U.S. ARMY

Center for Army Analysis

MODELING TO OPTIMIZE RESTORATION TRACKING AND INVESTMENTS II

OCTOBER 2000

CENTER FOR ARMY ANALYSIS
6001 GOETHALS ROAD
FORT BELVOIR, VA 22060-5230

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13. ABSTRACT *(Maximum 200 Words)*

The Center for Army Analysis developed an integer programming model to provide alternative schedules for environmental restoration projects, based on different objective functions. Restoration projects are broken down into phases that must occur sequentially and with specified phase lengths. This model was used to examine compliance with the Defense Planning Guidance.

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MODELING TO OPTIMIZE RESTORATION TRACKING AND INVESTMENTS II (MORTI II)

SUMMARY

THE PROJECT PURPOSE was to extend the methodology developed in the Modeling to Optimize Restoration Tracking and Investments (MORTI) Study to accommodate differing phase lengths for environmental restoration sites and to examine the strategies developed to determine the effects on compliance with the Defense Planning Guidance (DPG).

THE PROJECT BACKGROUND was the US Army has hundreds of active-duty installations that require environmental restoration. Environmental restoration is defined as "actions taken to identify contaminated sites, assess risk, and clean up hazardous wastes from previous Army activities." The Defense Planning Guidance mandates that all of these installations have a remedy in place by fiscal year (FY) 2014. Remedy in place is defined as having completed all phases of cleanup and have long-term operations and/or maintenance in place. In addition, it requires sites with the most serious environmental hazards, defined as high-risk sites, to have remedy in place by FY 2007. Restoration sites are assigned a risk level. These are high, medium, low, not evaluated, and not required. An example of a high-risk site would be a contaminated aquifer in a densely populated area, and its remedy in place would be a pump-and-treat plant that would continue to clean the water beyond the planning horizon. A site that has remedy in place has a risk rating of "not required."

THE PROJECT SPONSOR was the Assistant Chief of Staff for Installation Management (ACSIM).

THE PROJECT OBJECTIVES were to:

(1) Refine the MORTI formulation to include differing phase lengths for environmental restoration sites.

(2) Examine the strategies developed to determine the effects on compliance with the DPG.

THE SCOPE OF THE PROJECT was limited to current US Army environmental restoration projects scheduled to start before FY 2014. Formerly Used Defense Sites and environmental restoration due to Base Realignment and Closure were not considered. In addition, due to their politically charged nature, the Massachusetts Military Reserve and the Rocky Mountain Arsenal were not considered.

THE MAIN ASSUMPTIONS were that the data provided were comprehensive and correct and that the average phase lengths provided were a good approximation of the actual phase lengths at the sites.

THE PRINCIPAL FINDINGS are that it is possible to meet the DPG goal of having remedy in place for all sites by FY 2014, given the funds available. However, it is not possible to have all high-risk sites at remedy in place by FY 2007, which is also the DPG goal.

THE PROJECT EFFORT was conducted by Ms. Linda Coblentz, Resource Analysis Division, Center for Army Analysis (CAA).

COMMENTS AND QUESTIONS may be sent to the Director, Center for Army Analysis, ATTN: CSCA-RA, 6001 Goethals Road, Suite 102, Fort Belvoir, VA 22060-5230.

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FIGURES

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1 INTRODUCTION

1.1 Modeling to Optimize Restoration Tracking and Investments II (MORTI II)

This project was requested by the Assistant Chief of Staff for Installation Management (ACSIM) as a follow-on project for the Modeling to Optimize Restoration Tracking and Investments Study performed in 1998-1999 (see CAA-SR-99-3).

