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Progress Report
Final - E-20-E12

RESEARCH PROGRAM FOR
EXPOSURE-DOSE RECONSTRUCTION

Submitted to:

Agency for Toxic Substances and Disease Registry (ATSDR)

Project Officer: Morris L. Maslia, P.E. (DHAC, MS E-32)

**Centers for Disease Control and Prevention and ATSDR
Cooperative Agreement No.: U50/ATU499828-09**

Submitted by:

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May 31, 2004

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1.   OVERVIEW OF THE EXPOSURE-DOSE RECONSTRUCTION PROJECT

The competitive extension of the cooperative agreement on Exposure-Dose Reconstruction Project (EDRP) was awarded to Dr. M. M. Aral, School of Civil and Environmental Engineering, Georgia Institute of Technology, towards the end of September 2003. This competitive extension was based on successful completion of the second phase of the Exposure-Dose Reconstruction program. Starting on September 2003, our efforts focused on several projects in the area of the research program in order to continue with the proposed activities of the joint program in a most efficient and cost effective manner.

Prior to this extension, we have successfully completed the first phase of the project during the period 1994-1998 and the second phase during the period 1998-2002. Final completion reports of the projects completed during the first and second phases were submitted to ATSDR/CDC on October 21, 1998 and October 25, 2002. Included in these project completion reports were the latest versions of the ACTS and SAINTS computational tools. A complete list of these final reports and a list of joint technical publications that appeared in archival publications are included in Appendix I of this progress report.

In this progress report we first provide a summary of the progress we have made in the proposed activities of the EDRP program during the period 1998 through 2003. We also include a section on the progress made during the first year of the third period of the EDRP program (2003-2004) The progress report also includes the proposed activities during the next project year of the EDRP program (2004-2005) as well as a proposed budget for the period 2004-2005.

2.   REVIEW OF RESEARCH ACTIVITIES FOR THE PROJECT PERIOD 1998 THROUGH 2003

The research activities of the EDRP are multilevel as they relate to the very sensitive and complex issue of exposure of populations to natural or accidentally occurring contaminants in the environment and the risk based evaluation of adverse health outcomes due to exposure to these contaminants. The specific research needs in this broad area are primarily based on the long term and short term technical needs of ATSDR. Among these needs, without an order of priority, we may envision the following categories as the primary research needs of the EDRP program:

i.   The development of screening level exposure assessment tools, to be used by health assessors in evaluating site specific cases of exposure and adverse health outcomes. These screening level tools are to be developed for groundwater, surface water and air pathways and they should include risk based uncertainty analysis;

ii.   Development of computational tools for exposure assessment through inhalation, ingestion and dermal contact. This computational environment should work in harmony with the analytic environmental modeling tool described above;

iii.   The development of more detailed and GIS integrated analysis tools to evaluate exposure of populations to environmental contaminants. For this exposure analysis tools, the emphasis is on groundwater and surface water pathways;

iv.   Applications development in the "fuzzy logic" field to mimic uncertain data sources and incorporation of this methodology to exposure assessment studies; and,

v.   Study and analysis of site specific cases of exposure to environmental contaminants and evaluation of potential adverse health outcomes at these sites.

In this section, based on this outline, we first provide a review of the progress made during the period 1998-2003. In Section 3 we will provide the outline of the research goals and progress achieved during the period 2003-2004. Section 4 will include the proposed activities during the next project year of the EDRP program (2004-2005).

2.1   Development of Risk Based Exposure Analysis Module Associated with the ACTS Computational Tool

During the first phase of the EDRP program, the multi-pathway contaminant fate and transport analysis component of the ACTS software was successfully completed. This component included several analytical tools to evaluate contaminant concentration levels in multiple and interactive pathways as decided between ATSDR/CDC technical project officer and the GATECH principal investigator. These pathways included the following:

i.   Air pathway;
ii.   Ground-water pathway; and,
iii. Surface water pathway.

