# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# THESIS

**FUNDING SITE CLEANUP AT CLOSING ARMY INSTALLATIONS: AN INTEGER LINEAR PROGRAMMING APPROACH**

by

Samettin Oremis

December 2000

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20010215 052

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# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

| 1. AGENCY USE ONLY *(Leave blank)* | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | December 2000 | Master's Thesis |

**4. TITLE AND SUBTITLE**
Funding Site Cleanup at Closing Army Installations: An Integer Linear Programming Approach

**5. FUNDING NUMBERS**

**6. AUTHOR(S)**
Oremis,Samettin

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Naval Postgraduate School
Monterey, CA 93943-5000

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

**12a. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** ***(maximum 200 words)*** Since 1988, the United States Army has closed 112 and has completed or will soon complete realignment of another 27 of its domestic installations. The Army estimates the total cost (between 1988 and 2001) of these closures and realignments to be $5.3 billion, of which about $2.3 billion (43%) is associated with environmental cleanup. Beyond 2001, the Army expects to spend an additional $1.09 billion to complete cleanup and continue restoration. The Army Base Realignment and Closure Office (BRACO) is currently funding environmental cleanup at 649 sites on 39 current and former Army installations. BRACO's environmental restoration budget from 2001 to 2007 to support cleanup at these installations (totaling over $620 million) is not sufficient to support each installation's requirement for those years. Considering environmental policies and yearly funding requests from 2001 to 2015 for each site, this thesis develops optimization models and a spreadsheet interface to help BRACO allocate its budget. Model results prescribe either funding each site as requested or delaying cleanup by one to five years. Extensive model use helped BRACO analyze alternate yearly budgets, suggest alternate site funding, and determine site funding for 2001 to 2007.

**14. SUBJECT TERMS**
Integer Linear Program, Optimization, Environmental Cleanup, Budget Allocation

**15. NUMBER OF PAGES**
58

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 289)
Prescribed by ANSI Std. 239

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# FUNDING SITE CLEANUP AT CLOSING ARMY INSTALLATIONS: AN INTEGER LINEAR PROGRAMMING APPROACH


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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN OPERATIONS RESEARCH**

from the

**NAVAL POSTGRADUATE SCHOOL**
**December 2000**

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## ABSTRACT

Since 1988, the United States Army has closed 112 and has completed or will soon complete realignment of another 27 of its domestic installations. The Army estimates the total cost (between 1988 and 2001) of these closures and realignments to be $5.3 billion, of which about $2.3 billion (43%) is associated with environmental cleanup. Beyond 2001, the Army expects to spend an additional $1.09 billion to complete cleanup and continue restoration. The Army Base Realignment and Closure Office (BRACO) is currently funding environmental cleanup at 649 sites on 39 current and former Army installations. BRACO's environmental restoration budget from 2001 to 2007 to support cleanup at these installations (totaling over $620 million) is not sufficient to support each installation's requirement for those years. Considering environmental policies and yearly funding requests from 2001 to 2015 for each site, this thesis develops optimization models and a spreadsheet interface to help BRACO allocate its budget. Model results prescribe either funding each site as requested or delaying cleanup by one to five years. Extensive model use helped BRACO analyze alternate yearly budgets, suggest alternate site funding, and determine site funding for 2001 to 2007.

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## TABLE OF CONTENTS


I. INTRODUCTION ..... 1

- A. ENVIRONMENTAL CLEANUP ..... 3
- B. ENVIRONMENTAL CLEANUP POLICY ..... 5
- C. SITE CHARACTERISTICS ..... 5
- D. PROBLEM STATEMENT ..... 7
- E. OUTLINE ..... 7

II. LITERATURE REVIEW ..... 9

III. OPTIMIZATION MODELS FOR BUDGET ALLOCATION ..... 13

- A. CBAEC-1 ..... 13
- B. BAEC-1 ..... 16
- C. CBAEC-2 ..... 17
- D. BAEC-2 ..... 17

IV. IMPLEMENTATION AND RESULTS ..... 19

- A. DATA ..... 19
- B. IMPLEMENTATION OF MATHEMATICAL MODEL ..... 21
- C. DATA OUTPUT ..... 22
- D. COMPUTATIONAL RESULTS AND SENSITIVITY ANALYSIS ..... 28

V. CONCLUSIONS ..... 33

APPENDIX A ..... 35

APPENDIX B ..... 37

LIST OF REFERENCES ..... 39

INITIAL DISTRIBUTION LIST ..... 41

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## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AMC | Army Materiel Command |
| BAEC | Budget Allocation for Environmental Cleanup |
| BCT | Base Realignment and Closure Cleanup Team |
| BRAC | Base Realignment and Closure |
| BRACO | Base Realignment and Closure Office |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act (1980) |
| DoD | Department of Defense |
| EPA | United States Environmental Protection Agency |
| FFA | Federal Facility Agreement |
| FORSCOM | Forces Command |
| GAMS | General Algebraic Modeling System |
| GAO | United States General Accounting Office |
| IRA | Interim Remedial Action |
| LTM | Long-Term Monitoring |
| LTO | Long-Term Operations |
| MACOM | Major Army Command |
| MDW | Military District of Washington |
| MEDCOM | Medical Command |
| MORTI | Modeling to Optimize Restoration Tracking and Investments |
| MTMC | Military Traffic Management Command |
| NCP | National Contingency Plan |
| NPL | National Priority List |
| PCF | Programmatic Confidence Factor |
| RA-C | Remedial Action Construction |
| RA-O | Remedial Action Operation |
| RC | Response Complete |
| RCRA | Resource Conservation and Recovery Act |
| RD | Remedy Decision |
| RI | Remedial Investigation |
| RIP | Remedy in Place |
| SI | Site Investigation |
| TRADOC | Training and Doctrine Command |
| USARPAC | United States Army Pacific Command |

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## EXECUTIVE SUMMARY

Since 1988, the United States Army has closed 112 domestic installations and completed realignment of another 25 of 27 installations under Base Realignment and Closure programs. The Army estimates the total cost (between 1988 and 2001) of these closures and realignments to be $5.3 billion, of which about $2.3 billion (43%) is associated with environmental cleanup. Though closed, many installations still have a small active caretaker element overseeing required environmental cleanup. Beyond 2001, the Army expects to spend an additional $1.09 billion to complete cleanup and continue restoration. The Army Base Realignment and Closure Office (BRACO) is currently funding environmental cleanup at 649 sites on 39 current and former Army installations. BRACO's environmental restoration budget from 2001 to 2007 to support cleanup at these installations (totaling over $620 million) is not sufficient to support each installation's requirement for those years. Considering environmental policies and yearly funding requests from 2001 to 2015 for each site, this thesis develops optimization models and a spreadsheet interface to help BRACO allocate its environmental cleanup budget.

In addition to a yearly funding request for each site, installations also provide BRACO with numerous other site characteristics such as: presence of unexploded ordnance, existing legal agreements, planned reuse date (estimated date when the site will be conveyed to a receiving authority), and relative risk (determined as high, medium or low using a standard method). These characteristics are used to help gauge the relative value of funding the site according to the installation's request or to delay the cleanup.

Two optimization models are introduced in this thesis. Each model recommends either funding each site as requested or delaying cleanup. The models CBAEC-1 and BAEC-1 use six cleanup options, funding each site as requested or delaying cleanup by one to five years. The model variations CBAEC-2 and BAEC-2 are identical to CBAEC-1 and BAEC-1 except they have three more cleanup options. The integer programs BAEC-1 and BAEC-2 are identical to the linear models except they ensure the cleanup at each site is completed using exactly one cleanup option. Linear programs CBAEC-1 and CBAEC-2 can suggest possible alternative funding (using a convex combination of options) not available when using the integer linear programs. These convex combinations require careful review to insure they can be implemented, whereas the integer solutions provide simple delays that are easier to implement.

Extensive model use helped BRACO analyze alternate yearly budgets, suggest alternate site funding, and determine site-by-site funding for 2001 to 2007. Final results delayed cleanup at 43 sites located at only four different installations.

## ACKNOWLEDGMENTS

I wish to extend my sincere thanks and appreciations to the following individual:

- To my advisor, Professor Robert Dell, for his guidance, advice, and overall assistance. his expertise was instrumental in keeping things focused and moving forward throughout this research.
- To my family; Nuran and Saltuk Bugra. Your support and patience during the months of research made a challenging task infinitely more tolerable.

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# I. INTRODUCTION

Immediately after the Cold War, the United States considered its military infrastructure larger than required to meet anticipated future national security needs. Consequently, the United States Congress enacted two laws that instituted base closure rounds in 1988, 1991, 1993, and 1995 [United States General Accounting Office (GAO) 1996]. Through these four Base Realignment and Closure (BRAC) rounds, the Army has closed 112 domestic installations, realigned another 25, and has another two installation realignments almost complete [Martin 2000]. Though closed (all active military missions have ceased or relocated), many installations have a small active caretaker element overseeing required environmental cleanup [United States Department of the Army 2000].

In September 2000, the United States Army Base Realignment and Closure Office (BRACO), the primary office responsible for overseeing Army BRAC execution, was completing funding or was planning to fund environmental cleanup at 50 Army installations (Figure 1 and Appendix A) from seven Major Army Commands (MACOMs). As of December 2000, the number of installation has been reduced to 39. The total number of sites requiring cleanup (the term *site* refers to a sub-element of an installation, such as a military building, training area, ammunition breakdown point, or chemical disposal ground) at these installations is 649 [Martin 2000].

