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THE COST OF REMEDIAL ACTIONS (CORA) MODEL: OVERVIEW AND APPLICATIONS

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ABSTRACT

The Cost of Remedial Actions (CORA) model estimates site-specific remedial action costs for hazardous waste sites. The model is microcomputer-based and has two components: an expert system to recommend a range of remedial technologies, and a cost system. The expert system interacts with the user and develops ranges of recommended remedial action technologies. The cost system contains algorithms capable of developing order-of-magnitude cost estimates for 40 demonstrated technologies.

The CORA model has been used successfully in a number of different applications. The model was used for the U.S. EPA for the outyear Superfund remedial action budgeting for FY 1989 and FY 1990, and will be used for the upcoming FY 1991 budgeting. The model was also used to develop U.S. Navy Installation Program budgets for FY 1989, 1990, and 1991.

BACKGROUND

Capital and operation and maintenance (O&M) cost estimates are required for Superfund remedial actions at sites in the U.S. EPA's Superfund Comprehensive Accomplishments Plan (SCAP). These estimates are used to manage current activities and develop outyear budgets.

During the early years of the Superfund program (1981-83), little historical data existed for developing cost estimates for the wide variety of conditions found at Superfund sites. Therefore, the program instead relied on "average" pricing factors to develop budgets. However, the subjective nature of these pricing factors and the absence of studies to confirm the factors were considered weaknesses in the program.

In mid-1983, the U.S. EPA commissioned a study to attempt to quantitatively define pricing factors for remedial actions. Because of scant historical construction cost information, a modeling approach for developing pricing factors was selected. Information was obtained about site conditions at a small sample of Superfund sites and a set of written decision rules was used to select remedies. The sites in the study were segregated into site types (e.g., landfills, drum sites, etc.), and the costs of the remedies were estimated using a unit-pricing approach. The resultant estimated costs were averaged and extrapolated to include the 546 sites on the NPL. The estimates were then aggregated to arrive at an average cost of construction for an NPL site.

As the 1985 update of the FY 1986 budget approached, the U.S. EPA sought to develop site-specific budgeting. The U.S. EPA attempted to disaggregate the 1985 results for use on individual sites. Efforts to refine these estimates pointed out the need for a more accurate pricing technique for individual sites.

Since budgets are developed 18 months prior to the SCAP operating year, the U.S. EPA realized it needed a method to estimate remedial action costs in the prefeasibility stage of analysis. This method was to incorporate:

- A reproducible and consistent method of applying the remedy selection guidance
- A straightforward method of developing site-specific order-of-magnitude cost estimates

The CORA model was developed in response to these needs and is now being used to estimate the cost of outyear Superfund remedial actions for specific sites. Cost estimates are aggregated from the CORA model results and a variety of other sources, including U.S. EPA Records of Decision (RODs) and feasibility studies (FSs), to form the U.S. EPA regional and overall outyear budgets.

SUMMARY DESCRIPTION OF THE CORA MODEL

The CORA model includes two distinct microcomputer-based subsystems. One subsystem is an expert system for selecting a range of reasonable remedial action technologies from among 40 such technologies in the system. The other is a cost system with cost modules for all 40 remedial action technologies in the expert system. The cost system is used to develop order-of-magnitude cost estimates for site remedial scenarios. The cost and expert subsystems operate independently of each other.

The system is not intended to incorporate all of the many technologies that would be necessary to address every type of site; the goal instead was to address the majority of sites. "Outliers" include sites with radioactive waste and mining sites. Figure 1 lists the 40 technologies now in the expert system and cost modules. Four auxiliary cost modules (site preparation, site administration, health and safety, and contingencies and allowances) interface with these 40 primary technology cost modules to generate scenario-specific site costs for remediation. Each technology was selected based on its frequency of use for hazardous waste remediation, and the ability to define a scope range and develop cost estimates for it. Some emerging technologies (such as in situ vitrification or UV-ozonation) were not included in the model because of scope and cost uncertainties. However, the CORA framework allows for expansions, and other technologies will be considered for addition during annual updates of the model.

EXPERT SYSTEM

There are two components to an expert system: an "inference engine," which contains general problem-solving knowledge, and one or more programs ("knowledge bases") that contain the "domain knowledge" (specific knowledge about a particular problem area).

