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AUTOMATED REMEDIAL ASSESSMENT METHODOLOGY SOFTWARE SYSTEM

M. Whiting
M. Wilkins
D. Stiles

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Pacific Northwest Laboratory
Richland, Washington 99352

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Automated Remedial Assessment Methodology software system

M. Whiting, M. Wilkins, D. Stiles

Pacific Northwest Laboratory, P.O. Box 999, Richland, Washington, USA 99352

Abstract

The Automated Remedial Analysis Methodology (ARAM) software system has been developed by the Pacific Northwest Laboratory to assist the U.S. Department of Energy (DOE) in evaluating cleanup options for over 10,000 contaminated sites across the DOE complex. The automated methodology comprises modules for decision logic diagrams, technology applicability and effectiveness rules, mass balance equations, cost and labor estimating factors and equations, and contaminant stream routing. ARAM is used to select technologies for meeting cleanup targets; determine the effectiveness of the technologies in destroying, removing, or immobilizing contaminants; decide the nature and amount of secondary waste requiring further treatment; and estimate the cost and labor involved when applying technologies.

Introduction

The Pacific Northwest Laboratory (PNL) has developed and automated a structured engineering methodology to analyze options for environmental restoration. The Automated Remedial Assessment Methodology (ARAM) system supports the evaluation of strategies such as strict compliance with contaminant concentration standards (e.g., applicable regulations), various land-use options (e.g., remediate to conditions suitable for farming versus maintaining civil control over a contaminated area), or various technology-driven strategies (e.g., contain contamination in place, while awaiting future technologies). These studies allow owners of large, complex, widely distributed contamination problems to evaluate the cost and occupational risks associated with remediation operations. They also provide a means of determining the costs and hazards associated with subsequent transportation, storage, treatment, and disposal operations required for waste streams following field remediation.

Pacific Northwest Laboratory is supporting the national environmental restoration efforts of the U.S. Department of Energy (DOE) through the use of ARAM. The DOE has operated several installations throughout the United States that carry out various national missions, including nuclear weapons research, development, and production; energy technology research; high-level radioactive waste disposal; and spent nuclear fuel disposal. A recently adopted DOE mission is to remediate sites and facilities contaminated by DOE activities. Currently, each DOE installation performs environmental restoration and waste management activities autonomously. DOE believes a consistent national approach would, however, improve the effectiveness and efficiency of the program. Therefore, the DOE is analyzing their existing program and other options supporting an integrated program (U.S. Department of Energy [1]). ARAM is one of the automated tools assisting in this work.

ARAM software system

ARAM processes data that characterizes a contaminated site against logic diagrams that describe remediation options to generate estimated waste volumes and environmental restoration costs.

The system can process several categories of contaminated media: soil, groundwater, surface water, buried waste, liquid containment structures, and inactive facilities. ARAM analyzes the characteristics of contaminated media and determines which sets of restoration technologies would likely be applied. It transforms the media according to the specification of the technologies applied and generates subsequent waste streams to be processed. The system calculates cost and labor estimates for the application and iterates through this process until end conditions are reached.

Logic diagrams provide a control structure through which sets of technologies can be applied to contaminated sites. Logic diagrams consist of media-specific technology modules and decision modules linked in the style of a flowchart. Nodes represent technology and decision modules and links represent waste streams. A diagram may be linked to others to sequentially process contaminated material, e.g., following the buried waste material processing, a contaminated soils diagram may be invoked to handle the surrounding soil problems.

Initially, the system had a short list of requirements, including the following:

- to process groups of contaminated site data records without human-intervention (i.e., a "batch-mode" execution)
- to process contaminated site data quickly (i.e., three hours to process 10,000 sites was acceptable, but two days was not)
- to provide an easily modifiable, externally defined control specification (the logic diagram) to describe a remedial option
- to run on a 80486-processor desktop workstation, under the Microsoft Windows operating system.

Initial versions of the system met all of these initial requirements. Subsequent versions have incorporated many requested extensions, while maintaining the short list.

ARAM Architecture

The ARAM architecture is simple, comprising four primary components: the user interface; the input and output processor; the technology, decision, and end node modules; and the internal processor. Figure 1 shows the connections among the architecture components.