This tool, which included uncertainty analysis for all pathways considered, is delivered to ATSDR, and is being used by ATSDR personnel in numerous site specific projects. This computational tool will continue to be upgraded throughout the third phase of the EDRP in an effort to introduce to the computational tool, the most recent technical advances in the exposure assessment technology, as well as to introduce to the computational tool the most recent developments in information technology platforms. For example, during the period 2001-2002, this platform was moved to the Visual Basic 6 (VB6) platform which offers users a more user friendly environment and a flexible interface. This task, which was a complex and time consuming effort, was completed during this period. Under this platform the ACTS software now includes a more detailed "Help" menu option, which covers all components and chapters of the ACTS report submitted to ATSDR during 1998-2003 along with a more user friendly interface. These developments are included in the code (Version 6.3) and submitted to ATSDR. Since this code is in the public domain, we have also created a web site where users can download this code and use it in their specific applications. The interest on the code was more than what we expected, the code is downloaded by scientists worldwide and we have a record of these users.

During the project year 2001 through 2003 there was another modification to the ACTS software, which was requested by ATSDR. In this period, ATSDR computational platform was changed to Windows2000™ from an earlier version of Windows™ operating system. Unfortunately this change created significant problems with the execution of the ACTS software since the computational environment is completely different in Windows2000™ as opposed to the earlier versions. Thus considerable time was spent (about 8 to 10 months) in upgrading the ACTS software to Windows2000™ platform. This task is now complete and the latest version of the ACTS software is now operating under Windows2000™ platform. Earlier versions of ACTS software, operating under earlier versions of the Windows™ operating system will not be maintained from this point on. However, there is a more recent development in this visual development interface environment. That is the introduction of the Visual.NET application

platform by MS Corporation to the Visual Basic environment. This platform provides a better environment for this software, we are aware of this and eventually ATSDR computational environment will be shifted to this platform. We will undertake the task of transforming ACTS to this platform as one of our efforts during the period 2004-2008.

In addition to this ongoing upgrading effort, as we have proposed in our earlier program period, it is now necessary to bring this computational tool to the next level. This level includes the seamless integration of risk based human exposure calculations through three standard pathways. These pathways are:

i.   Inhalation pathway;
ii. Dermal contact pathway; and,
iii. Ingestion pathway.

These exposure calculations should again be based on risk based analysis for each pathway, should be applicable to multiple chemicals and a wide range of potentially exposed populations.   Using this tool, when completed, health assessors not only would be able to evaluate fate and transport of mixed chemicals in the three exposure pathways considered in the first phase of the research program, but they would also be able to evaluate the exposure-dose of these chemicals at the human contact level through the three exposure pathways identified above.

Development of this phase of the computational tool is the most important and also the most complex part of the overall effort since it is now integrated with fate and transport models of the ACTS software. This task will require significant effort on the part of the MESL personnel. Our initial effort has focused on the planning of the development of this component of the computational tool. As we have done earlier, proper planning of the interface is the most critical component of the computational tools development and should be considered first. Once this phase is completed, this will be followed by the coding of the necessary models into the ACTS computational tool. When completed, the computational tool can be used by health scientists to evaluate exposure-dose calculations through environmental as well as through human contact pathways. This is one of the major tasks that we have planed to undertake during the period 2002-2003. This activity is still ongoing and it will still be one of our active tasks during the period 2004-2008.

2.2   Monte Carlo Simulations in Human Exposure Analysis

Implementation of analytical tools in all exposure pathways requires a number of input parameters including human-specific, pathway-specific, and chemical-specific variables. Typically, the values of these parameters are not known accurately due to numerous assumptions and uncertainties involved in these selections.   Therefore, it is often more appropriate to express these parameter values in terms of a probability distribution rather than a single deterministic value and use an uncertainty propagation model to assess the effect of the variability introduced to the output of the models used in the ACTS software. Most suitable method that can be employed for this purpose is the Monte Carlo method. Based on the principles of this approach, these procedures will be incorporated to all components of the computational tool developed. This task is an important effort, which requires significant time and effort of the MESL personnel.

As was proposed in our first phase research program, the exposure-dose analysis through inhalation, dermal contact and ingestion pathways will include Monte Carlo Analysis as well, to evaluate the uncertainty in these computations. As demonstrated in the ACTS Version 6.3, these computations will be seamless and user friendly.