The expert system portion of CORA was developed using the Level 5 Expert System shell version 1.0. This functions as the inference engine, processing the compiled knowledge bases, making queries to the user, executing external programs, and evaluating the rules of the knowledge bases to establish conclusions and recommendations.

The CORA knowledge bases consist of approximately 670 decision rules for applying 40 fairly well-developed technologies at Superfund sites. The decision rules reflect both engineering expertise and approaches drawn from hazardous waste projects and policy issues. Also included in the decision rules are questions regarding interpretation of the language of the Superfund Amendments and Reauthorization Act (SARA) and Hazardous and Solid Waste Amendments (HSWA). The expert system analyzes a site by focusing on separate user defined contaminated areas. The user responds to system-selected questions for each waste type within a contaminated area. For a particular set of user answers corresponding to a certain contaminated area, the expert system recommends a range of potentially implementable and applicable remedial action technologies. These technologies can be combined by the user to form one or more remedial action alternatives. The user can change his or her answer to particular questions to explore a range of outcomes.

COST SYSTEM

The CORA cost system was developed using dBASE III Plus software. Ninety separate programs were developed, split into three different files, compiled with the Nantucket Clipper Compiler, and linked together to form the cost system.

After site remedial action scenarios are determined, the cost system is used to develop order-of-magnitude cost estimates, which have an accuracy range of +50 to -30 percent. The cost system currently comprises 40 primary cost modules and a system designed to organize the cost estimates by site, operable unit, and alternative scenario. The following approach was used for developing each cost module:

- Key parameter range limits were assumed (e.g., treatment systems for groundwater extraction were limited to 2,000 gpm per unit)
- Conceptual designs were developed for each technology
- Detailed cost line items were defined within specified range limits for each technology
- Microcomputer cost spreadsheets were created for each technology, with relationships allowing individual cost line items to vary over defined design ranges
- Sensitivity analyses were performed to identify key cost variables
- Cost algorithms were developed based on the key variables
- Cost modules were developed with the key variables as user inputs and with some default values where users may not initially have a site-specific value

The cost system is organized by site, operable unit, scenario, and technology. The system first asks the user to either select an existing site that is in the site cost data base, or designate a new site. The user then designates operable units and scenarios to be considered. Technologies for the scenarios may be based on recommendations from the CORA expert system or other technology screening and alternative development methods. The user then runs the cost modules and inputs the required costing parameters. The cost system calculates capital and first-year O&M cost estimates for each technology selected. Individual technology cost runs are stored under scenarios named by the user. The user can select combinations of previous cost runs from the site-summary cost scenario menu and generate ranges of overall site costs for different alternatives.

Most cost modules provide the user with base-case default values for some parameters. The user may use the default values, or input known or estimated site-specific information. Example default parameters include:

- **For a multilayered RCRA cap**—thicknesses for seven different cap layers
- **For a soil bentonite slurry wall**—percent bentonite required for slurry, percent slurry loss due to waste and seepage
- **For onsite incineration**—percentage ash and moisture content, depending on user-selected waste form; kiln and afterburner temperature, depending on user information on waste constituents
- **For air stripping**—volatile organic compound (VOC) specific effluent concentrations for discharge to surface water
- **For soil vapor extraction** (SVE)—default radius of influence for SVE extraction wells, depending on user-selected type of soil

If the user selects default values, he or she can easily edit the input value and update the cost estimate when site-specific information is available.

Some of the CORA cost modules contain powerful built-in modeling capabilities, including those for

- **Groundwater extraction.** If the number of extraction wells is not known, CORA will estimate a number based on the following factors: aquifer storativity, hydraulic conductivity, aquifer thickness, area of contamination, depth of wells, and desired time for cleanup.

- **Soil excavation.** CORA allows for sequencing of excavation activities at sites where multiple lifts may be taken and where there may be loss of productivity due to analytical turnaround times between lifts. The excavation productivity modeling algorithms include considerations for anticipated depth of contaminated zone, contaminated zone excavation layer thicknesses, area to excavate, and levels of worker health and safety protection.

- **Onsite incineration.** CORA runs through more than 70 material and energy balance equations to determine case-specific waste feed rates, auxiliary fuel, power requirements, and makeup water for a rotary kiln incinerator.