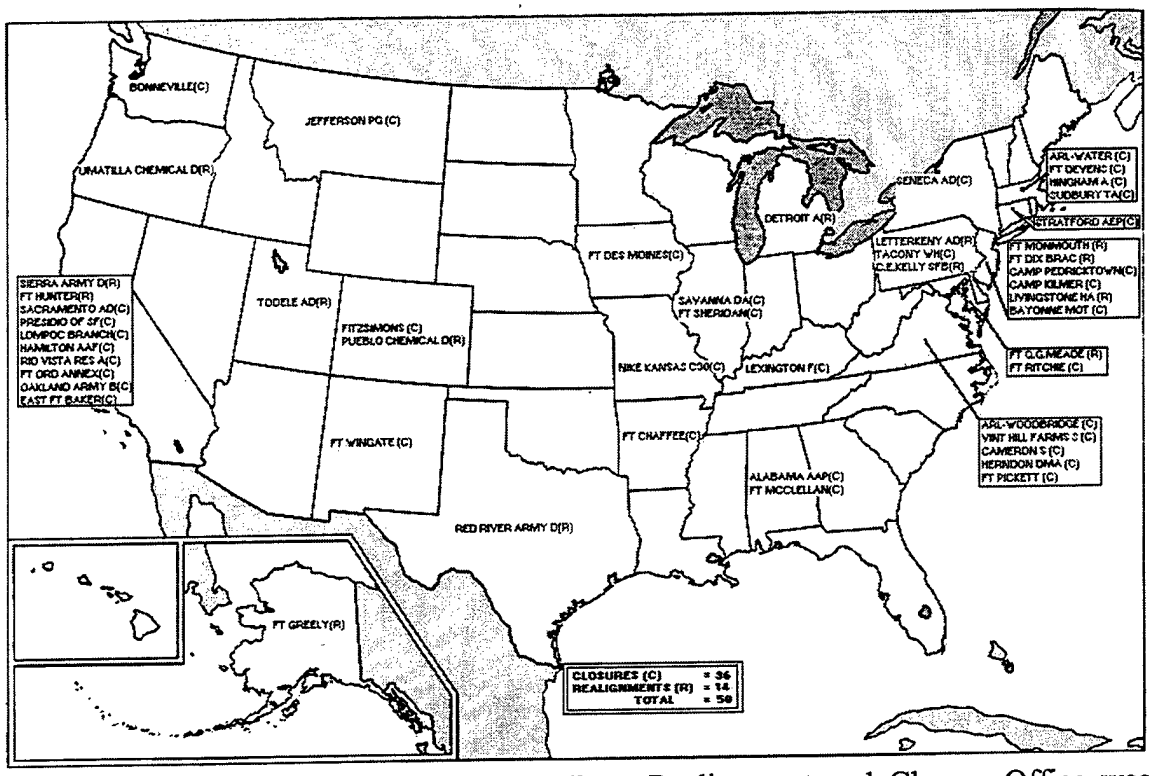


Figure 1. In September 2000, The Army Base Realignment and Closure Office was completing funding or was planning to fund environmental cleanup at 50 Army installations. The installation statute code "C" represents "Closure" and "R" represents installation "Realignment".

By 2001, after four rounds of BRAC, United States domestic military basing will be 20 percent smaller than its 1988 level. The Department of Defense (DoD) estimates the total cost of BRAC rounds as $23 billion, providing a net savings of $14 billion by 2001. Of the $23 billion estimated cost for the entire BRAC program, about $7.2 billion (31%) is associated with environmental cleanup. The Army's portion of this cost is $5.3 billion, of which $2.3 billion (43%) is associated with environmental cleanup [Martin 2000]. Beyond 2001, DoD expects to spend an additional $2.4 billion (the Army expects to spend $1.09 billion) to complete cleanup and continue restoration. [GAO 1999]

The main reasons for the high costs of cleanup at closed and realigned installations include: (1) the large number of contaminated sites and difficulties associated with types of contamination, (2) lack of cost-effective cleanup technology for certain contaminants (such as unexploded ordnance), and (3) intended property reuse [GAO 1996]. DoD must abide by laws and regulations when expediting property transfer for reuse that make environmental cleanup very time-consuming, complex, and costly.

## A. ENVIRONMENTAL CLEANUP

The purposes of environmental cleanup at BRAC installations are to: reduce risk to human health and the environment; make property at closing and realigning bases environmentally suitable for transfer to other entities; and have final remedies in place [BRACO 1999].

The major phases associated with DoD environmental cleanup are shown in Figure 2. Initially, *site identification* (through record search and/or visual inspection) produces a candidate list. *Site Investigation* (SI) of the candidates includes detailed environmental sampling and analysis that can result in an assessment of potential remedial actions to address environmental contamination, including a "proposed plan" for remediation. Site identification, SI, and *Remedial Investigation* (RI), not shown in the figure, may result in a decision that no environmental restoration or removal action is required. *Removal actions* are short-term actions to minimize or eliminate risk to human health and the environment. Similarly, *Interim Remedial Actions* (IRA) are commonly undertaken as components of larger actions where a proposed plan has not yet been finalized, or to reduce risks during ongoing investigations. [BRACO 1999]

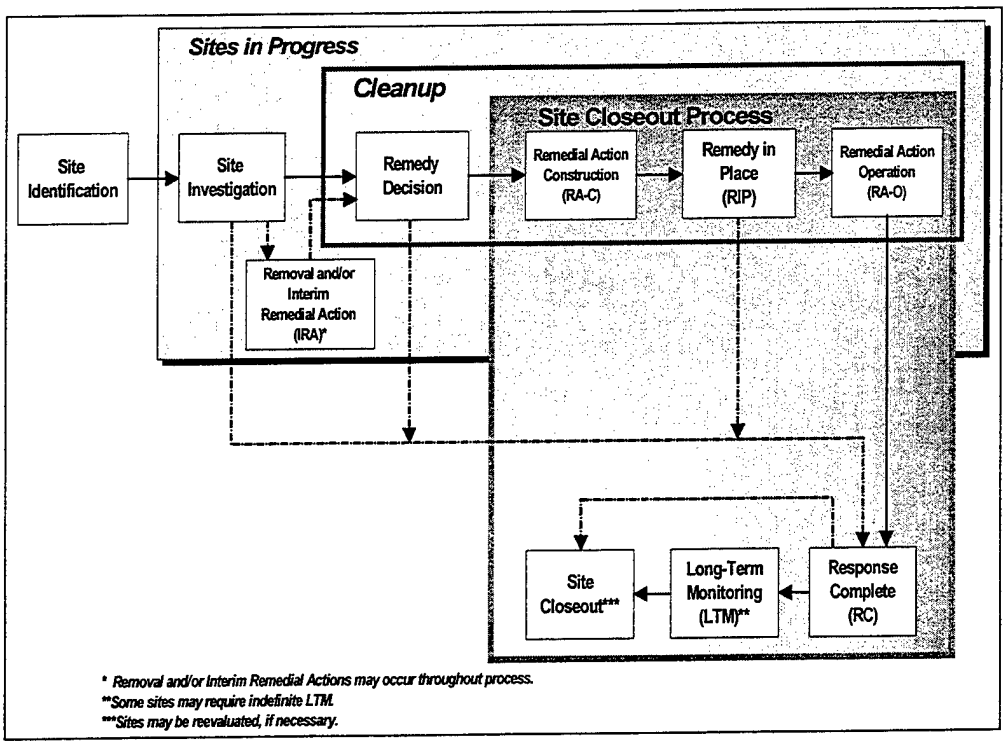


Figure 2. There are seven formal phases for environmental cleanup of a DoD site. Starting from site identification and site investigation each site goes through some or all of these phases. After completing all necessary phases, site closeout occurs. (Figure from BRACO [1999].)

The *Remedy Decision* (RD) formally documents DoD's decision for final cleanup of contamination, including the "no-action" option where supported by analysis. *Remedial Action Construction* (RA-C) (if appropriate) can then begin, and *Remedial Action Operation* (RA-O) (ongoing cleanup) can commence once the remedy has been constructed. In certain cases, a selected remedy may require only construction and no active, ongoing cleanup. *Response Complete* (RC) (cleanup goals met) is when the remedy has achieved the required reduction in risk to human health and the environment. Upon RC, a remedy may require *Long-Term Monitoring* (LTM) of effectiveness to ensure that the cleanup goals continue to be met. Lastly, when cleanup responsibilities have been completed at a site, site closeout can occur. [BRACO 1999]

The BRAC Cleanup Teams (BCTs) are responsible for preparing installations for closure or realignment. The BCT includes a BRAC Environmental Coordinator, and representatives from the State Environmental Agency and the U.S. Environmental Protection Agency (EPA) regional office. The roles of BCT are: (1) understand federal and state requirements for different components of site closeout, (2) ensure requirements beyond last Remedy in Place (RIP) are fully characterized and budgeted, and (3) consider innovative, flexible, and streamlined approaches to expedite the site closeout process and manage costs [United States Department of Defense 1995].

## B. ENVIRONMENTAL CLEANUP POLICY

DoD environmental cleanup occurs through four main legal and regulatory frameworks: the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and its implementing regulation, the National Contingency Plan (NCP); the Resource Conservation and Recovery Act (RCRA); and the Environmental Restoration provisions of Title 10 of the U.S. Code. Environmental cleanup should also consider the National Priorities List (NPL), Federal and State regulatory requirements, cleanup agreements including Federal Facility Agreements (FFA), and community involvement. [BRACO 1999]

## C. SITE CHARACTERISTICS

The BRACO budgets funds for each installation's environmental cleanup. It develops its yearly budget plan based on input from each installation. Table 1 shows an example of a yearly funding request for one site at one installation. Such information is available for every site and is subject to numerous audits before it is used by BRACO.