1.2 Purpose

- ❑ **To extend the MORTI methodology in order to develop and analyze alternative strategies for distributing funds to major commands for environmental restoration projects in a manner more representative of the real-world environment.**
- ❑ **To examine the strategies developed to determine the effects on compliance with the Defense Planning Guidance.**

Figure 1. Purpose

The purpose of MORTI II was to perform analysis similar to that of the MORTI Study with updated data and a refined formulation of the MORTI model to use differing phase lengths. The refined model will be used to develop and analyze alternative strategies for distributing funds to major commands for environmental restoration. These alternative strategies are then examined to determine if they are compliant with the DPG.

1.3 Background

Environmental restoration is defined as 'actions taken to identify contaminated sites, assess risk, and clean up hazardous wastes from previous Army activities.' The US Army has hundreds of active-duty installations that require such actions. The Defense Planning Guidance mandates that all of these installations have a remedy in place by FY 2014. Remedy in place is defined as having completed all phases of cleanup and have long-term operations and/or maintenance in place. In addition, it requires sites with the most serious environmental hazards, defined as high-risk sites, to have remedy in place by FY2007. Restoration sites are assigned a risk level. These are high, medium, low, not evaluated, and not required. An example of a high-risk site would be a contaminated aquifer in a densely populated area, and its remedy in place would be a pump-and-treat plant that would continue to clean the water beyond the planning horizon. A site that has remedy in place has a risk rating of "not required."

The cost to clean up these installations is in the billions of dollars. The Office of the Assistant Chief of Staff for Installations Management (ACSIM) provides restoration funds to the major Army commands (MACOMs). The MACOMs then provide funding to the installations. Currently the distribution of the funds from the ACSIM to the MACOMs is determined by a rule of thumb procedure, based on preliminary examination of the relative risk of the restoration sites within a MACOM and the Army goals.

Although the procedure mentioned above is somewhat adequate, ACSIM required a more analytical approach to support its development of the Program Objective Memorandum (POM). In addition, they required the ability to perform what-if analyses with respect to changing priorities and programmatics. As an example of changing priorities, ACSIM was interested in what effect changing priority from closing high-risk sites as soon as possible to closing certain MACOMs as soon as possible would have on completion. As an example of changing programmatics, the Army Environmental Center (AEC) was interested in finding out what would happen if the length of long-term maintenance and long-term operations was shifted to a different account after 5 years as opposed to 20 years.

In 1998, ACSIM asked the Center for Army Analysis (CAA) to develop an analytically defensible way to distribute funds to the MACOMs for environmental restoration projects. That project, the Modeling to Optimize Restoration Tracking and Investments (MORTI) Study, was the development of an integer program optimization model. The model optimized investment strategies for environmental restoration projects based on two different objectives. These objectives were to prioritize on risk level, i.e., close the high-risk sites earliest, and prioritize on closing certain MACOMs first. For more information, see the MORTI report (CAA-SR-99-3).

1.4 Scope

- This project is limited to current US Army restoration projects scheduled to start before FY2014.
- We will consider approximately 3,300 environmental restoration site/phase combinations.
- Formerly Used Defense Sites (FUDS) and restoration due to BRAC are not considered.
- Massachusetts Military Reserve and Rocky Mountain Arsenal are not considered.

Figure 2. Scope

The scope of the project is shown in Figure 2. The analysis was limited to active Army installations. Massachusetts Military Reserve and Rocky Mountain Arsenal were not considered due to the politically charged nature of these installations.

1.5 Assumptions

- ❑ **The list of site/phase combinations is complete.**
- ❑ **The costs are accurate.**
- ❑ **The following phase lengths were used.**
  - **Preliminary Assessment/Site Investigation: 1 year**
  - **Remedial Investigation/Feasibility Study:**
    - ✓ **If cost is less than $500K, 2 years**
    - ✓ **If cost is between $500K and $2M, 3 years**
    - ✓ **If cost is more than $2M, 4 years**
  - **Immediate Response Action: 2 years**
  - **Remedial Design: 2 years**
  - **Remedial Action: 3 years**
  - **Long-term Monitoring and Long-term Operations: until the end of the planning horizon.**

Figure 3. Assumptions

In Figure 3 above are the assumptions of the study. Essentially, we are assuming that the data provided by the Army Environmental Center are correct and complete. The phase lengths provided are an estimate of the average time necessary to complete the phase. Note that all sites do not have all of the phases.

