

1.3.1 Size and Location of Population

The Texaco oil Concession was located primarily in the Provinces of Sucumbrios and Orellana. This section considers areas within these provinces most likely to be affected by the Texaco oil exploration and production activities. The populations in the Concession area tend to live in the vicinity of the roads and highways within the provinces. There also are small communities near access roads leading to oil exploration and production facilities and along the main rivers.

1.3.1.1 Sucumbios

The four Cantons of Sucumbios primarily in the Concession area include Lago Agrio, Shushufindi, Cascales, and Cuyabeno. The estimated total population for this region in 2010 is 155,703, with urban and rural populations of 78,520 and 77,183, respectively. The projected total population for this region in 2030 using an average annual growth of approximately 2.4% is 250,205 (INEC 2004).

1.3.1.2 Orellana

The two Cantons of Orellana primarily in the Concession area include Orellana and La Joya de los Sachas. The estimated total population for this region in 2010 is 95,477, with urban and rural populations of 39,899 and 55,578, respectively. The projected total population for this region in 2030 using an average annual growth of approximately 2.4% is 153,425 (INEC 2004).

1.3.2 Existing Potable Water Supplies

Both surface water and groundwater resources have been used as sources of potable water in the Concession area. It is likely that collected rainwater also may be used as a potable water source by some individuals or households. An overall assessment of the water resources in this area is not readily available, although Cabrera (2008, Appendix R) surveyed the conditions regarding water supplies in this region based on literature and public resource reviews, as well as discussions with engineers responsible for drinking water systems in the area. No quantitative evaluation of the availability, quality, and sustainability of potable water within the Concession area was available for review. However, Cabrera (2008, Appendix R) provided a qualitative overview with representative examples of existing water sources.

Cabrera (2008, Appendix R) found that conditions in larger towns and communities varied greatly. Some communities had functional municipal water supplies, some had systems that were not operational, and others had no public water supply services. Conditions in the hundreds of smaller communities in the Concession area also varied, with many reportedly having no drinking water supply system or relying on hand dug groundwater or surface water supplied wells. Overall, some areas in the Concession area reportedly had operating water supply systems drawing on groundwater or surface water; whereas, some water supply systems were not operational and required repair or replacement. Plans for improving water systems existed in some, but not all, communities requiring repairs or upgrades.

In some cases, water supply engineers reported that they were investigating alternative water supply sources because of concerns over the safety of existing sources. Information regarding the reliability and safety of water from hand dug groundwater or surface water supplied wells was not available for review. Other sources are consistent with Cabrera's assessment that water service quality and sustainability is low in many areas of Ecuador (e.g., OAS 2005, WHO 2010a, b).

1.4 Source Water Options for a Potable Water System

As noted above, sources for potable water supplies in the Concession area include groundwater and surface water. However, current groundwater, surface water, and sediment contamination in the broad area potentially affected by Texaco oil exploration and production activities is not well characterized. Any sources tapped for use by the widely distributed population potentially affected by past and ongoing oil-related activities would require evaluation for safety as well as adequacy for public use.

Given the possibility of either direct contamination or the migration of contaminants into previously uncontaminated watersheds, the safety of any water source within the Concession area would need to be scrutinized via extensive sampling both initially and henceforth. Any water source within the Concession area found to be contaminated would therefore need immediate remediation prior to use or outright abandoned. Since significant resources would be necessary to remediate a contaminated source and/or conduct the necessary indefinite sampling and monitoring of any watershed within the Concession area, waters upstream and outside of the Concession zone found to be of acceptable quality are an alternative potable water source for the residents within the Concession area.

In addition, little is known about the potential fate and transport of environmental contamination in groundwater, in groundwater discharging to surface water, or in downstream transport in surface water. These factors also would require environmental and engineering analysis to assure that sources for potable water systems would remain safe and viable for future use by the communities that are served.

From an operation and maintenance perspective, potable water for individuals in the Concession area could potentially be designed, constructed, and funded on the regional, community, or local/individual level.

1.5 Summary of Potable Water System Options

1.5.1 Selective System Development, Upgrade, or Repair

As reported by Cabrera (2008, Appendix R) and supported by other assessments of potable water systems in Ecuador (e.g., OAS 2005, WHO 2010a, b), the availability of potable water in the Concession area is represented by a broad range of availability. Existing community water systems range from operational to requiring improvement or repair. In some cases, no community water systems are available. Water is supplied to some communities or individuals through the use of hand dug groundwater or surface water supplied wells.