During some of these audits at some of the installations, BRACO develops Programmatic Confidence Factors (PCF) [Giangiuli 2000] based on the worksheet in Appendix B.

| Phase Name | Phase Start | Phase End | YEARS | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
| SI | 199609 | 199610 | | | | | | | | | | | | | | | |
| RI | 200101 | 200112 | 212 | | | | | | | | | | | | | | |
| RD | 200210 | 200301 | | 33 | | | | | | | | | | | | | |
| RAC | 200301 | 200310 | | | 97 | | | | | | | | | | | | |
| RAO | 200401 | 200610 | | | | 57 | 57 | 57 | | | | | | | | | |
| LTM | 200401 | 200901 | | | | 34 | 34 | 34 | 34 | 34 | | | | | | | |
| IRA | 200106 | 200111 | 995 | | | | | | | | | | | | | | |

Table 1. The yearly funding request in 1000s of dollars for each environmental cleanup phase at site SVAD-076, an Army Reserve Motor Pool at Savanna Army Depot. At this site funding is requested for all phases except SI. The SI phase for this site has been completed before 2001.

In addition to a funding request for each site, BRACO also knows numerous other characteristics of each site such as:

- Presence of unexploded ordnance,
- Existing legal agreements that mandate the site be funded as requested (called *must-fund*),
- Planned reuse date (estimated date when the site will be conveyed to a receiving authority), and
- Relative risk (determined as high, medium or low based on an evaluation of contaminants, pathways and human and ecological receptors in ground water, surface water, sediment, and surface soils [Goette 1996]).

To help gauge the relative value of the site timeline adherence, each site has a benefit value calculated according to the relative risk, planned reuse date, and chosen cleanup option. The cleanup option corresponds to funding a site as requested or delaying the cleanup.

BRACO's yearly budget from 2001 to 2007 for environmental cleanup at these installations totaling over $620 million is not sufficient to support each installation's complete funding request.

## D. PROBLEM STATEMENT

Considering environmental policies and yearly funding requests from 2001 to 2015 for each site, this thesis develops optimization models that schedule environmental cleanup of sites at military installations that are closing or being realigned. Each model provides a yearly budget allocation to each site that adheres to overall budget limitations and provides the greatest overall benefit.

## E. OUTLINE

Chapter II provides an overview of research related to this thesis. Chapter III discusses two models (CBAEC-1 and BAEC-1) and two variations of those models (CBAEC-2 and BAEC-2). We use BAEC (Budget Allocation for Environmental Cleanup) to generalize and refer to any model. Chapter IV describes the data needed for BAEC and computer implementations using the General Algebraic Modeling System (GAMS) [Brooke, Kendrick, Meeraus, and Raman 1998] and MS-EXCEL 2000 [MICROSOFT Corporation 2000]. It discusses the results of the computer implementations. Chapter V presents conclusions.

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# II. LITERATURE REVIEW

As a result of military base downsizing, DoD has had to expedite the transfer of unneeded base property and perform environmental cleanup of contaminated property no longer needed. There are a few papers in the Operations Research literature about environmental cleanup and budget allocation. Bloemhof-Ruwaard, Van Beek, Hordijk and Van Wassenhove [1995] provide a general overview of operations research models and techniques used in environmental management.

Corbett, Debets and Van Wassenhove [1995] present an integer-linear program to help allocate budgets to maximize environmental effectiveness and economic efficiency. In their model, they divided the Netherlands into 16 regions. Each region has hundreds of polluted areas, which can be decontaminated using different methods such as removal of polluted soil or temporary storage of the polluted soil. The costs and environmental effects vary strongly between these decontamination methods. They develop an integer linear program to allocate the total available budget to the regions in order to achieve maximum overall environmental effect. In their model, regional authorities give limited summary information to the central government, which then allocates budgets. The central government aims to maximize total environmental benefits, subject to a central budget constraint. They use two hypothetical data sets to illustrate solutions and present a heuristic and show computational results on its performance. Although allocating budgets to regional governments is similar to allocation of budgets for environmental cleanup of military installations, they only consider one time period and their polluted areas are more homogenous than an installation's sites.

In his thesis, Goette [1996] introduces an integer linear program with a spreadsheet interface to help plan the distribution of a yearly environmental cleanup budget. His model maximizes the benefit received from environmental cleanup of sites subject to yearly budget constraints. His model serves as the basis for models developed in this thesis. In his model, he uses three hypothetical cleanup options for each site: (1) a cheap cleanup option which takes several years to finish, (2) a quicker and more expensive option, and (3) the most effective but also longest. His model suggests a budget allocation by selecting cleanup options from supplied alternatives. His model contains two categories of cleanup alternatives: funding-stream options that contain user-defined multi-year funding alternatives, of which the model must pick only one; and flexible options where the model has flexibility to pick both the year to start cleanup and the funding level per year. In short, the model provides the cleanup level for each site within each installation that provides the greatest benefit while adhering to yearly budgets. In contrast to Goette's hypothetical funding options, models in this thesis use six or more cleanup options (clean everything as requested, delay cleanup one, two, three, four, and five years). There are also additional real-world constraints and significant differences between the calculation of benefit value for each site.

The Center for Army Analysis [1999] introduces the integer program, MORTI (Modeling to Optimize Restoration Tracking and Investments) to develop and analyze alternative strategies for distributing funds to MACOMs for environmental restoration projects with hypothetical funding requirements on installations that are not closing or realigning. There are four versions of MORTI that are created by changing the objective function (e.g., prioritize by site risk) or the constraints (e.g., budget available) to enforce

different priorities. The four versions are: (1) Cleanup high risk sites as early as possible; followed by medium risk, and then low risk sites, and finally the sites that had not been evaluated. In this alternative, the funding for LTM and long term operations (LTO) are incurred every year for 20 years after LTM and LTO start, (2) Prioritize by site risk, but limit the funding for LTM and LTO to five years, (3) Prioritize by MACOM with a 20-year time limit for LTM and LTO, (4) Prioritize by MACOM, but limit the funding for LTM and LTO to five years.

The main differences between MORTI and models developed in this thesis are: (1) BAEC provides budget allocation for installations that are closed or realigned, (2) BAEC uses real data provided by BRACO with yearly funding from 2001 to 2015, (3) BAEC uses both the relative risk factor and the reuse date of each site to calculate benefit values and uses these to find the funding allocation that maximizes the total benefit value.

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# III. OPTIMIZATION MODELS FOR BUDGET ALLOCATION

BAEC schedules environmental cleanup of sites at military installations that are closing or being realigned. BAEC data for each site specify a funding timetable as well as several other site characteristics (e.g., site reuse date, legal agreements, relative risk, presence of unexploded ordnance) that help determine the relative benefit of timeline adherence. Using each site's relative benefit, BAEC provides a yearly budget allocation to sites that adheres to budget limitations and provides the greatest overall benefit. As well as an overall yearly budget limitation, BAEC also includes a minimum and maximum yearly installation and MACOM budget limit.

BAEC assumes projects at sites can either be 1) delayed none, one, two, three, four, or five years (respectively called options Opt0 to Opt5), 2) delayed for a minimum number of years (called *must-delay*), 3) incrementally funded, or 4) funded according to the input funding timetable (*must-fund*).

## A. CBAEC-1

The linear programming model CBAEC-1 is introduced below.

**Indices**

| | |
|---|---|
| $m$ | MACOM; |
| $i$ | installation; |
| $s$ | site; |
| $o$ | site phase fund option (Opt0,Opt1,…,Opt5); and |
| $t$ | year. |

**Index Sets**

$SITE_i$ set of sites at installation $i$;

$FORT_m$ set of installations belonging to MACOM $m$; and

$OPTION_s$ set of options for site $s$.

**Data**

$PCOST_{opst}$ phase $p$ cleanup cost in year $t$ at site $s$ for option $o$;

$COST_{ost}$ cleanup cost in year $t$ at site $s$ for option $o$

$$(COST_{ost} = \sum_p PCOST_{opst});$$

$MINF_{it}$ minimum budget for installation $i$ in year $t$;

$MAXF_{it}$ maximum budget for installation $i$ in year $t$;

$MINM_{mt}$ minimum budget for MACOM $m$ in year $t$;

$MAXM_{mt}$ maximum budget for MACOM $m$ in year $t$;

$BG_t$ maximum budget available for all installations in year $t$;

$BVALUE_{os}$ benefit value for option $o$ at site s;

$PENBG_t$ penalty for violating the total budget in year $t$;

$PENFA_{it}$ penalty for violating installation $i$ 's maximum budget in year $t$;

$PENFB_{it}$ penalty for violating installation $i$ 's minimum budget in year $t$;

$PENMA_{mt}$ penalty for violating MACOM $m$ 's maximum budget in year $t$; and

$PENMB_{mt}$ penalty for violating MACOM $m$ 's minimum budget in year $t$.

**Variables**

$y_{os}$ fraction of funding allocated under option $o$ at site $s$;

$efa_{it}$ allocation in excess of installation $i$ 's maximum budget in year $t$;

$efb_{it}$ allocation below installation $i$ 's minimum budget in year $t$;

$ema_{mt}$ allocation above MACOM $m$ 's maximum budget in year $t$;

$ema_{mt}$ allocation below MACOM $m$ 's minimum budget in year $t$; and

$ebg_t$ amount allocated above the total year $t$ budget.