- **Air stripping.** CORA sizes air stripping systems (tower diameter, packing height, blower horsepower, air flow rate) based on user inputs for influent flow rate and specific VOC influent and desired effluent concentrations.

EXAMPLE OUTPUT

Figure 2 shows an actual CORA expert system input summary and corresponding output. The summary is for a Superfund site where a city well field supplying potable water was found to be contaminated with VOCs, principally chlorinated solvents. The contamination source was found to be a solvent wholesaling company. VOC contamination in soils at the site was found to be as high as 1,000 parts per million (ppm). Well field groundwater concentrations were found to be contaminated at levels of up to 18 ppm.

Figures 3 and 4 show an actual CORA cost system site cost summary based on a U.S. EPA ROD-selected remedy. The proposed site remedy includes:

- A 66-acre clay cap

- A 9,000-foot-long and 60-foot-deep soil bentonite slurry wall

- An active landfill gas collection system and flaring for landfill gas from a 100-acre area

- A 120-gpm groundwater extraction system with subsequent air stripping, metals precipitation and sludge dewatering, and pressure discharge to the local publicly owned treatment works (POTW)

EXPERIENCE

Version 1.0 of the CORA model was completed in April 1987, and Version 2.1 in June 1988. The U.S. EPA contracted with an outside consultant to conduct a validation study of the model. The study (*Performance Evaluation of CORA Model*, ICF, January 1989) included a review of the decision rules and expert system operation and recommendations. The study also ran the CORA cost system for 12 Superfund sites to compare the results with existing design, bid, or construction costs. Of the 12 sites, 10 of the 12 Version 1.0 CORA estimates and all 12 Version 2.1 estimates were within the system design cost range based on comparison with the U.S. EPA design, bid, or construction costs. The study concluded that the expert system "is a useful tool for EPA budget estimates," uses sound logic, and develops reasonable recommendations.

In May 1987, the CORA model was used to develop cost estimates for 97 U.S. EPA Superfund sites likely to be FY 1989 remedial action candidates. For each site, CH2M HILL team members worked one-on-one with U.S. EPA regional project managers (RPMs) and completed CORA expert system and cost system runs.

Results for sites in the pre-FS stage were combined with cost information from FSs and RODs to develop the FY 1989 budget. A number of analyses have been conducted on the FY 1989 site costs, and the results have helped the U.S. EPA shape the selection of remedy processes under the Superfund Amendments and Reauthorization Act. The model was also used in April 1988 to develop costs for the FY 1990 budget, and will be used in April 1989 to develop costs for the FY 1991 budget.

The CORA model was also applied during the summer of 1988 to 661 Navy installation restoration program sites. As with the U.S. EPA costing exercise, each team member worked one on one with the Naval Facilities Engineering Command (NAVFAC) engineer responsible for the site. The costs were used by Navy personnel to estimate Defense Environmental Restoration Act funding for fiscal year 1989, 1990, and 1991. In addition, CORA is being used to develop remedial action strategies and estimate total Department of Defense wide remediation costs.

The CORA model has also been used for RCRA regulatory support. For the RCRA Location Standards Rule, the model was used to analyze remediation costs for six site types in differing hydrogeologic, ecological, and geographic settings to support the regulatory impact analysis. A total of 30 corrective action alternatives were identified and costed.

The CORA model has also been used to screen technologies, develop alternatives, and estimate initial remediation costs for several other sites. To date, more than 150 copies of the model have been distributed to federal and state agencies, foreign governments, environmental consultants, and industries.

FUTURE APPLICATIONS

The CORA expert and cost systems were both designed to allow revision and expansion. U.S. EPA funds have been appropriated for continued maintenance, enhancements, and incorporation of user feedback to reflect current regulatory policies, demonstrated technologies, and cost considerations.

Use of the CORA model is expected to continue to expand. Future applications include:

- Use by EPA regions to develop fiscal outyear Superfund remediation budgets and to perform initial site-specific remediation scoping
- Use by the U.S. Navy and other federal agencies to estimate outyear and total programmatic remediation budgets
- Use to anticipate cost effects for Regulatory Impact Analyses of new environmental regulations
- Use by states for total program and site-specific remediation budgeting and scoping
- Potential use by U.S. EPA, states, industries, and environmental professionals in technology screening, scoping, and budgeting of RCRA Corrective Actions and Facility Closures
- Use by environmental consultants for pre-FS (and some FS) technology screening, scoping, and budget estimating

The CORA model has proven to be a powerful tool for scoping potential costs of hazardous waste remediation, even during the initial stages of site investigations. Early awareness of potential site alternatives and cleanup costs can help expedite site remediation by focusing site investigations, studies, and designs on site-specific priorities.