Limited information was available for review concerning the extent of groundwater and surface water contamination in the Concession area. However, the available data reviewed elsewhere in this report suggest that the potential for contamination of these water sources does exist. Thus, it is unclear which existing water supplies may be affected by contaminants from the Concession area or which future sources and locations of water supplies may pose risks to human health.

There currently does not appear to be a comprehensive understanding of the condition of existing water supply systems within the Concession or the extent of improvement or repair that is needed to provide potable water to the existing population. The quality of water supplied to existing systems also is not well understood. Furthermore, there exists the potential that existing water sources could degrade over time due to migration of oil exploration and production contaminants. In addition, it may be difficult to address future water needs with uncontaminated water from within the Concession area.

Given the uncertainty regarding the current and future availability and safety of potable water within the Concession area, it appears that selective design, upgrade, or repair of water systems could provide sources of potable water in the short-term for selected population segments. However, it would not necessarily assure a continued and sustainable safe water supply for future use. Current use of contaminated water, degradation of water sources in existing systems, or tapping of contaminated water sources by smaller communities or individual households could result in health risks to some segments of the population. In any case, the implementation of this type of approach would require a comprehensive evaluation of existing water supply systems and ongoing monitoring of all water used as a potable supply in the Concession area to identify systems or individual households potentially at risk.

1.5.2 Broad, Comprehensive System Design and Implementation Summary

The broad, comprehensive system design outlined by Cabrera (2008, Appendix R) describes an approach to providing potable water for the residents of the Concession area that helps to avoid the uncertainty associated with use of groundwater or surface water from within the Concession area. It makes use of three regional water systems that would draw water from surface water upstream from the Concession area and known sources of contamination. This approach avoids the potential problem of current and future surface or groundwater contamination affecting the quality of potable water for the Concession area. It establishes an intrinsic framework for ensuring a safe water supply for most individuals in the area, now and in the future. It also will make available a water supply for individuals in the Concession area who do not currently have access to a safe water supply. This regional approach also will establish a physical and administrative infrastructure that could help ensure the sustainability of these water systems into the future in terms of system operation, maintenance, and funding.

The three regional systems described by Cabrera (2008, Appendix R) are as follows:

- Regional System 1 – supplies communities and areas north of the Aguarico River (Cascales, Lago Agrio).
- Regional System 2 – supplies communities bounded by the Aguarico River to the north, the Coca River to the west, and the Napo River to the south (Lago Agrio, Shushufindi, Sacha).
- Regional System 3 – supplies communities in the Canton of Orellana.

1.5.3 Broad, Comprehensive System Design and Implementation Review

The purpose of this section is to evaluate the proposed potable water system outlined by Cabrera (2008, Appendix R) from engineering and public health perspectives. To the extent that a system needs to be developed to provide potable water system to those living within the Concession area, then the design of that system will surely influence the subsequent costs projected in Cabrera (2008, Appendix R), and to the extent that the Cabrera proposed system (2008, Appendix R) either over or under designed the water system, then respective costs will be influenced respectively. The logical justification for supplying those within the Concession area with an uncontaminated source upstream and outside of the Concession area have been detailed previously and will not be revisited herein this section.

1.5.3.1 Costs Minimized through Economies of Scale

The overriding goal of all potable water public works projects is to supply all residents, customers, or inhabitants with safe potable water for ingestion and other usages. This would be best delivered, as proposed, via a number of universal water systems rather than supplying each residency with an in-home point-of-use treatment system. A universal system is typically the lowest cost method for delivering the same quality of potable water to all residents, since it employs efficiencies over larger economies of scale. Other factors can render at-home point-of-use treatment systems undesirable with respect to relying exclusively on these units to be the sole supplier of water treatment, including natural variation of these system with respect to the input source waters, variations in final water quality due to maintenance of these home units, variations in final water quality due to operator (resident) misusage, or other variances such as a resident opting to not use the treatment system. Therefore, in consideration, the proposed universal water system(s) provide the best opportunity for producing and delivering an equivalent quality of potable water to all residents or inhabitants within the Concession area at also the lowest unit cost.