**Formulation**

**MAXIMIZE**

$$\sum_{os} BVALUE_{os}\ y_{os} + \sum_{it} PENFA_{it}\ efa_{it} + \sum_{it} PENFB_{it}\ efb_{it}$$
$$+ \sum_{mt} PENMA_{mt}\ ema_{mt} + \sum_{mt} PENMB_{it}\ emb_{it} + \sum_{t} PENBG_t\ ebg_t$$

**Subject to**

$$MINF_{it} - efb_{it} \le \sum_{o,s \in SITE_i} COST_{ost}\ y_{os} \le MAXF_{it} + efa_{it} \qquad \forall it \quad (1)$$

$$MINM_{mt} - emb_{mt} \le \sum_{i \in FORT_m} \sum_{o,s \in SITE_i} COST_{ost}\ y_{os} \le MAXM_{mt} + ema_{mt} \qquad \forall mt \quad (2)$$

$$\sum_{os} COST_{ost}\, y_{os} \le BG_t + ebg_t \qquad \forall t \quad (3)$$

$$\sum_{o \in OPTION_s} y_{os} = 1 \qquad \forall s \quad (4)$$

$$0 \le y_{os} \le 1 \qquad \forall os \quad (5)$$

$$efa_{it}, efb_{it} \ge 0 \;\; \forall it \qquad ema_{mt}, emb_{mt} \ge 0 \;\; \forall mt \qquad ebg_t \ge 0 \;\; \forall t \qquad (6)$$

The objective function maximizes overall benefit with additional terms that penalize budget deviation. The penalties are typically set high enough that budget deviation only occurs when violation is necessary to satisfy other constraints.

Constraints (1) enforce yearly installation budget limits or measure their violation, (2) are yearly MACOM budget limits, and (3) are yearly total budget limits. Constraints (4) ensure each site receives funding. The funding is either for any single option $y_{os} = 1$ and $y_{o's} = 0$ $(\forall o' \neq o)$ or using a convex combination of options for each site. For a must-fund site $s$, $OPTION_s = \{\text{Opt0}\}$ and $OPTION_s = \{\text{Opt3, Opt4, Opt5}\}$ is an example of how $OPTION_s$ can be used for a must-delay site.

## B. BAEC-1

BAEC-1 is identical to CBAEC-1 except it replaces constraints (5) with $y_{os} \in \{0,1\}$. This ensures that cleanup at each site is completed using exactly one option. CBAEC-1 can suggest possible alternative funding (using a convex combination of options) not available under BAEC-1. But these alternatives require careful review to

insure they can be implement whereas BAEC-1 solutions provide simple delays that should be easier to implement.

## C. CBAEC-2

CBAEC-2 is identical to CBAEC-1 except it has three more cleanup options (Opt6, Opt7, Opt8). In option Opt6, all funding is delayed one year after the SI phase (the first phase of environmental cleanup), in Opt7, all funding is delayed two years after the SI phase, and in option Opt8, the delay is three years.

## D. BAEC-2

BAEC-2 is the combination of BAEC-1 and CBAEC-2. It has cleanup options Opt6, Opt7, and Opt8 and it restricts $y_{os}$ to be binary for all $o$ and $s$.

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# IV. IMPLEMENTATION AND RESULTS

BRACO provided all BAEC input data for 539 sites at 50 installations [BRACO 2000]. Results are either for a base case from BAEC-1 or comparisons to this base case.

## A. DATA

We present data in two categories: (1) data used directly by the model and (2) data used to calculate benefit values. Unless indicated otherwise, all data is for our base case. Data used directly include:

- The yearly phase funding request for each site from 2001 to 2015,
- The yearly BRACO budget available for all installations for 2001 to 2007,
- Initiation and completion time for each phase of cleanup at each site.

The yearly total cost for environmental cleanup if all sites are funded as requested, the budget available for each year, and the ratio of cost to available are shown in Table 2.

| TOTAL COST AND AVAILABLE BUDGET FOR ALL SITES | | | | | | | |
|---|---|---|---|---|---|---|---|
| YEAR | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
| COST | 247,436 | 143,848 | 124,540 | 64,908 | 53,846 | 35,738 | 34,561 |
| AVAILABLE | 238,915 | 133,231 | 123,300 | 47,950 | 39,100 | 30,871 | 27,555 |
| COST / AVAIL (%) | 104 | 108 | 101 | 135 | 138 | 116 | 125 |

Table 2. The yearly total cost required for all sites in 1000s of dollars if all are funded as requested, the BRACO yearly budget available, and the percent request. For example, the total cleanup cost for all sites in 2001 if funded as requested is $247,436,000 whereas BRACO only has $238,915,000 available for the same year, a difference of about 8.5 million dollars or 104% of the available budget.

Table 3 provides a distribution of total cost required for each site showing how total cost varies dramatically between sites. There are 203 sites that require less than $100,000 from 2001 to 2015 to closeout and 145 sites that require over $1 million.

| TOTAL COST DISTRIBUTION | | | | |
|---|---|---|---|---|
| **Interval** | (0 - 100K] | (100K -500K] | (500K - 1,000K] | (1,000K - ) |
| **Number of Sites** | 203 | 134 | 57 | 145 |

Table 3. The total number of sites having a total cost within the given interval. For example, there are 145 sites whose total cost to complete cleanup for all phases is more than $1 million.

Benefit values are in the form $\sum_n k_n * B_n$ where $k_n$ is a scaling factor for criterion $n$, and $B_n$ is the value of criterion $n$. The values for scaling factors are subjective and related to how each criterion is measured. Factors for the base case almost exclusively favor sites with scheduled reuse or closeout in the near future.

The values used by BAEC to calculate benefit values for option Opt0 are given in Table 4. A site with planned reuse between 2001 and 2007 receives the benefit contribution under the reuse year in Table 4 while sites without reuse that closeout from 2001 to 2007 receive the benefit contribution shown under the closeout year. In cases when the reuse year precedes the closeout year, the site receives a benefit contribution for the reuse year. For example, a site with high relative risk that is scheduled for reuse in 2002 has the benefit contribution of 75 (30 + 45) if it is funded without delay (Opt0). However a site with medium relative risk and a 2001 reuse year has the benefit contribution of 90 (20 + 70) for Opt0. From this example, we see that relative risk is important but closing sites according to reuse years is more important especially for the years 2001 and 2002.

The benefit values for options other than Opt0 are calculated by simply multiplying the Opt0 value by a scalar: 0.10, 0.09, 0.07, 0.05, 0.03, 0.01, 0.0081, and 0.0049 for options Opt1, Opt2, … , Opt8 respectively.

| Reuse Year | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|
| Benefit Contribution | 70.0 | 45.0 | 20.0 | 10.0 | 5.0 | 3.0 | 2.0 |
| | | | | | | | |
| **Closeout Year** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** |
| Benefit Contribution | 35.0 | 22.5 | 10.0 | 5.0 | 2.5 | 1.5 | 1.0 |
| | | | | | | | |

| Relative Risk | HIGH | MEDIUM | LOW |
|---|---|---|---|
| Benefit Contribution | 30.0 | 20.0 | 5.0 |

Table 4. The benefit contribution of reuse year, closeout year, and relative risk used by BAEC to calculate benefit values for each site if funded as requested. For example, a site with a 2001 reuse and closeout year and high relative risk has the benefit value contribution 100 (70+30) for cleanup option Opt0. If a high-risk site without a reuse year is planned to closeout in 2001, it has a benefit contribution of 65 (35+30) for cleanup option Opt0.

Other data required by BAEC include yearly MACOM and installation budgets. For all scenarios considered in this chapter, they are all set so the related constraints are non-binding.

In addition to legal agreements that mandate the site be funded as requested (*must-fund*), any site currently in a RAO or LTM phase must also be funded as requested. For all scenarios reported here, there are 230 must-fund sites.

Using the PCF, BRACO assigns 39 sites at two installations as must-delay with $OPTION_s = \{\text{Opt3, Opt4, Opt5}\}$. Several scenarios considered the effect of restricting these sites as *must-delays* but we only report results when they are so constrained.

## B. IMPLEMENTATION OF MATHEMATICAL MODEL

The BAEC models are generated using GAMS Version 2.50D [GAMS 1998]. OSL Version 1 [IBM 2000] solves the linear programs CBAEC-1 and CBAEC-2. CPLEX Version 6.6.1 [ILOG 2000] solves the integer linear programs BAEC-1 and BAEC-2. The implementation is done on a personnel computer with 192 Megabyte of

random access memory and a 333 Megahertz Intel Pentium processor. It takes less than a minute to generate and solve each model. Integer programs are solved to optimality.

The BAEC consists of about 600 equations and between 22,000 and 25,000 non-zero coefficients. The linear programs CBAEC-1 and CBAEC-2 have between 2,100 and 3,000 continuous variables, and the integer linear programs BAEC-1 and BAEC-2 have between 1,700 and 2,000 binary variables.

## C. DATA OUTPUT

All results from GAMS are exported to MS EXCEL files for numerical and graphical presentation. This section contains some of the output from the base case.