FIGURE 1
CORA COST MODULES

CONTAINMENT

101 Soil Cap
102 Asphalt Cap
103 Multilayered RCRA Cap
105 Soil/Bentonite Slurry Wall
106 Surface Controls

REMOVAL

201 Soil Excavation
202 Sediment Excavation/Dredging
203 Pumping Contained Wastes
204 Drum Removal
205 Active Landfill Gas Collection
206 Groundwater Extraction

AUXILIARY

Health and Safety
Site Preparation
Site Administration
Contingencies and Allowances

TREATMENT

301 Onsite Incineration
302 Offsite Incineration
303 Soil Flushing
304 In-Situ Bioremediation
305 Soil Vapor Extraction
306 Flaring
307 Air Stripping
308 Vapor Phase Carbon
309 Activated Carbon
310 Activated Sludge
311 Metals Precipitation
312 Ion Exchange
313 Pressure Filtration
314 Residential Activated Carbon Units
315 Offsite RCRA Treatment and Recycling
316 Solidification

DISPOSAL

401 Offsite RCRA Landfill
Onsite RCRA Landfill
- 402 Below Grade
- 403 Above Grade

404 Offsite Solid Waste Landfill
405 Discharge to POTW
406 Discharge to Surface Water
407 Water Reinjection
408 Water Infiltration

MISCELLANEOUS

501 Transportation
502 Municipal Water Supply
503 Groundwater Monitoring
504 Site Access Restrictions
505 User-Supplied Costs

Figure 2

Examples of CORA Expert System Remedial Technology Selection

*************** DRAFT ****************

DATE: 03/08/89
TIME: 09:24:46

CORA EXPERT SYSTEM

RUN: EXAMPLE TREATMENT RUN
RUN BY: KLK
SITE: HAZMACON EXAMPLE
CONTAMINATED AREA: SOILS AT SOLVENT PLANT & CITY WELLFIELD AQUIFER

WASTE TYPE: HOT SPOTS (UNSATURATED MTL AROUND LEAKY TANKS OR DRUMS)

INPUT
Response type: Treatments
Soil description: Medium sand
Soil contaminant: Volatile organic compounds
Site conditions could threaten: True
Exposed to erosion: False

RECOMMENDATIONS FOR HOT SPOTS (UNSATURATED MTL AROUND LEAKY TANKS OR DRUMS)

GENERAL
o 504 Site access restrictions
o 503 Groundwater monitoring

IN SITU SOILS TREATMENTS
o 305 Soil vapor extraction for VOCs
Either
o 306 Flaring for VOCs
Or
o 308 Vapor phase carbon for VOCs

WASTE TYPE: CONTAMINATED SATURATED SOILS (GROUNDWATER)

INPUT
Saturated zone description: Karst limestone
Response action: Active restoration
Source in saturated zone: False

USER RESPONSES FOR contaminated saturated soils
Liquid phase contaminants: VOCs in water solution
Discharge options: Discharge to surface water
Impermeable stratum exists: False
Domestic water supply is contaminated: True
Permanent alt water supply: False
Exceed cancer risk: True

RECOMMENDATIONS FOR CONTAMINATED SATURATED SOILS (GROUNDWATER)

GENERAL
o 503 Groundwater monitoring
o 502 Municipal water supply

GROUNDWATER EXTRACTION
o 206 Groundwater extraction

DISCHARGE
o 406 Discharge to surface water

WATER TREATMENT of water from extracted groundwater
o 307 Air stripping for VOCs
o Evaluate need for 308 vapor phase carbon or 306 flaring for VOCs

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NOTE: Numbers used with "Recommendations" (e.g., "504 site access restrictions") correspond to CORA cost system module numbers (see Figure 1).