2.3 GIS Integrated Exposure Analysis Tools

It is our understanding that ATSDR/CDC's needs for computational tools in the area of health and exposure assessment is multilevel. The range of complexity of these tools may vary between screening level tools, similar to the analytical computational environment described in Section 2.1 above, to the sophisticated GIS integrated multimedia modeling tools, which may be used to analyze more complex cases. Given the number of sites that needs to be analyzed by ATSDR/CDC periodically and given the variability in complexity of the contaminant migration pathways in these sites, there would be a need for sophisticated approaches as well as the screening level tools. Thus, in addition to the analytical tool development phase of the project, the joint project team is also in the process of developing user friendly GIS interface programs to simplify the analysis steps necessary in these complex cases. Our initial efforts in this category were concentrated towards the development of a shell structure for the GISPlus software, which was used by ATSDR/CDC in early periods of the EDRP program. This shell program simplified the manipulation of data structures within a GIS integrated computation and the interaction of the complex simulation tools with the GIS system. The preliminary shell structure jointly developed by ATSDR/CDC and GATECH scientists during the first period of the project may describe our line of thought in this effort.

ATSDR/CDC also utilizes ARCView software in their site investigation studies. The joint project team is also collaborating to move the groundwater pathway analysis tools to PC-ARCView platform as an additional extension of the existing project plan. Part of this work was completed during the first phase of the project and the preliminary ARCView integrated groundwater flow and contaminant transport models jointly developed by ATSDR scientists are being used by ATSDR/CDC professionals in site specific applications. We have completed this project during the second phase of the project.

2.4 Site Specific Applications for Exposure-Dose Reconstruction

ATSDR/CDC and MESL/GATECH are jointly involved in several site specific Exposure-Dose Reconstruction studies as a part of the cooperative effort. We provide below a list of these sites where MESL personnel has cooperated with the ATSDR personal in successful completion of these studies:

(i) ***Toms River Water Distribution Exposure Analysis study:***
This is an important site specific study. During the beginning of the second project period MESL program was asked to develop an optimization code to be used in the reconstruction of the historical management strategy for the water distribution system at Dover Township. This was a new request which was not in the original plan of the EDRP program, but a very good example of how a cooperative agreement can be used to provide support to address immediate needs of ATSDR. Based on this request, MESL personnel put on hold all other activities of the EDRP research program and developed an optimization algorithm to reconstruct the management of this water distribution network. This was a time consuming process and required all personnel resources of the

MESL program during the first half of the second project period. MESL research personnel provided the complete sensitivity runs necessary for the Dover Township project. For this purpose an optimization model was developed using Genetic Algorithms (GA). The results of the sensitivity runs established that alternative ways the water supply may be distributed to the system may not have altered the delivery of water to specific points of concern. The project was successfully completed during the end of year 2001 and the final reports were submitted to ATSDR during December 2001. The outcome of the project was published jointly with ATSDR, which yielded results of national importance. This study is referred to in numerous national media as a benchmark study and it helped resolve environmental issues raised for a large community in NE USA. To the best of our knowledge, this site specific study is the first study in the literature which showed association between pediatric cancer and documented environmental contamination. This study also won the First Prize in Research Category in the American Academy of Environmental Engineers awards for the year 2003.

(ii) ***Exposure Assessment Study, Site 802, Flanders, New York, FP&M Project No. 439-96-01***:
This exposure assessment study is a site specific study and is completed by MESL personnel. The outcome of the exposure study was submitted to EDRP Technical project officer towards the end of 1998.

(iii) ***Contaminant Transport Analysis for the Sawyer's/GAF/View-Master/Tyco/Mattel Facility***:
This exposure assessment study is a site specific study and is completed by MESL personnel. The outcome of the exposure study was submitted to EDRP Technical project officer on May 28, 1999.

Site specific support MESL program provides to ATSDR is an important component of the cooperative agreement established between ATSDR and MESL. We intend to continue with this collaboration on several other site specific applications of the exposure assessment tools during the second phase of the EDRP project. The projects listed above have been completed during the period 1998-2003.

2.5   Summary of Research Tools Developed Jointly with ATSDR during the period 1998-2003

During the period 1998-2003 the following computational tools were developed jointly with ATSDR/CDC. Some of these tools are still in the development or upgrading stage and should not be considered to be a final product. All of these computational tools are presently used by ATSDR/CDC health assessors in evaluating health consequences of contaminants released to subsurface pathways.