Table 5 shows the funding allocation for each MACOM for each year and Figure 3 graphically compares the total request across all installations, BAEC-1 allocation, and the available budget. In Table 5, the *plan* column shows the total cleanup cost as requested for each year across all MACOMs, the *baec* column provides the optimal funding by BAEC-1, and the *avail* column presents the total budget available for each year.

| YEARS | AMC | FORSCOM | MDW | MEDCOM | MTMC | TRADOC | USARPAC | PLAN | BAEC | AVAIL |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | 87,688 | 57,102 | 3,609 | 1,040 | 15,225 | 71,449 | 427 | 247,436 | 236,540 | 238,915 |
| 2002 | 53,727 | 14,163 | 3,631 | 40 | 2,271 | 59,099 | 300 | 143,848 | 133,231 | 133,250 |
| 2003 | 43,863 | 6,610 | 544 | 240 | 187 | 53,389 | 300 | 124,540 | 105,133 | 123,300 |
| 2004 | 18,005 | 2,433 | 467 | 240 | 273 | 26,361 | 151 | 64,908 | 47,930 | 47,950 |
| 2005 | 13,734 | 2,310 | 348 | 165 | 236 | 22,148 | 150 | 53,846 | 39,091 | 39,100 |
| 2006 | 19,573 | 2,550 | 275 | 140 | 208 | 7,800 | 120 | 35,738 | 30,666 | 30,871 |
| 2007 | 16,889 | 2,354 | 275 | 140 | 161 | 7,637 | | 34,561 | 27,456 | 27,555 |
| 2008 | 26,835 | 4,101 | 265 | 40 | 531 | 10,346 | | 35,417 | 42,118 | 1,000,000 |
| 2009 | 18,934 | 3,688 | 265 | 140 | 835 | 13,220 | | 32,533 | 37,082 | 1,000,000 |
| 2010 | 17,115 | 3,676 | 265 | 40 | 39 | 13,125 | | 31,644 | 34,260 | 1,000,000 |
| 2011 | 13,824 | 3,084 | 255 | 100 | 29 | 14,280 | 138 | 28,268 | 31,710 | 1,000,000 |
| 2012 | 11,115 | 2,852 | 255 | | 29 | 14,091 | | 27,480 | 28,342 | 1,000,000 |
| 2013 | 9,817 | 2,805 | 255 | 100 | 29 | 15,972 | | 26,978 | 28,978 | 1,000,000 |
| 2014 | 10,195 | 2,822 | 255 | | 29 | 15,944 | | 27,096 | 29,245 | 1,000,000 |
| 2015 | 68,834 | 68,373 | 2,400 | | 496 | 101,574 | 156 | 179,322 | 241,833 | 1,000,000 |
| TOTAL | 430,148 | 178,923 | 13,364 | 2,425 | 20,578 | 446,435 | 1,742 | 1,093,615 | 1,093,615 | 8,640,941 |

Table 5. Summary of the yearly budget request at MACOM, BAEC-1 solution, and total budget available. In 2001, the available budget is $238,915,000, the total request for the same year is $247,436,000, and BAEC-1 allocates $236,540,000.

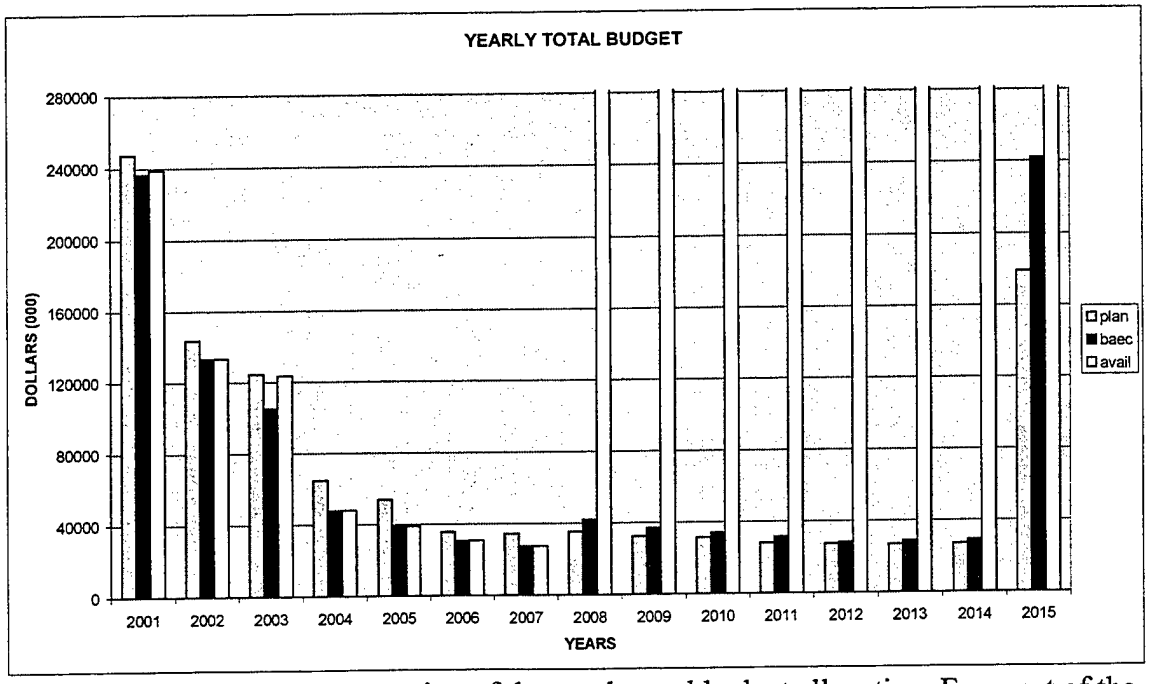


Figure 3. Column chart presentation of the yearly total budget allocation. For most of the years, BAEC-1 uses all budget available for given years. (See also Table 5)

Table 6 shows the percentage funding received by each installation. Most of the installations (46 of 50 installations) are funded as requested. Delays occur only at installations Camp Bonneville (BONNEVIL), Fort Ord (POMORD), Pueblo Chemical Depot (PUEBLO), and Savanna Depot Activity (SAVANNA) (PUEBLO and SAVANNA had *must-delay* sites).

| YEARLY PERCENT BUDGET ALLOCATION FOR EACH INSTALLATION | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **installation** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** |
| ALABAMA | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ARLWATER | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ARLWOOD | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| BAYONNE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| BONNEVILL | **70** | **61** | **62** | **5** | **5** | **22** | **21** | **115** | 100 | 100 | 100 | 100 | 100 | 100 | **120** |
| CAMERON | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| CEKELLY | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| CHAFFEE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| DETROIT | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| DEVENS | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| DIXBRAC | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| EASTBAKE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| FITZSIMON | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| GREELY | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| HAMILTON | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| HERNDON | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| HINGHAM | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| HUNTER | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| JEFFERSON | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| KILMER | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| LETTERKE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| LEXINGTON | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| LIVINGSTON | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| LOMPOC | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| MCCLELLAN | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| MEADE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| MOINES | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| MONMOUTH | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| NIKEKANSAS | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| OAKLAND | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| PEDRICKTO | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| PICKETT | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| POMORD | 100 | 100 | 100 | 100 | **73** | **50** | **49** | **70** | **93** | **81** | **87** | **87** | 100 | 100 | **145** |
| PRESIDIO | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| PUEBLO | **93** | **82** | **84** | **71** | **91** | **211** | **129** | **112** | **138** | **394** | **258** | **106** | 100 | 100 | 100 |
| REDRIVER | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| RIOVISTA | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| RITCHIE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| SACRAMEN | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| SAVANNA | **74** | **12** | **27** | **7** | **15** | **103** | **107** | **238** | **165** | **133** | **186** | **161** | **143** | **148** | **225** |
| SENECA | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| SHERIDAN | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| SIERRA | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| STRATFORD | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| SUDBURY | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| TACONY | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| TOOELE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| UMATILLA | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| VINTHILL | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| WINGATE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Table 6. The percent funding allocated to each installation by BAEC-1. Most of the installations are funded as they requested. Only four installations have different funding that causes some delays in the completion of some sites at these installations. For example, installation Savanna Depot Activity gets 74% of requested budget for 2001 and 103% of requested budget for 2006.

Figure 4 shows a visual presentation of the total site closeout for each year requested by installations and recommended by BAEC-1. Available funding is sufficient to allow nearly all sites to closeout without delay.

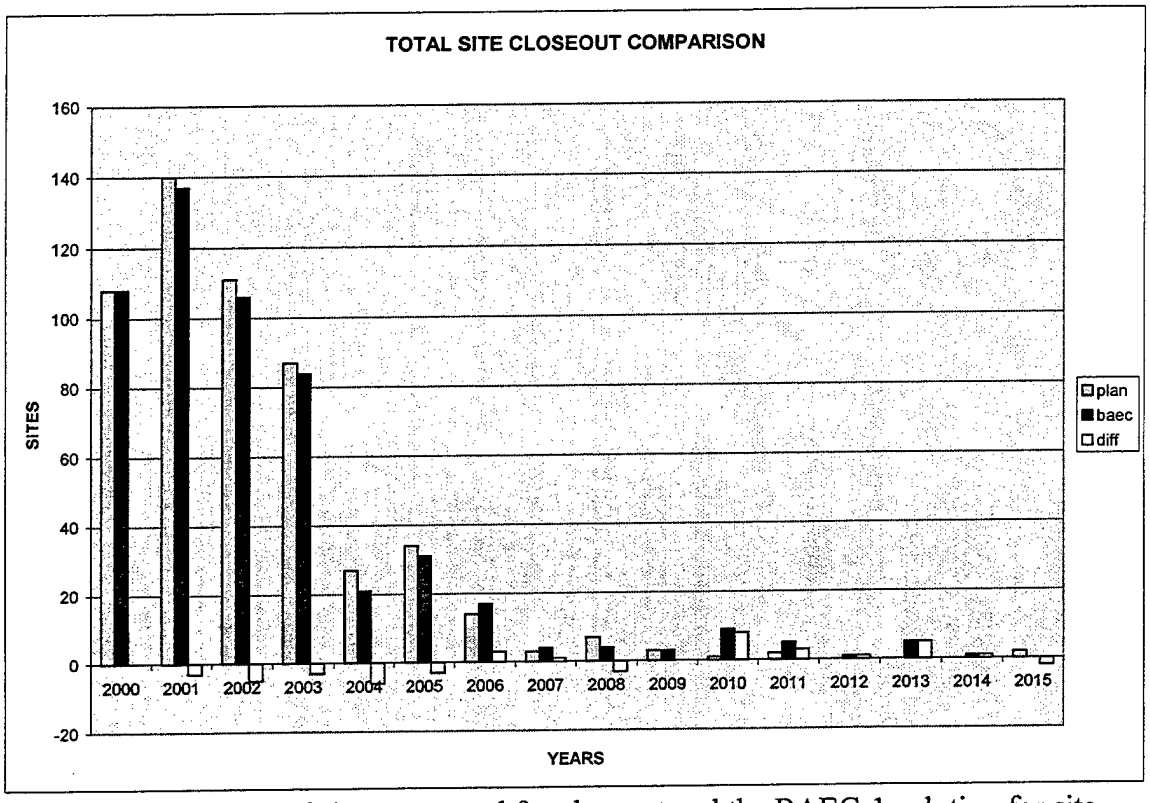


Figure 4. The number of sites requested for closeout and the BAEC-1 solution for site closeout for each year. For example, when providing all requested funding in 2001, 140 site closeouts are requested and BAEC-1 funds 137 site closeouts, a difference of three sites. The requested site closeout cost for 2001 is $247,436,000 and with only $238,915,000 for the same time period BAEC-1 is able to closeout nearly all sites.