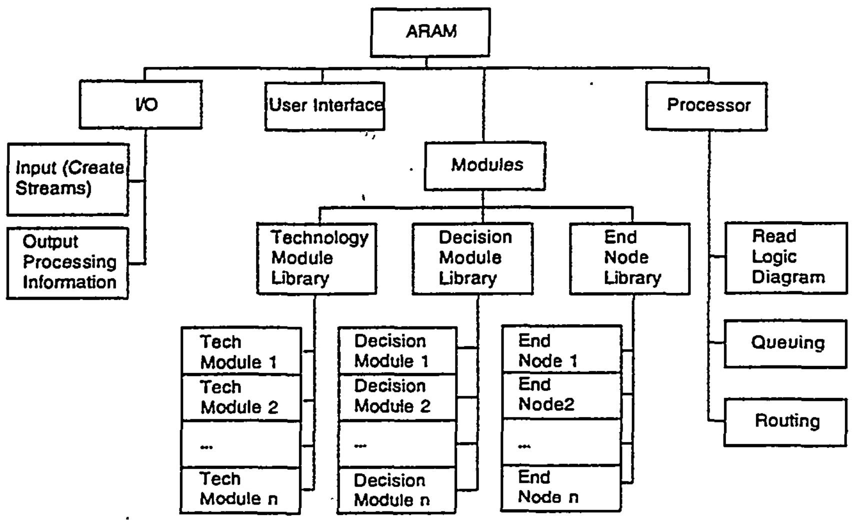

Figure 1. ARAM Architecture.

The technology, decision, and end node modules are linked as application-specific libraries. This architecture is flexible as it may be reused in a completely different application from environmental restoration. For example, waste management data could be analyzed by linking a waste management module library.

The major architectural components of ARAM are described below.

ARAM input/output

The ARAM system requires several diverse data sets to process remedial options on contaminated sites. Besides site characterization data, the control structures (the logic diagrams) are part of the input. Other data to support the analysis include unit risk factors, regulatory data, and contaminant classification and properties. The input files are read using CodeBase 5.0™, a library of application programming interface modules compatible with dBASE IV formatted files. Output data is written to a Microsoft ACCESS database via Open Database Connectivity (ODBC) software or to tab-separated text files. Figure 2 displays the flow of data into and out of the ARAM software system.

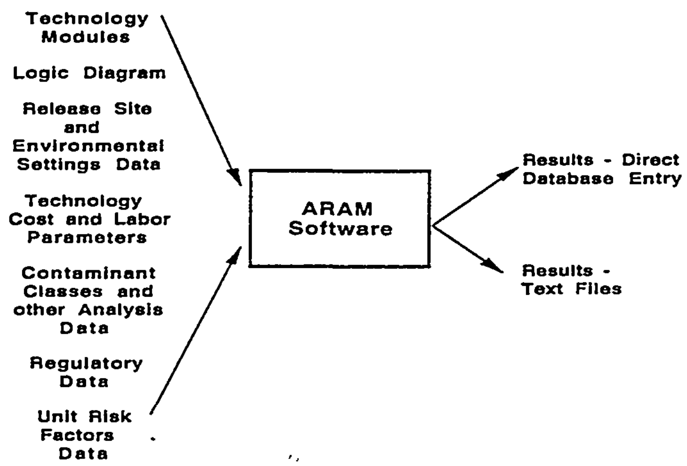

Figure 2.. ARAM data flow.

The input component initially creates a contaminated site object that represents the contaminated site to undergo remediation. This includes the following data:

- physical description (length, width, area, volume) of the contaminated area
- contaminant inventories
- target concentrations, based on regulatory and risk data, associated with an environmental restoration objective
- classification of contaminants.

Output information describes the processing and fate of the site and waste streams. This includes:

- history - a description of the logic diagram processing
- processes - the results of technology application on waste streams, with their cost and labor estimates
- streams - their volumes and compositions
- contaminants - their resulting inventory, volume, and concentration within waste streams and on site
- risk - residual public risk estimates via various pathways.

ARAM Processor

The ARAM processor manages waste streams and technology module invocation. When the ARAM system is started, an initial stream is created and passed to the first processing module on the logic diagram. The first module (representing the application of some technologies) creates secondary waste streams, and the processor hands these off to subsequent modules.

Inputs to and outputs from all modules are streams. If a module has two outputs, then it will produce up to two streams. The module definition computes the contents of the output streams (volumes and concentrations). An example of a typical technology module, as it would appear on a logic diagram, is shown in Figure 3. This module has two output streams which are named solid_particulate and treated_stream. In addition, it has a reject stream. When the module does not accept a stream, it sends the input stream unchanged along the reject arc. If it does accept an input stream, it sends an output stream along each of the two other output arcs.