(i)   Analytical Contaminant Transport analysis System   (ACTS 6.3)
(ii)   Numerical Groundwater flow and Contaminant Transport Analysis Tools integrated with GisPlus   system
(iii) Spatial Analysis INTerface System (SAINTS). ARCVIEW interface for numerical groundwater flow and contaminant transport analysis tools (SLAM/GIS and CLAM/GIS)

3.   PROGRESS OF RESEARCH ACTIVITIES FOR THE PROJECT PERIOD (2003-2004)

As described above, the progress made in all of the activities summarized above are substantial during the period 1998-2003. The progress in technical product development activities summarized above was in addition to several important site-specific studies conducted jointly with ATSDR/CDC. These joint site-specific studies are an excellent example of the collaborative effort undertaken by the two institutions. Technical papers published, which were the outcome of these efforts, not only were accepted for publication in prestigious journals and conferences, but also these technical publications received several prestigious awards from the U.S. DHHS and ASCE as well as American Academy of Environmental Engineers (AAEE).

During the third phase of the EDRP project, our ongoing efforts will be directed towards the completion of site specific studies and improving the tools we are developing jointly with ATSDR/CDC. In this effort, new models will be incorporated into the computational environment of the ACTS software. This is an important and ongoing task and is an essential component of the computational tool development. For example during the project period 2003-2004 a land fill module and a water/air interface model was included to the ACTS software. These models were specifically requested by the ATSDR personnel to be included in the ACTS software. These computational tools will be periodically tested jointly with ATSDR/CDC professionals. In addition to this upgrading and expansion of the capabilities of the software effort, the primary effort scheduled for the period 2003-2004 was the development of the interface which will integrate the environmental pathway computational environment of the ACTS tool with the exposure pathway computational tool (dermal contact, ingestion and inhalation). As described above this exposure-dose computation tool will be built on the environmental pathway tool completed earlier. This is a very complex task and will require proper initial planning and organization of the module as was done during the first phase of the study for environmental pathway computations. Preparation of this organization and initiation of the coding of this module into the ACTS tool for the three exposure pathways, preparation of "help" platforms and including the Monte Carlo analysis into this newly formed module will be a significant addition to the ACTS software. This component of the project is still on going and will be one of the major tasks for the project period 2004-2005.

In addition to this activity, the GIS integrated groundwater and contaminant transport and fate models developed for the ArcView interface will be completed jointly with ATSDR/CDC scientists. In this effort we intend to extend the user friendly interface developed for ARCView 3.2 platform to ARCView 8.0 platform which is released by ArcView. This release includes several new options on ARCView platform which can be made use of in the SAINTS program. For example calibration of these models for site specific cases is an important effort. Certain menus will be included to the SAINTS platform to accelerate this process. This task will be included to the activities of the third project phase.

For technology transfer efforts, several workshops are also planned during the second project phase. The first of these workshops was held during June 14-18, 1999. During these workshops the use of the computational tools jointly developed with ATSDR/CDC will be introduced, the technical background will be explained and applications will be demonstrated. This is a very time consuming effort but needs to be completed for transfer of the technology developed to the users at USDHHS. This task will be also included to the activities of the third project phase. It is anticipated that this activity will continue throughout the third project phase. Our intention is to organize at least two training workshops per year throughout the duration of the second project phase.

Other Site Specific Studies:

In addition to the technical project items described above, ATSDR has requested MESL research program to participate and provide support for several important health risk characterization and exposure-dose reconstruction studies associated with several sites. These site-specific studies will include a military site in North Carolina and also the Conrail site in Indiana. These groundwater modeling studies is an extremely important health characterization study and define a new direction and focus area for our ongoing cooperative research program. These are very important health risk characterization studies which, in analytic models development sense, are associated with an earlier studies completed by ATSDR health scientists. We have started working on these two sites during the period 2003-2004, however the completion of these two site specific studies is expected to be extended to the period 2003-2005.

As MESL research program scientists we consider these requests as challenging extensions to our existing cooperative agreement program and a good demonstration of our ongoing support of ATSDR's current needs in addressing Healthy People 2000 and beyond initiative of the public health service.

4.   RESEARCH ACTIVITIES FOR THE PROJECT PERIOD (2004-2005)

The research activities that are included into our program are given in the list below. These constitute or proposed activities for the project period 2004-2005.

   i.   Continued development of the ACTS software;
   ii. Continued development of the RISK software;
   iii. Continued development of the SAINTS software;
   iv. Providing support to ATSDR on the site specific study at a military base in N.C.
   v.   Providing support to ATSDR at Conrail site in Indiana;
   vi. Providing support to ATSDR at Endicott site in NY; and,
   vii. Introduction of possibility analysis to our computational platforms along with probability analysis.