2 METHODOLOGY

2.1 Approach

- ❑ **Modify the integer program developed in the MORTI project to reflect the time lengths of the phases.**
- ❑ **Modify the IP to enhance run time, as needed.**
- ❑ **Modify programmatics (i.e., budget), as needed.**

Figure 4. Approach

The modification of the original MORTI model formulation to reflect the time lengths of the phases was minor. Below is a description of the original formulation as well as a description of the modifications that were made. The only modification was to the constraint that imposes the phase lengths. This change is highlighted.

In the notation, *i* refers to a site, *j* and *n* to phases, and *k* to a year.

a. The variables in the model are:

$$x_{ijk} = 1 \text{ if site } i\text{, phase } j \text{ is started in year } k\text{, 0 otherwise}.$$

b. The data elements for the model are:

b_k = budget for year k,
c_{ij} = cost of site i, phase j,
l_j = length of phase j,
a_{ijk} = objective coefficient for site i, phase j, in year k,
SP = the set of site/phase combinations under consideration,
$BIGMACOM$ = the set of MACOMs that can be smoothed,
p_{low} = lower bound on the percentage change in cost from the previous year, and
p_{up} = upper bound on the percentage change in cost from the previous year.

c. The constraints are described below.

(1) Every site/phase combination must be started once and only once.

$$\sum_{k=2001}^{2014} x_{ijk} = 1, \forall (i,j) \in SP$$

(2) The budget cannot be exceeded in any year. The costs incurred in a year include the cost of any site/phase combination that starts in that year and the yearly cost of LTM/LTO, if those phases have begun previous to that year.

$$\sum_{\substack{(i,j)\in SP \\ j\notin\{LTM,LTO\}}} c_{ij}x_{ijk} + \sum_{\substack{(i,j)\in SP \\ j\in\{LTM,LTO\}}} \sum_{y=2001}^{k} c_{ij}x_{ijy} \le b_k, \forall k \in Years$$

(3) Because the purpose of the study is to distribute funds to the MACOMs, it is desirable to prevent large differences between the funds from one year to the next. Ideally, all MACOMs would have smooth budget streams. However, due to the phase lengths and the small number of site/phase combinations of some MACOMs, these constraints introduce infeasibility when applied to all but the larger MACOMs. The two following equations describe the lower and upper bound smoothing constraints. Note that the costs for LTM and LTO are continued to the end of the timeframe after these phases are started.

$$\sum_{\substack{(i,j)\in SP\\ j\notin\{LTM,LTO\}}} c_{ij}x_{ijk} + \sum_{\substack{(i,j)\in SP\\ j\in\{LTM,LTO\}}} \sum_{y=2001}^{k} c_{ij}x_{ijy} - p_{low}\left(\sum_{\substack{(i,j)\in SP\\ i \text{ in m}\\ j\notin\{LTM,LTO\}}} c_{ij}x_{ijk-1} + \sum_{\substack{(i,j)\in SP\\ i \text{ in m}\\ j\in\{LTM,LTO\}}} \sum_{y=2001}^{k-1} c_{ij}x_{ijy} \right) \geq 0, \forall m \in BIGMACOM, k \in Years$$

and

$$\sum_{\substack{(i,j)\in SP\\ j\notin\{LTM,LTO\}}} c_{ij}x_{ijk} + \sum_{\substack{(i,j)\in SP\\ j\in\{LTM,LTO\}}} \sum_{y=2001}^{k} c_{ij}x_{ijy} - p_{up}\left(\sum_{\substack{(i,j)\in SP\\ i \text{ in m}\\ j\notin\{LTM,LTO\}}} c_{ij}x_{ijk-1} + \sum_{\substack{(i,j)\in SP\\ i \text{ in m}\\ j\in\{LTM,LTO\}}} \sum_{y=2001}^{k-1} c_{ij}x_{ijy} \right) \leq 0, \forall m \in BIGMACOM, k \in Y$$