1.5.3.2 Additional Treatment Processes Necessary

Cabrera (2008, Appendix R) proposed a water system utilizing surface waters upstream of the Concession area and upstream of pollution or contamination. The proposed treatment would be a special collection vessel in the surface water that reduces, followed by disinfection before supplying the residents or inhabitants within the Concession area. The following was stated by Cabrera (2008, Appendix R): "Horizontal collector wells or river bed filtering systems would reduce treatment costs because sediment removal would not be necessary, and chlorination is likely to be the only necessary treatment."

This proposed system would not pass drinking water standards in many developed countries including the United States. For example, while most pathogens are inactivated by conventional disinfectants, certain pathogens, namely the protozoa *giardia* and *cryptosporidium* have a very high resistance to conventional disinfectants. Both of these pathogenic protozoa can be common in surface waters, carried by a variety of host animals, and can lead to human death via dehydration (vomiting and diarrhea). These protozoa form protective oocytes that are highly resistant to inactivation from conventional chlorine (free chlorine), chloramines, or chlorine dioxide disinfectants.

There are three conventional practices employed by the water industry to inactivate the protozoa, *giardia* and *cryptosporidium*: physical separation through a sand media filter, ozone disinfection, and/or reverse osmosis membranes. Incorporating any of these treatment steps would be imperative to increase the likelihood that the potable water would be less likely to contain pathogens including *giardia* and *cryptosporidium*. In fact, in the United States, surface waters are required to be subjected to a sand media filter as specified in the Enhanced Surface Water Treatment Rule (EPA-4).

There is no indication of these factors being considered or included in the Cabrera (2008, Appendix R) proposal. Adopting any of these additional treatment steps would thereby increase the cost of treatment. Of the three proposed additional treatments for protozoa removal, the simplest, and most commonly employed, is a conventional gravitational flow sand media filter—although it should be noted that frequent operational maintenance (i.e. backwashing) is required to eliminating filter stoppage and to maintain water treatment. The relative operation costs, initial investment costs, and operational maintenance (i.e. costs) are much greater comparatively with a membrane or ozone treatment.

In summary, in order to improve the quality of supplied water to the residents and inhabitants within the Concession area, additional (conventional) treatment processes that more effectively remove or inactivate all pathogens including the protozoa *giardia* and *cryptosporidium* should be considered and included in the proposed potable water system. Introducing these treatments would certainly increase the original costs proposed by Cabrera (2008, Appendix R).

1.5.3.3 Disinfection Residuals, Loss, and Booster Stations

A disinfectant is applied to a potable water to inactivate pathogens. As the disinfectant reacts with various constituents, it will decay. To the extent that the disinfectant completely decays and is lost, there is the possibility for bacterial regrowth thereafter in the system, thereby potentially contaminating the water. Consistent with the goals of water treatment to provide a safe water source free of pathogens, a residual disinfectant is commonly maintained through the distribution pipeline as the water flows on route from a treatment plant/center to the final end use (i.e. customers or residents).

It is not apparent that this was considered in the proposed treatment outlined by Cabrera (2008, Appendix R). Additionally, assuming that treatment is as specified in that report with direct injection of a disinfectant being the primary treatment of a river surface water, then it can be presumed that there would be a rather rapid decay of the disinfectant as it reacts with the many constituents indicative of a surface water source; therefore, it is rather possible that some or most of the system could be subjected to complete loss of the disinfectant. The common engineering approach is to install booster stations along the distribution pipeline to ensure necessary minimum levels of disinfectant.

It is not clear whether the design or costs proposed by Cabrera (2008, Appendix R) consider the possibility of disinfectant loss and the inclusion of booster stations to maintain a sufficient residual disinfectant level through the potable water system. Disinfection demand in this system as well as methods to maintain a consistent residual level of disinfectant would need to be determined through engineering methods and analyses. To the extent that this was not factored into calculations and to the extent that booster stations are deemed to be a necessary requirement to help reduce biological regrowth within the potable water system, then respective investment and operational costs would increase.

1.5.3.4 Consideration of Distribution System Materials

The materials selected for the distribution system would certainly influence the costs of the potable water system. At one extreme, some developed countries are installing stainless steel pipes that have the advantageous properties of being highly corrosion resistant, which in turn produces less undesirable internal corrosion scale (i.e. scale that creates pumping headloss or provides a safe haven for bacteria) and should last longer than other materials. In contrast, equivalent sized plastic pipe is about 25 – 57 x less expensive than stainless steel tubing.