All of these tasks constitute important components of the EDRP program. We anticipate that, during the period 2004-2005, our involvement in the project identified in item four above will be significant and will require significant resource allocation from the MESL program.

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Professional Registration: Professional Eng. : GA : 15254; Prof. Hyd., Nat. Reg.: No.: 649

Educational Background
Ph.D. in Water Resources Engineering with minor in Numerical Analysis and Applied Mathematics, September 1971, School of Civil Engineering, Georgia Institute of Technology.
M.S. in Civil Engineering with major in Environmental and Water Resources Engineering, June 1969, School of Civil Engineering, Georgia Institute of Technology.
B.S. in Civil Engineering, June 1967, Department of Civil Engineering, Middle East Technical University (Ankara, Turkey).

Professional Experience

1995-present	Professor	At School of Civil and Environmental Engineering,
1993-present	Director	Multimedia Environmental Simulations Laboratory
1982-1995	Associate Professor	Georgia Institute of Technology, Atlanta, Georgia.
1979-1982	Visiting Professor	(on sabbatical)
1974-1979	Adjunct Professor	At Marine Sciences Dept., Civil Eng. Dept., Eng. Science Dept.,Middle East Technical University.
1977-1982	Associate Professor	At Mathematics Department, Middle East Technical
1975-1978	Assistant Chairman	University, Ankara, Turkey.
1971-1977	Assistant Professor	

Honors and Awards
8. Award of Recognition for the Org. of the East-West Adv. Study Institute on Env., NATO, August 1995.
9. Engineering Technical Excellence Award, Public Health Serv.,US DHHS for the technical paper: "Estimating Exposure to VOCs from Municipal Water System Pipelines: Use and Application of a Computational Model, Archives of Environmental Health, May 1996.
10. Research Program Development Award, in Recognition for Developing a Consistent and Comprehensive Research Program, School of Civil and Env. Engineering, Georgia Institute of Technology, May 1997.
11. Science Publication Award, ATSDR, US DHHS, for the technical paper: "Use of Computational models to Reconstruct and Predict Trichloroethylene Exposure," in Toxicology and Industrial Health, April 1997.
12. Award of Appreciation in acknowledgment of cont. to the org. of the Int. Conf. on Geo. and Env., 1997.
13. Engineering Literary Excellence Award, Public Health Serv.,US DHHS for the technical paper: "Exposure Assessment Using Analytical and Numerical Models: A Case Study," in ASCE Practice Periodical of Hazardous, Toxic, and Radioactive waste Management, April 1998.
14. Honorary Professor of Environmental Sciences, Huazong University of Science and Technology, Wuhan, Peoples Republic of China. 1998.

Publications: Over 100 publications. See references section of this proposal for most relevant publication list or visit www at http://groups.ce.gatech.edu/Research/MESL/

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Educational Background
Georgia Institute of Technology, Ph.D. in Environmental Hydraulics and Water Resources with
    minor in Numerical Analysis and Applied Mathematics, March 1998.
Georgia Institute of Technology, M.S. in Civil and Environmental Engineering with major in
    Geohydrology and Water Resources, March, 1996.
Huazhong University of Science and Technology, M.E. in Automation of Electric Power System,
    Department of Electrical Engineering, June 1987.
Huazhong University of Science and Technology, B.E. in Dept. of Electrical Engineering,
    January 1982.

Professional Experience

1998-present	Research Engineer	School of Civil and Environmental Engineering, Georgia Institute of Technology.
1994-1998	Graduate Research Assistant	School of Civil and Environmental Engineering, Georgia Institute of Technology.
1992-1993	Associate Professor	Department of Electrical Engineering, Huazhong University of Science and Technology, China
1987-1992	Assistant Professor	Department of Electrical Engineering, Huazhong University of Science and Technology, China
1982-1987	Teaching Assistant	Department of Electrical Engineering, Huazhong University of Science and Technology, China