(4) The following constraint imposes both the phase ordering and the phase lengths. In the notation below, phase n precedes phase j.

$$\sum_{y=2001}^{k-l_n-1} x_{ink} \geq x_{ijk}, \quad \forall k; \forall \{i,j,n \mid (i,j),(i,n) \in SP; j > n\}$$

This is the only constraint that needed to be changed from the original model. In the original formulation, $l_n = 1$ for all phases. In the modified formulation, l_n is equal to the phase lengths as discussed in the assumptions.

d. The objective function is

$$Maximize \sum_{(i,j)\in SP} \sum_{k=2001}^{2014} a_{ijk}x_{ijk}$$

where a_{ijk} is the objective function coefficient. These coefficients are changed to enforce the different priorities in the "what-if" analyses.

2.2 Modified Formulation

The following formulation is the one used to produce the results in this report.

This problem, as formulated above, is extremely large. There are over 3,300 site/phase combinations that must be scheduled over 14 years. Consequently, there are almost 170,000 binary variables. In the general case, the probability of getting a solution to this model is very small. However, because the objective function coefficients are left to the discretion of the modeler, the objective function can be structured in such a way so as to provide more powerful branching and pruning. Additionally, there are some inherent special ordered sets within the structure of the model that improve the probability of getting a solution.

However, despite the actions that can be taken, the model sometimes will not solve to completion. When this occurs, there is an alternate formulation that can be used that increases the probability of reaching a solution by reducing the size and complexity of the problem. This formulation fixes the phase start times for each site based on the starting year and the phase lengths. Each site is considered to be a collection of all of its phases. When a phase is completed at a site, the next phase starts the next year. In this manner, the number of sites that must be scheduled over 14 years is only about 1600, thereby reducing the number of variables.

Below is the formulation for the alternative model.

a. In this model, a site is considered to include all of its phases. Therefore, the variables for the model are

$$x_{ik} = 1 \text{ if site } i \text{ is started in year } k, 0 \text{ otherwise}$$

b. The data elements for the model are

$$b_k = \text{budget for year } k$$

$$c_{it} = \text{cost of site } i \text{ the } t^{th} \text{ year after the site starts}$$

$$a_{ik} = \text{objective coefficient for site } i \text{ in year } k$$

$$l_i = \text{the total length of time for site } i \text{ to reach LTM/LTO}$$

The project cost data are what ensures the phase lengths are accurately depicted. The cost of the phase is incorporated into the cost stream of the site.

c. The following set of equations ensures that the budget for any given year is not exceeded.

$$\sum_{i \in Sites} \sum_{\substack{y=2001 \\ t=k-y+1}}^{k} c_{it} x_{iy} \le b_k, \forall k \in Years$$

d. The following set of equations ensures that each site is started once and only once.

$$\sum_{k=2001}^{2014} x_{ik} = 1, \forall i \in Sites$$

e. The following set of equations ensures that all of the sites are started in a year that allows all of the phases to be completed.

$$\sum_{k=2001}^{2014-l_i} x_{ik} = 1$$

f. The objective function is given below. The objective function coefficients are defined as they were for the original formulation.

$$Maximize \sum_{i \in Sites} \sum_{k=2001}^{2014} a_{ik} x_{ik}$$

As mentioned at the beginning of this chapter, this is the formulation that was used to produce the results in the following chapter.

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3 RESULTS

3.1 Introduction

The following figures depict the results of the project. The version of the model used to produce these results was presented in Chapter 2. Because of the current political climate, the sponsor was only interested in the results of the optimization when the objective was to close the high-risk sites as early as possible, medium-risk sites next, and the others last. Consequently, other alternatives were not examined.