Figure 3

CORA Cost System Summary for EPA-Selected Remedy (Capital Costs)

********** DRAFT **********

DATE: 03/07/89
TIME: 17:39:34

CAPITAL COST DEVELOPMENT

SITE NAME: HAZMACON EXAMPLE SITE — TOXIC LANDFILL   REGION: 10

OPERABLE UNIT: ENTIRE SITE
ESTIMATED START: MID FY 1989
RUN BY: PHONE NUMBER:

INDIVIDUAL TECHNOLOGY COSTS

SCENARIO: ROD REMEDY

SOIL CAP	9,400,000
SOIL/BENTONITE SLURRY WALL	3,800,000
SURFACE WATER DIVERSION/COLLECTION	24,000
PUMPING CONTAINED WASTES	450,000
ACTIVE LANDFILL GAS COLLECTION	1,600,000
GROUNDWATER EXTRACTION	120,000
FLARING	110,000
AIR STRIPPING	68,000
METALS PRECIPITATION	1,900,000
OFFSITE RCRA TREATMENT & RECYCLING	0
TRANSPORTATION TO OFFSITE RCRA TREATMENT & RECYCLING	0
OFFSITE RCRA LANDFILL	0
TRANSPORTATION TO OFFSITE RCRA LANDFILL	0
DISCHARGE TO POTW	99,000
GROUNDWATER MONITORING	59,000
SITE ACCESS RESTRICTIONS	330,000
SUBTOTAL	18,000,000

SITE COSTS

SITE PREPARATION	0
SITE ADMINISTRATION	510,000

GENERAL CONDITIONS

START-UP COSTS	190,000
CONSTRUCTION SUBTOTAL	19,000,000
BID CONTINGENCIES	3,800,000
SCOPE CONTINGENCIES	2,900,000
CONSTRUCTION TOTAL	26,000,000
PERMITTING AND LEGAL COSTS	900,000
SERVICES DURING CONSTRUCTION	1,600,000
TOTAL SITE CAPITAL COST	29,000,000

NOTES

*** All costs are rounded to two significant figures.

*** The cost estimates shown are based on the data input to the program and cost algorithms developed for generic conditions. The final costs will depend on actual site, design and market conditions. As a result, the final project costs will vary from the estimates presented here.

Figure 4

CORA Cost System Summary for EPA-Selected Remedy (Operation and Maintenance Costs)

********** DRAFT **********

DATE: 03/07/89
TIME: 17:39:47

OPERATION AND MAINTENANCE COST DEVELOPMENT

SITE NAME: HAZMACON EXAMPLE SITE — TOXIC LANDFILL   REGION: 10

OPERABLE UNIT: ENTIRE SITE
ESTIMATED START: MID FY 1989
RUN BY: PHONE NUMBER:

INDIVIDUAL TECHNOLOGY COSTS

SCENARIO: ROD REMEDY

SOIL CAP	42,000
SOIL/BENTONITE SLURRY WALL	31,500
SURFACE WATER DIVERSION/COLLECTION	1,400
PUMPING CONTAINED WASTES	0
ACTIVE LANDFILL GAS COLLECTION	320,000
GROUNDWATER EXTRACTION	57,000
FLARING	4,400
AIR STRIPPING	30,000
METALS PRECIPITATION	342,200
OFFSITE RCRA TREATMENT & RECYCLING	88,200
TRANSPORTATION TO OFFSITE RCRA TREATMENT & RECYCLING	4,700
OFFSITE RCRA LANDFILL	30,000
TRANSPORTATION TO OFFSITE RCRA LANDFILL	19,000
DISCHARGE TO POTW	71,000
GROUNDWATER MONITORING	62,000
SITE ACCESS RESTRICTIONS	77,000
SUBTOTAL	1,200,000

SITE COSTS

SITE PREPARATION	0

GENERAL CONDITIONS

INSURANCE AND PERMIT RENEWAL	180,000
SUBTOTAL	1,400,000

INDIRECT COSTS

ADMINISTRATION	210,000
CONTINGENCIES	210,000
TOTAL SITE O & M COST	1,800,000

NOTES

*** All costs are rounded to two significant figures.

*** The cost estimates shown are based on the data input to the program and cost algorithms developed for generic conditions. The final costs will depend on actual size, design and market conditions. As a result, the final project costs will vary from the estimates presented here.