Publications
1.   M. M. Aral and Jiabao Guan, Progressive Genetic Algorithm and Its Application,
      Submitted to *Simulation and Computation for Engineering and Environmental Systems*,
      1998.
2.   M. M. Aral and Jiabao Guan, Optimal Remediation with Well Location and Pumping
      Rates Selected as Continuous Decision Variables, Submitted to *ASCE Journal of
      Hydrologic Engineering*, April 1998.
3.   M. M. Aral and Jiabao Guan, Identification of Contaminant Source Locations and
      Release Histories in Aquifer, Submitted to *Water Resources Research*, April 1998.
4.   M.M. Aral and Jiabao Guan, Groundwater Contaminant Source Identification in
      Heterogeneous System with Source Locations as Unknown Variables, *Research Report,
      MESL*, 1998.
5.   M.M. Aral and Jiabao Guan, Optimal Groundwater Remediation System Design with
      Well Locations Selected as Decision Variables, *Research Report, MESL-01*, 1997.
6.   M.M. Aral and Jiabao Guan, Optimal Groundwater Remediation Design Using
      Differential Genetic Algorithm, *Computational Methods in Subsurface Flow and
      Transport Problems*, Computation Mechanics Publications, 1996.

Research Experience
Assistant investigator, *Research Program on Exposure-Dose Reconstruction*, Funded by the
ATSDR, US DHHS, 1993-1998.

APPENDIX I

During the period 1998-2003 several completion reports were submitted to ATSDR. A list of these reports and other technical publications related to the EDRP project is given below.

Technical Completion Reports Submitted to ATSDR/CDC:

1. **Title:** Analytical Contaminant Transport Analysis System (ACTS), MESL-02-1998
    Number of pages: 153 pages, Interim Final report.
    Copies submitted: 10 copies.
    Comments: The VERSION 4.5 of the ACTS software was submitted during September, 1998.

2. **Title:** Analytical Solutions for Two-Dimensional Transport equation with Time-Dependent Dispersion Coefficients, MESL-01-1996.
    Number of pages: 40 pages, Final report.
    Copies submitted: 25 copies.
    Comments: This report is prepared as a complement to the MESL-02-1998 report discussed above and contains the mathematical description of analytical solutions to variable dispersion models, which are included in the ACTS software.

3. **Title:** Geographic Information Systems Integrated Groundwater Flow and Contaminant Fate and Transport Modeling (SAINTS), MESL-03-1998
    Number of pages: 88 pages, Interim Final report.
    Copies submitted: 10 copies.
    Comments: The VERSION 4.1 of the SAINTS software was submitted during September, 1998.

4. **Title:** A Computational Method for Wave Propagation Simulation in Open Channel Networks, MESL-03-1996.
    Number of pages: 63 pages, Final report.
    Copies submitted: 25 copies.
    Comments: In this report analytic and numerical methods utilized in the solution of open channel flow equations, which are used in the RiverNET software are given. RiverNET software is a Windows$^{(TM)}$ based software, which may be used in the analysis of flow and contaminant transport processes in open channel and river networks. This software was developed primarily to study contaminant transport processes in TOMS RIVER project.

5. **Title:** Identification of Groundwater Contaminant Sources and Release Histories Using Genetic Algorithms, MESL-01-1998.
    Number of pages: 50 pages, Final report.
    Copies submitted: 25 copies.
    Comments: In most health risk assessment studies, field data on contaminant source location and release histories of contaminants from these sources are either not known or incomplete data exists to characterize these contaminant sources. This poses significant problems in health risk assessment studies since exposure-dose and exposure-duration associated with these sources cannot be predicted without complete information on this data. During the first phase of the cooperative

program we have developed a solution to this very complex and very difficult problem using Genetic Algorithms. In this report the theoretical approach and a numerical method used in this process is summarized.

6.   **Title:** Optimal Groundwater Remediation System Design with Well Locations Selected as Decision Variables, MESL-01-1997.
     Number of pages: 68 pages, Final report.
     Copies submitted: 25 copies.
     Comments: Aquifer remediation is an essential component of eliminating sources of contaminants, which are health hazards to communities. Determination of optimal remediation alternatives for such polluted sites are important to citizens who are exposed or in danger of being exposed to these contaminants. During the first phase of the cooperative program we have developed a solution to this very complex and very difficult problem using Genetic Algorithms. In this report the theoretical approach and a numerical solution used in this process is summarized.

7.   **Title:** Multi-Pathway Environmental Exposure Assessment Using "ACTS" and "SAINTS" Software, MESL-05-1998.
     Number of pages: 159 pages, Final report.
     Copies submitted: 25 copies,
     Comments: In this report we have utilized the "ACTS" and the "SAINTS" software and provided a step-by-step procedure demonstrating how these software may be used in environmental exposure characterization studies. We intend to use this report in the workshops we will be organizing jointly with ATSDR. The application discussed in this report is a site specific application, which was of importance to ATSDR.