3.2 Budget for MORTI II

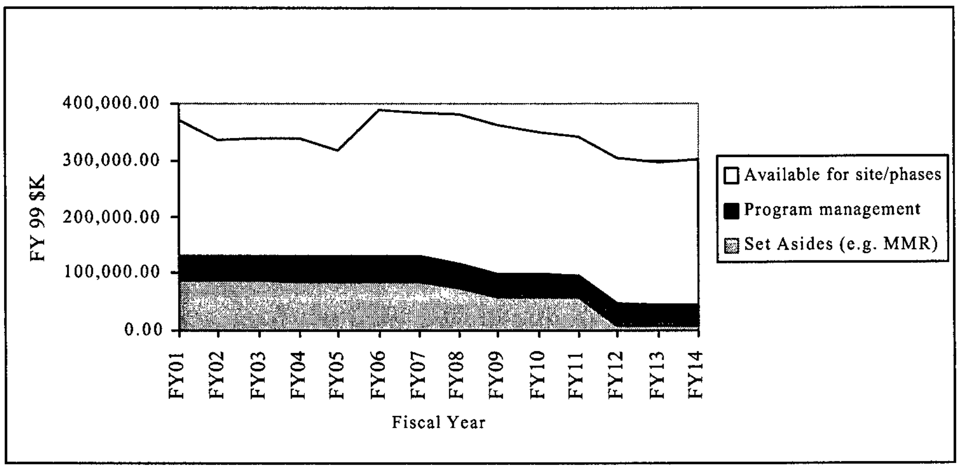

Figure 5. Budget for MORTI II

The following results use the yearly fund constraints shown in Figure 5 above. The funds that were available for environmental restoration projects are the upper tier of the figure.

3.3 Number of Site/Phases Remaining

RESULTS

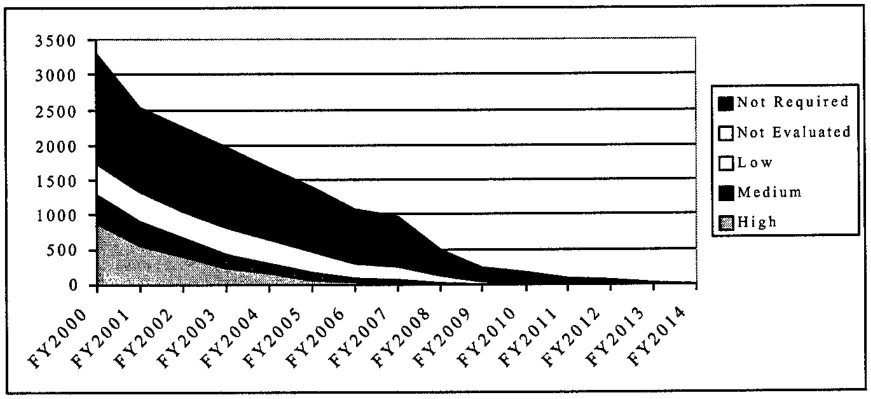

Figure 6. Number of Site/Phases Remaining

This figure depicts the number of site/phase combinations remaining to be started by year by risk factor. Note that, given the assumptions, it is possible to meet the Defense Planning Guidance goal of having all of the sites at remedy in place by FY 2014. Also note that there is a drop in "Not Required" category in the first year, despite the fact that it has the least priority. This is because several sites have some reason that they must start in that year, such as contractual obligations and agreements with the community in which they are located.