While plastics do not corrode, they can still degrade, such as when plastic tubing becomes brittle from too much exposure to ultraviolet fraction of sunlight. Therefore, plastic distribution pipes would need to be buried below the subsurface, creating higher installation costs than a stainless steel pipe that would not necessarily need to be buried.

These two simplistic examples illustrate how the selection of materials would greatly influence the potable water system costs. Specific details pertaining to the distribution system were clearly specified in the proposal by Cabrera (2008, Appendix R), so depending on the final material selection, the original costs of the distribution system may fluctuate accordingly.

1.5.3.5 Summary of Potable Water System Options

The considerations in this section illustrate how the design of the potable water system would impact the total investment costs of this system. In many respects, the potable water system proposed by Cabrera (2008, Appendix R) is a very simplistic design—one that would not be permitted in many developed countries including the United States. In order to elevate these proposed potable water systems to the standards of many developed countries would likely entail a significant cost increase, such that one perspective of the costs detailed in Cabrera (2008, Appendix R) could potentially be a lower bound with respect to the true, actual costs associated with developing a suitable potable water system to supply the inhabitants within the Concession area. As the potable water treatment system becomes more elaborate the associated costs should increase respectively.

1.6 Cost of Proposed Potable Water Supply

Developing detailed, up-to-date costs for the regional systems described by Cabrera (2008) would require an in-depth engineering design effort and is not the intent of this report. Rather, the conceptual approach recommended was examined using largely information developed by Cabrera

(2008, Appendix R) during his more detailed research and system design analysis to develop basic, *preliminary* estimates of potential costs for the proposed system.

1.6.1 Factors Used for Cost Projections

Typical engineering costs stem from the projected design capacity, which often is determined from the population after establishing a water demand per capita. Water treatment designs are based upon a 10 – 25 year capacity, projecting population growth over that time period. The 20-year design period used by Cabrera (2008, Appendix R) is acceptable.

The demand factor used by Cabrera (2008, Appendix R) was 150-180 L/capita initially, with the upper bound increasing to 250 Lpd/capita. For comparison, an average design value for potable water system design in the United States (US) is 570 Lpd/capita, which includes domestic (190 Lpd/capta), commercial and industrial (250 Lpd/capta), and public (40 Lpd/capita) uses as well as waste due to leaks (95 Lpd/capita) (Reynolds and Richards, 1996).

While this US design factor is not completely applicable to Ecuador, considering the likely applicable components are still instructive. For example, domestic water use in the US varies between 60-265 Lpd/capita (Reynolds and Richards, 1996), and the water demand assumed by Cabrera (2008, Appendix R) (150 Lpd/capita) is within the lower-mid region of typical US domestic potable water demand. Considering real losses due to leaks (95 Lpd/capita), the upper assumed Ecuadorian water demand (250 Lpd/capita) is still less than the average potable water domestic and leaks demand in the United States.

The demand due to commercial businesses and industry should be considered, and this may be included in the Cabrera (2008, Appendix R) assumed water demand. Without any further information regarding typical Ecuadorian water demand and usage patterns, the potable water demand factors assumed by Cabrera (2008, Appendix R) are at least reasonable based upon this very simplistic comparison presented herein. An engineering analysis would need to determine projected water demand for the respective areas to be supplied.

Cabrera (2008, Appendix R) used a population growth of 4.4%, which might be somewhat high. For example, information published by the US Central Intelligence Agency (CIA) documents the average Ecuadorian growth rate lower at 1.5% (CIA 2). Likewise, the international agency UNICEF has documented an average Ecuadorian growth rate of 1.1% for the whole country and 2.2% for urban areas for the most recent data time period (2000-2008) (UNICEF reference). The national Ecuador census agency projects growth rates regions that would be supported by the proposed potable water system to be 2.4 % (INEC, 2004).

The selection of the 4.4% growth rate was not documented or justified in the Cabrera section detailing the potable water system (2008, Appendix R). The selected growth rate would influence all subsequent calculations, since most available potable water project data is normalized per capita.

The numerical value of population growth rates are influenced by births, deaths, and migration. The latter factor could disproportionately skew any population estimates, in the event that large sections of the Ecuadorian population will be migrating with respect to the Concession area. Mass migrations into an area recently plumbed and supplied with potable water would have the net result of effectively increasing the population, one method of accounting for this would be to make an assumption and then elevate the growth rate variable respectively. It is unknown whether this was a consideration assumed by Cabrera (2008, Appendix R).