Table 7 provides the requested and BAEC-1 budget allocation for each year for each MACOM and the percent of the allocation that corresponds to *must-fund* sites. For almost all MACOMs, we see the percent *must-fund* is less than 50% of the total allocation. Figure 5 shows the visual presentation of the yearly request and BAEC-1 budget allocation for a particular MACOM.

| macom | years | plan | baec | diff | mustfnd | permust | perfund |
|---|---|---|---|---|---|---|---|
| TRADOC | 2001 | 71,449.00 | 71,449.00 | | 34,110.00 | 47.74 | 100.00 |
| TRADOC | 2002 | 59,099.00 | 59,099.00 | | 27,439.00 | 46.43 | 100.00 |
| TRADOC | 2003 | 53,389.00 | 53,389.00 | | 25,839.00 | 48.40 | 100.00 |
| TRADOC | 2004 | 26,361.00 | 26,361.00 | | 24,600.00 | 93.32 | 100.00 |
| TRADOC | 2005 | 26,148.00 | 22,148.00 | -4,000.00 | 20,420.00 | 78.09 | 84.70 |
| TRADOC | 2006 | 14,800.00 | 7,800.00 | -7,000.00 | 6,546.00 | 44.23 | 52.70 |
| TRADOC | 2007 | 14,637.00 | 7,637.00 | -7,000.00 | 6,296.00 | 43.01 | 52.18 |
| TRADOC | 2008 | 14,346.00 | 10,346.00 | -4,000.00 | 5,086.00 | 35.45 | 72.12 |
| TRADOC | 2009 | 14,220.00 | 13,220.00 | -1,000.00 | 5,086.00 | 35.77 | 92.97 |
| TRADOC | 2010 | 16,125.00 | 13,125.00 | -3,000.00 | 5,086.00 | 31.54 | 81.40 |
| TRADOC | 2011 | 16,280.00 | 14,280.00 | -2,000.00 | 5,066.00 | 31.12 | 87.71 |
| TRADOC | 2012 | 16,091.00 | 14,091.00 | -2,000.00 | 5,066.00 | 31.48 | 87.57 |
| TRADOC | 2013 | 15,972.00 | 15,972.00 | | 5,066.00 | 31.72 | 100.00 |
| TRADOC | 2014 | 15,944.00 | 15,944.00 | | 5,066.00 | 31.77 | 100.00 |
| TRADOC | 2015 | 71,574.00 | 101,574.00 | 30,000.00 | 46,219.00 | 64.58 | 141.91 |
| | **Total** | 446,435.00 | 446,435.00 | | 226,991.00 | 50.85 | 100.00 |

Table 7. The yearly budget requested and the BAEC-1 budget allocation for a particular MACOM. For 2001, BAEC-1 funds all requested funding $71,449,000 (*perfund* of 100%) of which $34,110,000 is as a *must-fund* allocation (*permust* of 47.74%).

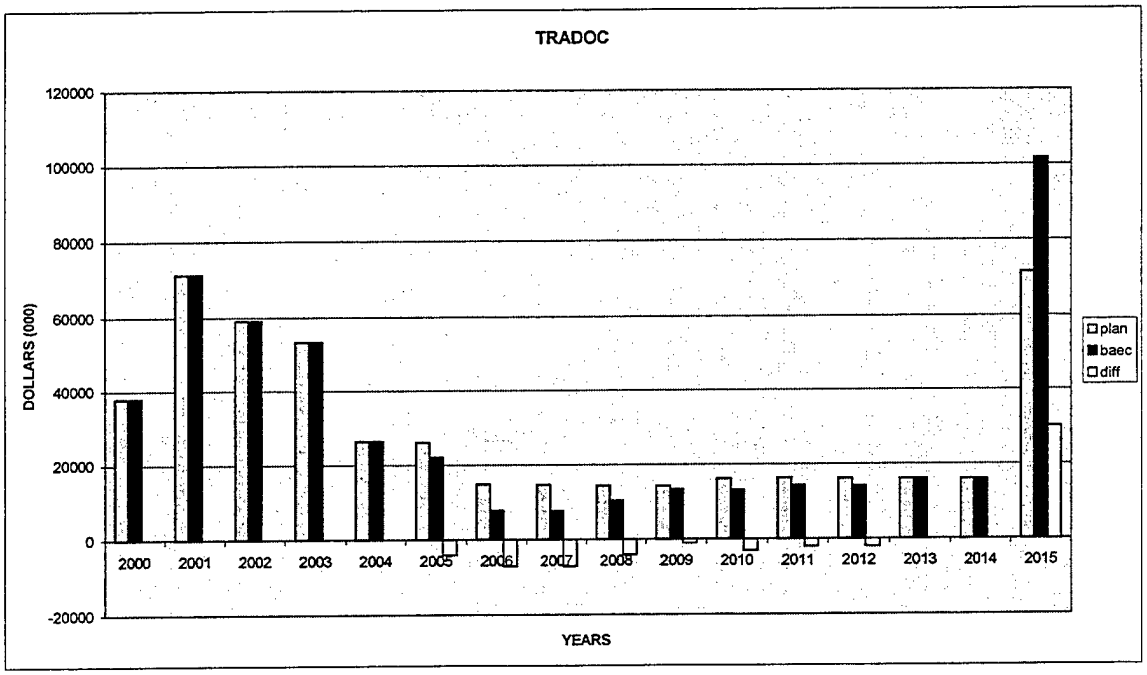


Figure 5. Yearly budget requests and budget allocated by BAEC-1 for a particular MACOM. For TRADOC, all funding requests are funded by BAEC-1 except years 2005-2008. (See also Table 7)

The model also provides an output (Table 8) showing the comparison of planned reuse dates for each site and the BAEC-1 site closeout dates. Totally, there are 171 sites where the reuse year is before the installation's planned closeout year. The BAEC-1 solution has an additional 19 sites where the reuse year occurs before the closeout year.

| macom | installation | site | reuse | plan | late | baec | baeclate |
|---|---|---|---|---|---|---|---|
| AMC | ALABAMA | SITE-22 | 2001 | 2002 | 1 | 2002 | 1 |
| AMC | ALABAMA | SITE-34 | 2001 | 2002 | 1 | 2002 | 1 |
| AMC | ALABAMA | SITE-35 | 2001 | 2002 | 1 | 2002 | 1 |
| AMC | ALABAMA | SITE-36 | 2001 | 2002 | 1 | 2002 | 1 |
| AMC | ARLWATER | MTL-29 | 2000 | 2002 | 2 | 2002 | 2 |
| AMC | ARLWATER | MTL-33 | 2000 | 2001 | 1 | 2001 | 1 |
| AMC | ARLWOOD | WBRF-01 | 2000 | 2000 | | 2000 | |
| AMC | ARLWOOD | WBRF-02 | 2000 | 2000 | | 2000 | |
| AMC | ARLWOOD | WBRF-03 | 2000 | 2000 | | 2000 | |
| AMC | ARLWOOD | WBRF-04 | 2000 | 2000 | | 2000 | |

Table 8. The requested reuse dates and the BAEC-1 site closeout dates for some sites. For example, site MTL-29 of installation ARL-WATERTOWN has a reuse year of 2000, but the installations requested funding closes the site in 2002 and BAEC-1 allocates the requested funding so that no additional delay occurs.

## D. COMPUTATIONAL RESULTS AND SENSITIVITY ANALYSIS

When considering the base case data, the optimal objective function values provided by the two models and variations are very close (CBAEC-1 28,116.12, BAEC-1 28,111.94, CBAEC-2 28,118.83, and BAEC-2 28,114.82) indicating that all obtain almost identical decisions. All models fix 230 of 539 sites to be cleaned without delay (because of *must-fund* conditions). From the remaining 309 sites, only four installations have delays at some sites in all models. The results show that most of the sites are funded as requested by each installation.

The total site closeout comparisons of four models are given in Figure 6. All models complete the same number of site closeouts in fiscal years 2001 and 2002. By 2008, CBAEC-2 completes more site closeouts than the others.