3.4 Cost by Risk Factor

RESULTS

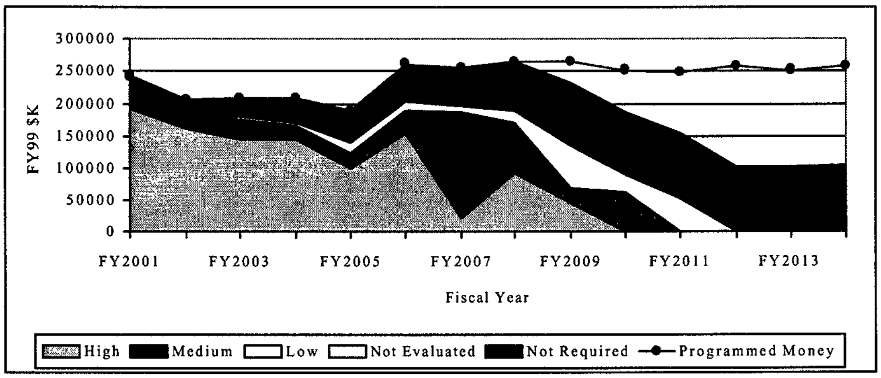

Figure 7. Cost by Risk Factor

Figure 7 depicts the costs associated with the figure above it. The peaks and valleys in the cost streams are due to the phase lengths. The cost for a site/phase is incurred in the first year of the phase except for the "Not Required" site/phases. Recall that a site rated "Not Required" means that the site has remedy in place and therefore has a yearly cost that extends beyond the planning horizon.

3.5 Findings

- ❑ It is possible to meet the DPG goal of having remedy-in-place for all sites by FY 2014, given the funds available.
- ❑ It was not possible to meet the DPG goal of having all high risk sites at remedy-in-place by FY 2007.

Figure 8. Findings

Above in Figure 8 are the findings for the study. Given the funds available, the Army is able to meet the DPG goals for FY 2014. However, because of the contractual obligations for some of the "Not Required" sites, funds were not available to meet the DPG goal of having all high-risk sites at remedy in place by 2007. More detailed results are presented in Appendix C.

APPENDIX A PROJECT CONTRIBUTORS

1. PROJECT TEAM

a. Project Director

Ms. Linda Coblentz, Resource Analysis Division

2. PRODUCT REVIEW

Mr. Ronald Iekel, TQM Specialist

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APPENDIX B REQUEST FOR ANALYTICAL SUPPORT

P *Performing Division:* RA | *Account Number:* **99062**

A *Tasking:* Verbal | *Mode (Contract-Yes/No):* No

R *Acronym:* **MORTI-II**

T

Title: Modeling to Optimize Restoration Tracking and Investments II

1 *Start Date:* 01-Feb-99 | *Estimated Completion Date:* 30-Apr-99

Requestor/Sponsor (i.e., DCSOPS): ACSIM | *Sponsor Division:* DAIM

Resource Estimates: ***a. Estimated PSM:*** 3 ***b. Estimated Funds:*** $0.00

c. Models to be **MORTI**

Description/Abstract:

The ACSIM has requested CAA to help the allocation of funds for environmental restoration in support of the FY 02-07 POM build. To do this, CAA will modify and apply the MORTI model.

Study Director/POC Signature:Original Signed | *Phone#:* 703-806-5364

Study Director/POC: **Ms. Linda Coblentz**

If this Request is for an External Project expected to consume 6 PSM or more, Part 2 Information is Not Required. See Chap 3 of the Project Directors' Guide for preparation of a Formal Project Directive.

Background:

P

A

R *Scope:*

T

2

Issues:

Milestones:

Signatures ***Division Chief Signature:*** *Original Signed and Dated* ***Date:***

Division Chief Concurrence: Mr. Steven Siegel

Sponsor Signature: *Original Signed and Dated* ***Date:***

Sponsor Concurrence (COL/DA Div Chief/GO/SES)

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APPENDIX C RESULTS

The following tables provide the results of the analysis. There are four tables. The first table gives the annual cost of the projects as scheduled by the model broken out by risk factor. The risk factors, in order of severity, are High, Medium, Low, Not Evaluated, and Not Required. Not Required means that a site is in Long-term Operations or Long-term Monitoring. The risk factor for a site is provided by the sponsor. The cost figure in FY 2015 is the cost of the Not Required sites that will continue for several years beyond the planning horizon. The second table gives the annual cost broken out by major command (MACOM).