1.6.2 Summary of Existing Projected Costs (Cabrera, 2008, Appendix R)

The following preliminary analysis relied on per-capita costs for the proposed systems along with population estimates for the potentially affected Concession areas. Using this information, estimates of the costs for providing potable water for residents of the Concession area as determined by Cabrera (2008, Appendix R) are outlined below.

Cabrera (2008, Appendix R, Table 5) estimated total costs for the three regional water systems outlined above. He included costs for piping and treatment; distribution network; household connections; metering; pumping, transport, and storage, and a contingency for unanticipated expenses. These costs were based on experiences from other similar water supply systems and professional judgment. The total cost for the three systems was $428,004,417. The per capita costs for the Regional Systems 1, 2, and 3 were approximately $1026, $1237, and $1917, respectively. These values are calculated based on the projected 2027 population listed in Table 5 of 348,232, where the total 2007 population for the regions (140,985) was adjusted by Cabrera to account for potable water needs in 20 years using an assumption of 4.4% annual population growth.

Overall, the per capita estimate for the three systems weighted by the sizes of the populations served is approximately $1229. Adjusting for an inflation rate of 3% per year since 2007 when Cabrera's original estimates were made gives a current average per capita cost of approximately $1342.

1.6.3 Additional Cost Analysis

Without a more detailed understanding of the population distribution relative to surface water and groundwater sources in and adjacent to the Concession area, this analysis did not attempt to identify specific population segments to be served by separate regional systems. Therefore, the assumption was that the entire populations of Lago Agrio, Shushufindi, Cascales, and Cuyabeno in the Province of Sucumbios, and Orellana and La Joya de los Sachas in the Province of Orellana would be supplied by the proposed regional water systems.

As summarized above, the total estimated 2030 population for the areas under consideration is 403,630. This estimate was based on adjusting the INEC (2004) estimated 2010 population total of 251,180 to account for potable water needs in 20 years using an assumed 2.4% average annual population growth (INEC 2004). Based on an average per capita cost of $1342 and a population of 403,630, the estimated costs for providing regional water systems to supply residents of the Concession area is approximately $541,500,000. If the actual population requiring a potable water supply is less than the total populations of the Cantons considered in our estimates, the total cost could be lower.

1.6.4 Summary of Cost Considerations

As detailed herein, the subsequent costs for a potable water system to supply the inhabitants within the Concession area are normalized based upon projected population. Cabrera (2008, Appendix R) assumed a higher growth rate than that generated from the national Ecuador Census data (INEC, 2004). The lower population growth rates assumed in our estimates along with the higher modern-day population estimates tend to offset in these comparison calculations.

As detailed in section 4.5.3, the proposed water system was evaluated based upon the summary presented in Cabrera (2008, Appendix R). To the extent that this proposed treatment system is expanded to include additional treatment steps or processes, then costs projected development and operational costs would correspondingly increase.

It is also important to note that there may be residents in the Concession area that could not be served by the proposed regional systems and that would require alternative water supply systems to ensure safe, potable water. This could add to the total cost estimates for the more limited population estimates used by Cabrera. Conversely, existing water supply systems may be available for some of the population in the region and this could reduce the total cost estimates for the more inclusive population base considered in our estimates. These considerations reflect, to some extent, the difficulty in making accurate estimates of total costs for a safe and reliable water supply to the Concession area without more comprehensive environmental, demographic, and engineering analyses.

There are other potential alternatives to providing the regional water supplies outlined in the Cabrera (2008, Appendix R) analysis. These could include smaller, community based systems, or individual household systems with water sources drawing from groundwater and surface water resources within the Concession area. The costs of alternative types of water supplies can vary greatly. For example, Cabrera (2008, Appendix R) describes per capita costs for water systems ranging from $188 to $1000 per person. However, these estimates are based on data from operating or proposed systems and do not necessarily include all the project components that might be necessary to provide a functional water supply system. Thus, the estimated per capita costs could be higher than those provided. Additionally, as noted above, these types of alternative systems have the potential disadvantages of uncertain water quality for potential sources within the Concession area and limitations with regard to efficient operation, maintenance, and funding.