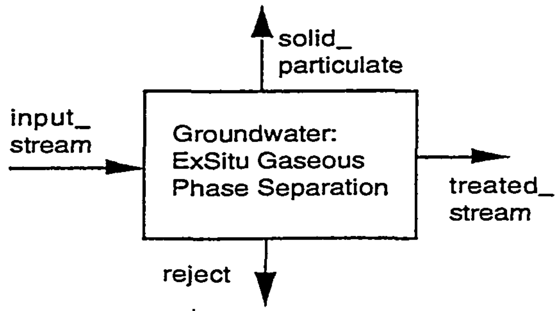

Figure 3. Technology Module

Note that the logic diagram and the technology module software must be consistent in the number and kinds of output streams. Mismatches are reported as run-time errors.

Decision modules always have two output arcs, a "yes" and a "no." An example of a decision module is shown in Figure 4. For each input stream, these produce a single output stream on one arc depending on the contents of the stream and the module definition.

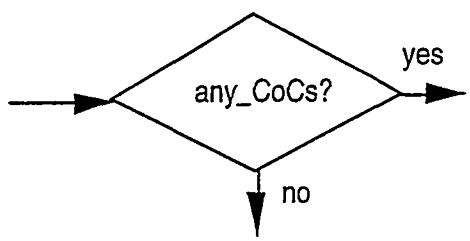

Figure 4. Decision Module

Because modules can produce more than one stream, the ARAM software system stores streams for processing in a first-in-first-out (FIFO) queue. When more than one stream must be processed, the ARAM software system chooses the first stream on the queue and sends it to the next appropriate module on the logic diagram. This continues within a single logic diagram for a single site until all streams have been deleted by being processed through end nodes.

The components of the processor were developed as C++ classes using Borland® C++ 3.1.

Technology, Decision, and End Node Modules

Technology modules process waste streams. The modules specify the following:

- applicability rules, where conditions of the waste stream control whether a technology may be applied
- mass-balance algorithms, which calculate residual contaminant concentrations and waste volumes, maintaining material balance and applying effectiveness factors
- cost and labor factors, based primarily on waste volume processed.

ARAM software is flexible about what constitutes a technology module. For the library of technology modules currently under development, treatment technologies are occasionally grouped to be representative of a collective behavior for a category of technologies. For example, algorithms for the gas phase removal category for contaminated soils represent the behavior of only a single technology, soil vapor extraction. However, algorithms formulated for the physical/chemical separation category for groundwater and surface water encompass the collective behavior of several technologies: coagulation and flocculation, gravity separation,, media filtration, forced evaporation, ion exchange, and liquid adsorption.

Decision modules have been built to provide correct waste stream routing when choices must be made on which chain of technologies to apply. The decisions are generally made based on contaminants of concern; those contaminants whose concentrations exceed some evaluative threshold. The threshold may be dictated by regulations, risk, or other means. Decision modules do not modify streams; they simply make a decision based on the stream data and pass the stream along one of two possible routes. Decision modules support the rules established to select the remediation option or to support rules of technology module applicability.

For example, one remediation option PNL has reviewed is known as a "totally restricted land use" scenario. Here, an entire area is restricted, and only risks to boundary receptors drive the remediation logic. For this option, a logic diagram might be created according to the following guidelines: in situ treatment and containment methods are the first steps in reducing risk, followed by removal and treatment. Containment methods are preferred because of expectations that costs and worker exposures are lower than treatment, but practical volumetric limits are set at which removal is more reasonable.

In a logic diagram for the totally restricted option, decision modules included may be the following:

- Has the in situ treatment reduced the risk to within targets?
- Has the containment procedure reduced risk to within targets?

Applicability rules generally check whether conditions are adequate for a treatment, for example:

- Are organic contaminants of concern present?
- Are conditions sufficient for contaminant destruction?

End nodes are a third type of module that accepts streams but do not output any streams. Typical end nodes include "To on-site disposal" indicating that the waste stream is sufficiently remediated for on-site disposal handling; and "To Waste Management" indicating that a stream has now passed from the purview of the environmental restoration handling, to that of waste management. This information would be of interest waste management organizations in making decisions about how to handle the kinds and amounts of waste material generated by environmental remediation actions.

The technology, decision, and end-node modules were written as C functions with standard call interfaces using Borland® C++ 3.1.