8.   **Title:** Reconstruction of Hydraulic Management of a Water Distribution System Using Optimization, MESL-01-01.
     Number of pages: 59 pages, Final report.
     Copies submitted: 25 copies,
     Comments: In this report we have developed and optimization method using genetic algorithms and utilized it in the solution of all sensitivity runs made in Toms River study. The application discussed in this report is a site specific application, which was of importance to ATSDR.

In addition to these eight final technical reports the following technical publications were published during the first phase of the cooperative program in collaboration with technical project personnel at DHAC/ATSDR:

Technical Journal Publications:

Maslia, M., Aral, M. M., and Houlihan, M., "Evaluation of Ground-Water Flow Regime at a Landfill with Liner System," *Journal of Env. Science and Health*, Vol. A27, No. 7, pp. 1793-1816, 1992.

Aral, M. M., Maslia, M., and Williams, R., "Ground-Water Remediation Using Smart Pump-and Treat," *Ground Water Journal*, Discussion, Vol. 31, No. 4, pp. 680-681, 1993.

Aral, M. M., M. L. Maslia, R. C. Williams, R., A. Susten and J. L. Heitgerd, "Exposure Assessment of Populations Using Environmental Modeling, Demographic Analysis, and GIS," Water Resources Bulletin, Vol. 30, No. 6, pp. 1025-1041, 1994.

Maslia, M. L., Aral, M. M., Williams, R. C., S. W. Fleetwood, L. C. Heyes, L. C. Wilder, "Use of Computational Models to Reconstruct and Predict Trichloroethylene Exposure," *Journal of Toxicology and Industrial Health*, Vol. 12, No. 2, pp. 139-152, 1996.

Aral, M. M., Maslia, M., Ulrisch, G. and Reyes, J. J., "Estimating Exposure to VOCs from Municipal Water-Supply Systems: Use of a Better Computational Model," *Archives of Environmental Health an International Journal*, Vol. 51, No. 4, pp. 300-309, 1996.

Maslia, M. L., Aral, M. M. and Williams, R. C., "Exposure assessment Using Analytical and Numerical Models: A Case Study," *ASCE Practice Periodical of Hazardous, Toxic, and Radioactive waste Management*, Vol. 1, No. 2, pp. 50-60, April, 1997.

Aral, M.M., Guan, J. and Maslia, M.L., "Identification of Contaminant Source Location and Release History in Aquifers," *ASCE, Journal of Hydrologic Engineering*, Vol. 6, No. 3, pp.225-234, May 2001.

Aral, M.M., Guan, J. and Maslia, M.L., "Identification of Contaminant Source Location and Release History in Aquifers," *ASCE, Journal of Hydrologic Engineering*, Closure: Vol. 7, No. , pp.-, May 2002.

Maslia, M.L. and Aral, M.M., ACTS – A Multimedia Environmental Fate and Transport Analysis System, ASCE Practice Periodical of Hazardous, Toxic and Radioactive Waste Management, 2003 (in publication).

Aral, M.M., Guan, J., Liao, B., Maslia, M.L., Sautner, J., Williams, R. and Reyes, J.J., "Optimal Reconstruction of Historical Water Supply to a Water-Distribution System: A. Mathematical Model and the Solution Algorithm", *Journal of Water and Health*, 2004 (in publication).

Aral, M.M., Guan, J., Liao, B., Maslia, M.L., Sautner, J., Williams, R. and Reyes, J.J., "Optimal Reconstruction of Historical Water Supply to a Water-Distribution System: B Applications", *Journal of Water and Health*, 2004 (in publication).

Publications in Conference Proceedings:

Maslia, M., Aral, M. M., and Gill, H. E., "The Importance of Hydrogeologic Controls on Remedial Action Alternatives," *Geophysical Society of America*, Southeastern Section Meeting, Contaminant Hydrogeology Session, Vol. 24, No. 2, pp. 53, 1992.

Maslia, M., Aral, M. M., Williams, R., Williams, S., Hayes, L. and Wilder, L., "Use of Computational Models to Determine Human Exposure Resulting from Remediation Activities at Hazardous Waste Sites," Proceedings of the Water Environment Federation Specialty Conference *How Clean is Clean*, 85p, January 10-13, 1993.