1.7 Summary of Valuation and Conclusions

Conceptually, provision of potable water to residents in Sucumbios and Orellana potentially affected by oil production contamination appears to be an effective means to provide a safe and sustainable water supply. It would not require as comprehensive an evaluation of existing and future water sources and supply systems in the Concession area that would be necessary to implement a selective system development, upgrade, and repair approach to providing potable water supplies from sources within the Concession area. Nevertheless, it would provide for taking advantage of existing systems or infrastructure or to use alternative supplies for more remote population segments unable to be served by these systems. Furthermore, this approach may have the added advantage of establishing a physical and administrative infrastructure that could help ensure the sustainability of these water systems into the future in terms of system operation, maintenance, and funding.

Comprehensive demographic and engineering analyses would be required to design, estimate costs, and implement the most effective potable water delivery system for this region. However, based on preliminary data for development of a regional approach to this problem, estimated costs for a comprehensive series of regional water systems is approximately $541,500,000.

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AWARDED RESEARCH GRANTS:

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Scardina, P. and M. Edwards. "Distribution System Water Quality Strategic Initiative: Premise Plumbing Water Quality Changes." $75,000 via American Water Works Association Research Foundation.

Edwards, M., **P. Scardina**. "Helping Small Water Systems Develop and Manage a Corrosion Control Strategy." $75,000 via Environmental Protection Agency (EPA).

Edwards, M., **P. Scardina**. "Non-Uniform Corrosion in Copper Piping—Monitoring Techniques."
$400,000 via American Water Works Association Research Foundation.

Edwards, M., **P. Scardina**, G.V. Loganathan, D. Bosch, and S. Dwyer "Non-Uniform Corrosion in Copper Piping—Assessment."
$400,000 via American Water Works Association Research Foundation.

Edwards, M. and **P. Scardina**. "Gas Supersaturation and Treatment Plant Performance: A Fundamental Understanding for New Regulations."
$150,000 via American Water Works Association Research Foundation.

Edwards, M. and **P. Scardina**. "Role of Light and Algae and Dissolved Gas on Water Treatment."
$36,000 via Washington Suburbs Sanitation Commission (WSSC).

Edwards, M. and **P. Scardina**. "Investigation of UVT Improvements for the Potomac WFP Improvement Projects."
$35,000 via Washington Suburbs Sanitation Commission (WSSC).

PROFESSIONAL PRESENTATIONS:

Scardina, P. "Recent Advances in the Understanding and Fundamental Science of Copper Pinhole Leaks." AwwaRF Webcast, December 4, 2008.

Scardina, P. "A Plethora of Pipes." Infrastructure Rehabilitation for Young Professionals, AWWA, Concord, NC, 2008.

Scardina, P. and M. Edwards. "Recent Advances in the Understanding of Copper Pinhole Leaks." AWWA DSS Conference Workshop: Corrosion Control and Water Quality in the Distribution System, Phoenix, AZ, 2006.

Lattyak, R., M. Edwards, and **P. Scardina**. "Copper Pinhole Leaks." American Water Works Association Annual Conference, San Antonio, TX, 2006.

Scardina, P. "Methods to Reduce Floating Floc Disruptions during Coagulation and Sedimentation." American Water Works Association Annual Conference, San Francisco, CA, 2005.

Edwards M. and **P. Scardina**. "Lead, Chloramine, and Beyond." VA AWWA Regional Seminars: Water Quality in Distribution Systems, Christiansburg, VA, 2005.

Scardina, P. "Effects of Dissolved Gas Supersaturation & Bubble Formation on Treatment Plant Performance." Senior Operators Forum (VA), Charlottesville, VA, 2004.

Edwards, M., R. Letterman, and **P. Scardina**. "Dissolved Gas Interference to Particle Counting and Turbidity Measurements." American Water Works Association Annual Conference, Orlando, FL, 2004.

Scardina, P., M. Edwards, and R. Letterman. Poster: "Effects of Gas Supersaturation and Bubble Formation on Treatment Plant Performance." American Water Works Association Annual Conference, Orlando, FL, 2004.

PROFESSIONAL PRESENTATIONS: (continued)

Scardina, P. and M. Edwards. "Understanding the Fundamentals of Air Bindings in Filters." American Water Works Association Annual Conference, Anaheim, CA, 2003.

Scardina, P. and M. Edwards. "Understanding, Diagnosing, and Preventing Air Binding in Filters." Advances in Rapid Granular Filtration in Water Treatment, London, England, 2001.

Scardina, P. and M. Edwards. "The Fundamentals and Practical Impacts of Bubble Formation in Water Treatment." American Water Works Association Annual Conference, Denver, CO, 2000.