User Interface

The user interface, produced using Visual Basic 2.0™, provides the mechanism for specifying the parameters and input files for processing contaminated sites against logic diagrams. It supports easy "batch" processing, that is, it sets up runs of the system for several sites and processes without further user intervention.

ARAM Processing Example

It should be noted that in the current application of ARAM, logic diagrams commonly contain over 100 nodes with several linked diagrams to describe a remediation option. Also, multiple secondary streams are processed. As a simple example of ARAM processing, suppose the system were presented with a logic diagram similar to the one shown in Figure 5, which might be the foundation of a totally restricted land-use option for a soils release site.

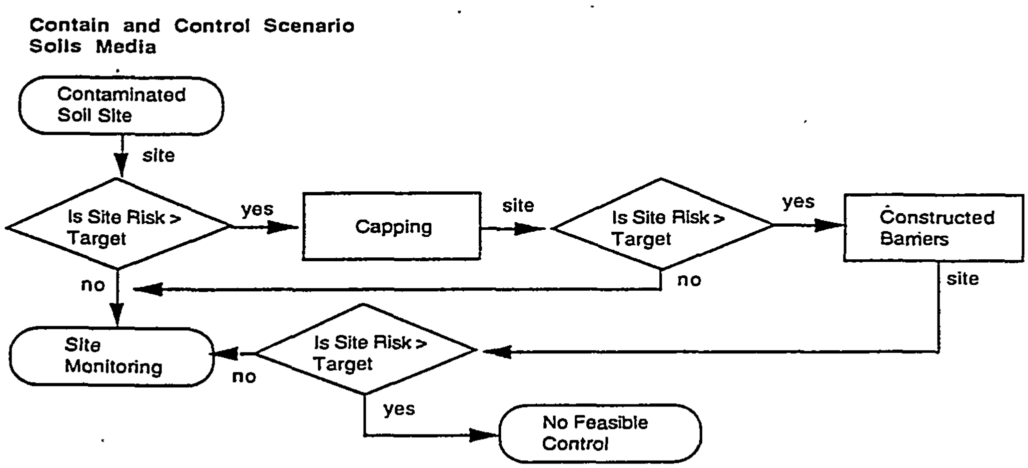

Figure 5. A Simple Containment Logic Diagram.

In this example, the site data is read into the system and an initial stream is created for processing. The first decision module examines the contaminants associated with this stream to decide whether any of them are above target levels for public risk. If the answer is yes, then processor passes the stream to the

Capping technology module. A cap is a horizontal constructed surface barrier consisting of alternating layers of sand, gravel, rock, clay, and occasionally, asphalt and/or a synthetic membrane. Stream volume would not be changed because of this technology, although certain contaminant mobility reduction factors are applied.

Following the application of this technology, a decision module analyzes the site again to decide whether the contaminants are above the risk target. If the answer is still yes, the stream is passed to the Constructed Barriers technology module. Constructed barriers consist of slurry walls encircling the contaminated soil site. Again, the volume of the material would not be changed because of this technology, although contaminant mobility reduction factors are applicable.

Following application of this technology, the last decision module analyzes the site to decide whether the contaminants are above the risk target. If the answer is still yes, control is passed to an end node signifying that no feasible control can be discovered by this logic diagram for the site.

The ARAM software generates output data that describes the state of the site as it is processed, the state of the contaminants as they are processed, the processing pathway and information concerning the decisions as they are made. In the example above, an analyst might be most interested as to the cause of the system reaching the No Feasible Control module and would review the pathway and the interim states for resolution.

If additional sites are to be processed, the ARAM system continues until all sites specified in the initial set up are analyzed.

Conclusion

This paper describes the ARAM software system created by the Pacific Northwest Laboratory to analyze environmental restoration options for large, distributed contamination problems. The system has supported an estimated 50,000 site analyses for DOE to date, generating approximately 2GB of results data. Users of ARAM have acknowledged a distinct advantage over their original process of analyzing this data by hand.

The ARAM system is flexible. It can be configured to support comparative analyses within a domain through the addition or modification of logic diagrams or reconfigured for a completely new application through modification of the technology module library.

There are several interesting extensions that could be made to the ARAM software to better support users. Often requested is an interactive mode, where the state of the system may be examined during execution. Another extension is to include aggregation of information beyond the site level. Currently, all aggregation and summarization are done externally to the ARAM.

References

1. U.S. Department of Energy. *Implementation Plan: Environmental Restoration and Waste Management Programmatic Environmental Impact Statement*, Washington, D.C., 1994.

Acknowledgment

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