Maslia, M., Aral, M. M., Williams, R., Williams, S., Hayes, L. and Wilder, L., "Use of Computational Models to Reconstruct and Predict Trichloroethylene Exposure," Proceedings of the International Congress on the Health Effects of Hazardous Waste, p 271-283, May 3-6, 1993.

Maslia, M. L. and Aral, M.M., "Health Implications Associated with Hazardous Waste Site Clean-Up Goals: A Case Study of Trichloroethylene (TCE) Contamination", *Proceedings of the Annual Meeting of the Geological Society of America*, Boston, 1993.

Aral, M.M. and Maslia, M. L., Radtke, T. M., "Conducting Exposure Assessment of Populations by Integrating Environmental Transport Models, Demographic Analysis, and Geographic Information Systems," *Proc. of the Int. Symposium on Assessing and Managing Health Risks from Drinking Water Contamination: Approaches and Applications*, Rome, Italy, pp. 221-233, September 1994.

Maslia, M. L. and Aral, M.M., "Application of Geographic Information Systems and Numerical Models to Exposure Assessment", *Sixth Joint Conference of the International Society for Environmental Epidemiology and International Society for Exposure Analysis*, The University of North Carolina at Chapel Hill, September 18-21, 1994.

Aral, M. M., M. L. Maslia, "Evaluation of Human Exposure to Contaminated Water Supplies Using GIS and Modeling," *Proceedings of the International Conference HydroGIS'96*, pp. 243-252, Vienna, Austria, 1996.

Aral, M. M., M. L. Maslia, R. C. Williams, J. E. Abraham, "ATSDR's Exposure-Dose Reconstruction Program: Case Studies in Public Health Analysis of Exposure to Environmental Contamination," Proceedings of the 1995 Pacific Rim Conference on Occupational and Environmental Health, (in publication), Sydney Australia, October 1995.

Holm, D. M., Maslia, M.L., Reyes, J. J., Williams, R. C., and Aral, M.M., 195, Geographic Information Systems: A Critical Resource in Exposure Assessment, Superfund XVI Conference and Exhibition Proceedings, Vol. 2, pp. 860-866, Washington, DC, Nov. 6-8, 1995.

Aral, M. M., M. L. Maslia, Exposure Assessment Using Simulation and GIS, Proceedings CSCE/ACSE Environmental Engineering Conference, Edmonton, Alberta, Canada, pp. 885-892, July 22-26, 1997.

Sautner, J.B. Maslia, M.L. and Aral, M. M., "Water-Distribution System Modeling as a Tool to Enhance Epidemiologic Case-Control Investigations: A Case Study, The Dover Township

(Toms River) Childhood Cancer Investigations," 26th Annual Water Resources Planning and Management Conference WRPMD '99, ASCE, Tempe, Arizona, June 6-9, 1999.

Aral, M. M., Liao, B., Guan, J., Maslia, M. L., Sautner, J., Williams, R. and Reyes, J. J., "Reconstruction of Hydraulic Management of a Water-Distribution System Using Genetic Algorithms," World Water & Environmental Resources Congress, ASCE, Orlando, Florida, May 20-24, 2001.

Aral, M. M., Guan, J., Maslia, M. L., "Modeling techniques to aid exposure analysis through Water Distribution Systems," at An International ISEA/ISEE Symposium, August 11-15, 2002, Vancouver, BC, Canada.
Maslia, M. L., Sautner, J. B., Aral, M. M., Gillig, R. E., Reyes, J. J. and Williams, J. "Using Water Distribution System Modeling to Assist Epidemiologic Investigations," at An International ISEA/ISEE Symposium, August 11-15, 2002, Vancouver, BC, Canada.

Maslia, M.L., Aral, M.M., and Sautner, J., Reconstructing Historical Operations of Water Distribution Systems. In: Bizier, P., and DeBarry, P., editors. Proceedings of the American Society of Civil Engineers, World Water & Environmental Resources Congress 2003 [CD ROM document]. Philadelphia, PA: June 23–26, 2003.

Aral, M.M., and Maslia, M.L. Application of Monte Carlo Simulation to Analytical Contaminant Transport Modeling: In: S. Mishra, editor. Proceedings of the Symposium, Groundwater Quality Modeling and Management Under Uncertainty, Environmental and Water Resources Institute of the American Society of Civil Engineers, Philadelphia, PA, American Society of Civil Engineers, pp. 305–312, June 23–25, 2003.