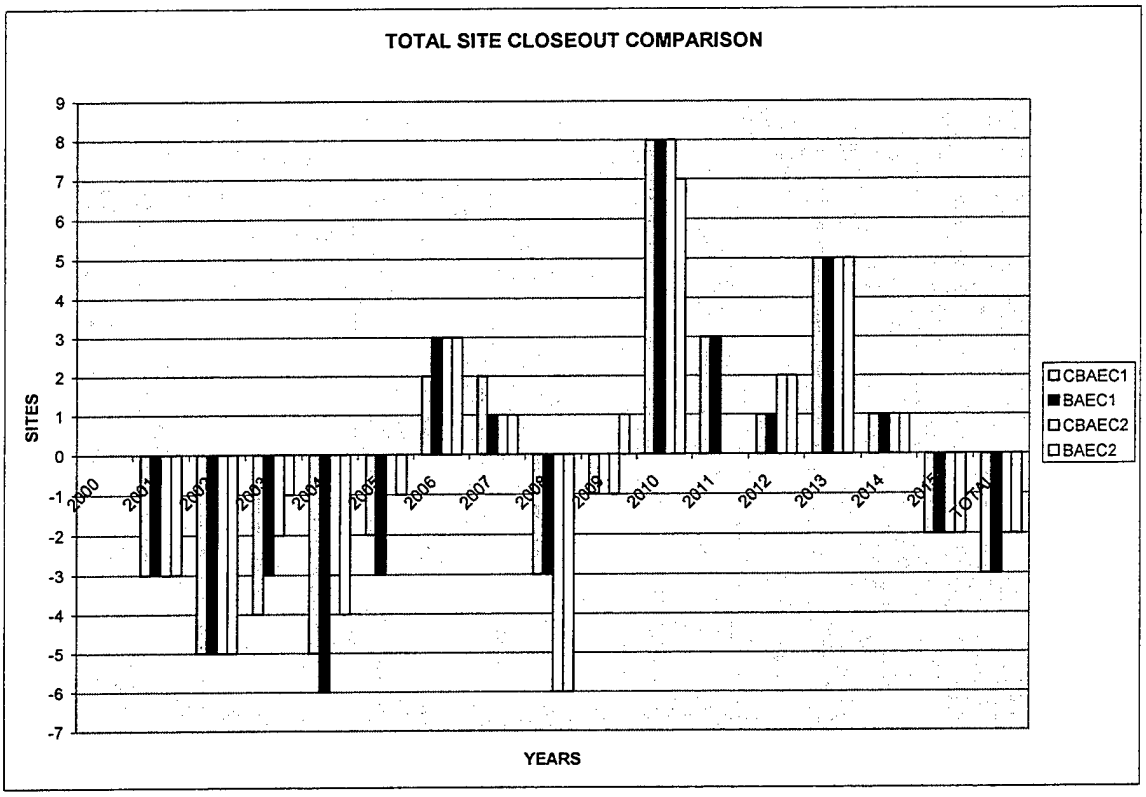


Figure 6. The total site closeouts provided by BAEC compared with installation closeout requests (Negative numbers indicate less site closeout than requested by installations). All four models complete the same number of site closeouts in years 2001-2002. In 2003, the installations plan to closeout 87 sites, CBAEC-1 completes 83 (a difference of four), BAEC-1 completes 84, CBAEC-2 completes 85, and BAEC-2 completes 86. Over all years, CBAEC-1 and BAEC-1 closeout 536 of 539 sites by 2015 and CBAEC-2 and BAEC-2 closeout 537.

The total budget available for each year and funding allocations provided by BAEC are presented in Table 9.

| YEARS | AVAIL | PLAN | CBAEC-1 | BAEC-1 | CBAEC-2 | BAEC-2 |
|---|---|---|---|---|---|---|
| 2001 | 238,915 | 247,436 | 236,556 | 236,540 | 236,556 | 236,540 |
| 2002 | 133,250 | 143,848 | 133,250 | 133,231 | 133,250 | 133,231 |
| 2003 | 123,300 | 124,540 | 105,638 | 105,133 | 105,638 | 105,133 |
| 2004 | 47,950 | 64,908 | 47,950 | 47,930 | 47,950 | 47,930 |
| 2005 | 39,100 | 53,846 | 39,100 | 39,091 | 39,100 | 39,091 |
| 2006 | 30,871 | 35,738 | 30,871 | 30,666 | 30,871 | 30,666 |
| 2007 | 27,555 | 34,561 | 27,555 | 27,456 | 27,555 | 27,456 |
| 2008 | 1,000,000 | 35,417 | 41,598 | 42,118 | 41,598 | 42,118 |
| 2009 | 1,000,000 | 32,533 | 36,824 | 37,082 | 36,824 | 37,082 |
| 2010 | 1,000,000 | 31,644 | 34,260 | 34,260 | 34,260 | 34,260 |
| 2011 | 1,000,000 | 28,268 | 31,710 | 31,710 | 31,710 | 31,710 |
| 2012 | 1,000,000 | 27,480 | 28,342 | 28,342 | 28,342 | 28,342 |
| 2013 | 1,000,000 | 26,978 | 28,978 | 28,978 | 28,978 | 28,978 |
| 2014 | 1,000,000 | 27,096 | 29,245 | 29,245 | 29,245 | 29,245 |
| 2015 | 1,000,000 | 179,322 | 241,738 | 241,833 | 241,738 | 241,833 |
| **TOTAL** | **8,640,941** | **1,093,615** | **1,093,615** | **1,093,615** | **1,093,615** | **1,093,615** |

Table 9. The total budget available for each year and funding allocations provided by BAEC. For example, in 2002 the total cost of cleanup for all sites if funded as requested is $143,848,000 and the available budget for the same year is only $133,250,000. All the models provide almost identical funding; CBAEC-1 and CBAEC-2 fund $133,250,000 (the available budget for 2002) and BAEC-1 and BAEC-2 fund $133,231,000. For 2001, all the models allocate slightly less than the available funds. Although sites require funding in 2001 (a planned requirement of $247,436,000), the multiyear funding requirement at sites makes it optimal to delay some of the sites requesting 2001 funding.

A delay occurs at one site (FTO-055) at POMORD (Fort Ord) that requires an additional $4 million in 2006 and 2007 to eliminate. We use BAEC-1 to evaluate the effect of different increases to the 2006 and 2007 budget, change to the yearly funding request at FTO-055 (reducing the requested amount in 2001 and 2002 so that there is a $7M request each year from 2001 to 2007), and changing this site to a *must-fund*. Table 10 shows results obtained with and without a budget increase of $4M in years 2006 and 2007. Increasing the total budget in fiscal years 2006 and 2007 and changing the requested funding, allows completion of two more site closeouts by 2007 and increases the total number of site closeout by one. Without a budget increase, the yearly $7M funding requirement with FTO-055 as a *must-fund* decreases the number of site closeouts

in 2002. With $4M budget increase and yearly $7M funding for site FTO-055 through years 2001-2007, BAEC-1 completes three more site closeouts by 2007.

| TOTAL SITE CLOSEOUT WITH DIFFERENT BUDGET AND FUNDING ALLOCATION | | | | | | |
|---|---|---|---|---|---|---|
| | | | | FTO-055 must-fund | $4M+ | FTO-055 must-fund & $4M+ |
| YEARS | PLAN | BAEC-1 | dif | dif | dif | dif |
| 2000 | 108 | 108 | 0 | 0 | 0 | 0 |
| 2001 | 140 | 137 | -3 | -3 | -3 | -3 |
| 2002 | 111 | 106 | -5 | -7 | -5 | -6 |
| 2003 | 87 | 84 | -3 | -1 | -4 | -1 |
| 2004 | 27 | 21 | -6 | -1 | -6 | -4 |
| 2005 | 34 | 31 | -3 | -3 | -2 | -3 |
| 2006 | 14 | 17 | 3 | -3 | 4 | -1 |
| 2007 | 3 | 4 | 1 | 2 | 2 | 5 |
| 2008 | 7 | 4 | -3 | -5 | -5 | -4 |
| 2009 | 3 | 3 | 0 | 3 | 1 | 1 |
| 2010 | 1 | 9 | 8 | 9 | 6 | 7 |
| 2011 | 2 | 5 | 3 | 4 | 5 | 3 |
| 2012 | 0 | 1 | 1 | 1 | 1 | 2 |
| 2013 | 0 | 5 | 5 | 1 | 4 | 2 |
| 2014 | 0 | 1 | 1 | 2 | 1 | 1 |
| 2015 | 2 | 0 | -2 | -2 | -1 | -2 |
| TOTAL | 539 | 536 | -3 | -3 | -2 | -3 |

Table 10. Results of four different combination of $4M budget increase in years 2006 and 2007 with a $7M constant budget allocation for site FTO-055 through years 2001-2007. Allocating a constant $7M for site FTO-055 without increase in the available budget in 2006 and 2007 results in two more site closeout delays in 2002, but it does not affect the total closeout number by 2007. Increasing the available budgets of 2006 and 2007 without constant funding allocation helps to complete two more site closeouts by 2007. A constant funding allocation with budget increase in given years causes one more site closeout delay in 2002, but completes three more site closeouts by 2007.

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# V. CONCLUSIONS

This thesis develops optimization models, BAEC (Budget Allocation for Environmental Cleanup), to help allocate funds for environmental cleanup at closing and realigning Army installations. Extensive model use helped the Army analyze alternate yearly budgets, suggest alternate site funding, and determine site funding for 2001 to 2007. This site funding allows all sites at 46 of 50 installations to proceed with cleanup. The remaining four installations have only 43 of 539 sites where cleanup will be delayed because of insufficient funds.

BAEC allows the Army to easily analyze the impact of increased budgets, mandated site funding, mandated site delay, and alternate site funding. One version of BAEC helps suggest alternate site funding.

BAEC uses site priorities based on subjective values to guide site delay. These values can be easily adjusted to satisfy different priorities and provide alternate funding for environmental cleanup.

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## APPENDIX A: MACOM AND INSTALLATIONS

In September 2000, The Army Base Realignment and Closure Office was completing funding or was planning to fund environmental cleanup at 50 Army installations from seven Major Army Commands (MACOMs). Table A1 shows the state, MACOM, and status (Closure (C) or Realignment (R)) of each installation. Major Army Commands are: Army Material Command (AMC), Forces Command (FORSCOM), Military District of Washington (MDW), Medical Command (MEDCOM), Military Traffic Management Command (MTMC), Training and Doctrine Command (TRADOC), and US Army Pacific Command (USARPAC)).

| NO. | MACOM | INSTALLATION | STATE | ACTION |
|---|---|---|---|---|
| 1 | AMC | LETTERKENNY ARMY DEPOT | Pennsylvania | R |
| 2 | AMC | ARL - WATERTOWN | Massachusetts | C |
| 3 | AMC | ARL-WOODBRIDGE | Virginia | C |
| 4 | AMC | FORT MONMOUTH | New Jersey | R |
| 5 | AMC | VINT HILL FARMS STATION | Virginia | C |
| 6 | AMC | SACRAMENTO AD | California | C |
| 7 | AMC | SIERRA ARMY DEPOT | California | R |
| 8 | AMC | ALABAMA AAP | Alabama | C |
| 9 | AMC | SAVANNA DEPOT ACTIVITY | Illinois | C |
| 10 | AMC | LEXINGTON FACILITY-LBAD | Kentucky | C |
| 11 | AMC | FORT WINGATE | New Mexico | C |
| 12 | AMC | SENECA AD | New York | C |
| 13 | AMC | TOOELE ARMY DEPOT | Utah | R |
| 14 | AMC | PUEBLO CHEMICAL DEPOT | Colorado | R |
| 15 | AMC | UMATILLA CHEMICAL DEPOT | Oregon | R |
| 16 | AMC | JEFFERSON PROVING GROUND | Indiana | C |
| 17 | AMC | RED RIVER ARMY DEPOT | Texas | R |
| 18 | AMC | STRATFORD ARMY ENGINE PLANT | Connecticut | C |
| 19 | AMC | DETROIT ARSENAL & DETROIT TANK PLT | Michigan | R |
| 20 | FORSCOM | EAST FORT BAKER | California | C |
| 21 | FORSCOM | FORT HUNTER LIGGETT BRAC | California | R |
| 22 | FORSCOM | PRESIDIO OF SAN FRANCISCO | California | C |
| 23 | FORSCOM | LOMPOC BRANCH DISCIPLINARY BARRACKS | California | C |
| 24 | FORSCOM | HAMILTON ARMY AIR FIELD | California | C |
| 25 | FORSCOM | RIO VISTA RES TRNG AREA | California | C |
| 26 | FORSCOM | FORT DES MOINES | Iowa | C |
| 27 | FORSCOM | FORT SHERIDAN | Illinois | C |
| 28 | FORSCOM | FORT DEVENS | Massachusetts | C |
| 29 | FORSCOM | HINGHAM ANNEX | Massachusetts | C |
| 30 | FORSCOM | SUDBURY TRAINING ANNEX | Massachusetts | C |
| 31 | FORSCOM | FORT DIX BRAC | New Jersey | R |
| 32 | FORSCOM | CAMP PEDRICKTOWN | New Jersey | C |
| 33 | FORSCOM | CAMP KILMER | New Jersey | C |
| 34 | FORSCOM | HOUSING AREA LIVINGSTON, NJ | New Jersey | R |
| 35 | FORSCOM | C.E. KELLY SUPPORT FACILITY BRAC | Pennsylvania | R |
| 36 | FORSCOM | TACONY WAREHOUSE | Pennsylvania | C |
| 37 | FORSCOM | FORT PICKETT | Virginia | C |
| 38 | FORSCOM | CAMP BONNEVILLE | Washington | C |
| 39 | TRADOC | PRESIDIO OF MONTEREY (FORT ORD ANN) | California | C |
| 40 | TRADOC | FORT MCCLELLAN | Alabama | C |
| 41 | TRADOC | FORT CHAFFEE | Arkansas | C |
| 42 | TRADOC | NIKE KANSAS CITY 30 | Missouri | C |
| 43 | MTMC | OAKLAND ARMY BASE | California | C |
| 44 | MTMC | MILITARY OCEAN TERMINAL, BAYONNE | New Jersey | C |
| 45 | MDW | FORT GEORGE G. MEADE | Maryland | R |
| 46 | MDW | FORT RITCHIE | Maryland | C |
| 47 | MDW | CAMERON STATION | Virginia | C |
| 48 | MDW | DEFENSE MAPPING AGENCY - HERNDON | Virginia | C |
| 49 | MEDCOM | U.S. ARMY OPERATIONS FITZSIMONS | Colorado | C |
| 50 | USARPAC | FORT GREELY | Alaska | R |

Table A1

## APPENDIX B: PROGRAMMATIC CONFIDENCE FACTORS

Giangiuli [2000] uses the worksheet shown below to help BRACO develop the Programmatic Confidence Factors (PCF). These factors, determined during BRACO reviews of installation site cleanup estimates, provide a quantitative evaluation of the installation's ability to execute its site cleanup if provided requested funding. These factors help nominate *must-delay* sites.

**PROGRAMMATIC CONFIDENCE EVALUATION FORM**

Installation: _____ MACOM: ____ BEC: _____

Description:

Risks/Hazards:

Clean-up Drivers:

| Facilitation | Yes 100% | Weight | 75% | Weight | Confidence 50% | Weight | 25% | Weight | No 0% | Weight | N/A | Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Work Scope Definition | | | | | | | | | | | | |
| A. Has the site been fully characterized? If not, when is full characterization expected? RI: _____ | Comp | 10 | FY01 | 7.5 | FY02 | 5 | FY03 | 2.5 | FY04+ | 0 | | 0.00 |
| B. Has the characterization defined the "Path" to achieve RIP/RC? | | 10 | | 7.5 | | 5 | | 2.5 | | 0 | | 0.00 |
| C. Has the "Path" received "buy-in" from Regulators | | 10 | | 7.5 | | 5 | | 2.5 | | 0 | | 0.00 |
| Technical Review (ITR, GWETER, etc.) | | 10 | | 7.5 | | 5 | | 2.5 | | 0 | | 0.00 |
| Chain of Command | | 10 | | 7.5 | | 5 | | 2.5 | | 0 | | 0.00 |
| D. Has a formal "Project Plan" been developed which includes: Integrated Schedule | | 10 | | 7.5 | | 5 | | 2.5 | | 0 | | 0.00 |
| Critical Path | | 10 | | 7.5 | | 5 | | 2.5 | | 0 | | 0.00 |
| Slack/Contingency | | 10 | | 7.5 | | 5 | | 2.5 | | 0 | | 0.00 |
| RACER (or better) Cost Estimates | | 10 | | 7.5 | | 5 | | 2.5 | | 0 | | 0.00 |
| E. Have resources been adequately captured in RCTCS / DSERTS and BRAC Work Plan | | 10 | | 7.5 | | 5 | | 2.5 | | 0 | | 0.00 |

2. Work Scope Execution

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A. Has the installation/USACE managed previous elements of the work scope to successful completion (scope, schedule, cost, regulatory satisfaction, etc.)? | ☐ | 5 | ☐ | 3 | ☐ | 2 | ☐ | 1 | ☐ | 0 | ☐ | 0.00 |
| B. Has the contractor completed previous elements or a similar work scope to successful completion (scope, schedule, cost, regulatory satisfaction, etc.)? | ☐ | 5 | ☐ | 3 | ☐ | 2 | ☐ | 1 | ☐ | 0 | ☐ | 0.00 |
| C. Have there been any significant contract management issues in the past 3 years? | ☐ | 0 | ☐ | 1 | ☐ | 2 | ☐ | 3 | ☐ | 5 | ☐ | 0.00 |
| D. Does the proposed technology/cleanup method meet with the regulators satisfaction? | ☐ | 5 | ☐ | 3 | ☐ | 2 | ☐ | 1 | ☐ | 0 | ☐ | 0.00 |
| E. Has the proposed technology/cleanup method been proven on this installation? | ☐ | 5 | ☐ | 3 | ☐ | 2 | ☐ | 1 | ☐ | 0 | ☐ | 0.00 |
| F. If restoration is underway, is it on track from an "earned value" and "RIP/RC" standpoint? (Missed phase milestones and CTC % change) / phase slips CTC change = | ☐ | 5 | ☐ | 3 | ☐ | 2 | ☐ | 1 | ☐ | 0 | ☐ | 0.00 |
| TOTALS | | | | | | | | | | | | 0.00 |

3. Other Factors & Amplifying Notes:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A. Does a significant difference exist between the stakeholders (public, regulators, etc.) and the installation on the importance or risks associated with cleanup? | ☐ | 0 | ☐ | 1 | ☐ | 2 | ☐ | 3 | ☐ | 5 | ☐ |
| B. Is there a pressing reuse opportunity for significant parcels on this installation? | ☐ | 5 | ☐ | 3 | ☐ | 2 | ☐ | 1 | ☐ | 0 | ☐ |
| C. Is there significant political pressure to cleanup this installation? | ☐ | 5 | ☐ | 3 | ☐ | 2 | ☐ | 1 | ☐ | 0 | ☐ |
| D. Is there significant near term risk with delayed funding of this program? | ☐ | 5 | ☐ | 3 | ☐ | 2 | ☐ | 1 | ☐ | 0 | ☐ |

Issue:

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