The third table gives the number of site/phase combinations that are remaining, broken out by risk factor. As can be seen, all site/phase combinations are funded by FY 2014 for all alternatives. The fourth table provides this information broken out by MACOM.

Cost by Risk Factor (FY99 $K)															
	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15
High	191144	161167	144542	143989	101182	153983	21675	93007	44994	977	458	0	0	0	0
Medium	20628	13604	30396	22196	21878	35958	164615	75812	23453	63199	875	0	0	0	0
Low	1286	916	3922	2496	16972	13659	9595	19869	67561	24946	52473	0	0	0	0
Not Evaluated	0	0	0	0	154	50	0	90	3946	2100	269	0	0	0	0
Not Required	28574	28615	29604	40060	47167	56349	59110	76140	91576	94508	99890	102729	103245	103920	103920
Programmed Money	241633	204675	208483	208743	187355	260000	255000	265000	265000	252000	247000	257000	252000	257000	

Cost by Major Command (FY99 $K)															
MACOM	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15
AMC	187688	156102	141282	154151	128655	190763	230369	194146	166120	132838	70568	68260	68459	68957	68957
USACE	110	50	3072	50	50	306	306	354	354	354	354	354	354	354	354
FORC	20597	9199	36587	11727	18444	38332	10399	13673	16164	15598	15782	15374	15374	15436	15436
MDW	160	660	160	160	210	210	210	380	533	533	533	533	533	533	533
MEDCOM	0	0	0	655	0	2427	0	23625	2329	169	760	771	771	771	771
NGB	11338	3594	7639	8720	8790	3564	1924	3623	3936	10612	2348	2348	2408	2408	2408
TRADOC	7007	19801	9101	13893	8184	5769	5321	14362	25396	7333	14489	5050	5206	5288	5288
USAPC	10316	6377	1615	4548	18189	8677	3165	6475	8777	11697	42926	3721	3750	3783	3783
USARC	3801	8344	8834	14629	4623	9732	3081	7988	7629	6303	5913	6025	6097	6097	6097
USMA	615	175	175	208	208	218	218	293	293	293	293	293	293	293	293
Total	241632	204302	208464	208741	187353	259999	254995	264918	231530	185730	153965	102729	103245	103920	103920
Programmed Money	241633	204675	208483	208743	187355	260000	255000	265000	265000	252000	247000	257000	252000	257000	

Number of Site/Phases Remaining	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15
High	879	550	411	216	170	57	35	12	5	3	2	0	0	0	0
Medium	407	333	244	204	123	100	45	40	11	5	2	0	0	0	0
Low	438	428	387	377	335	311	207	186	100	34	17	0	0	0	0
Not Evaluated	12	12	12	12	12	11	10	10	8	3	1	0	0	0	0
Not Required	1572	1208	1195	1175	1037	901	763	703	354	175	155	69	43	22	0
Total	3308	2531	2249	1984	1677	1380	1060	951	478	220	177	69	43	22	0

Number of Site/Phases Remaining															
MACOM	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15
AMC	2096	1580	1370	1166	971	772	566	499	234	106	86	36	22	15	0
USACE	9	7	7	6	6	6	4	4	0	0	0	0	0	0	0
FORC	258	177	165	151	127	106	90	87	48	16	10	6	2	2	0
MDW	14	12	11	11	11	10	10	10	4	0	0	0	0	0	0
MEDCOM	10	10	10	10	9	9	8	8	6	3	3	1	0	0	0
NGB	83	72	64	59	47	41	31	27	16	11	5	4	4	0	0
TRADOC	433	360	325	294	258	216	175	149	87	37	30	12	9	4	0
USAPC	137	85	81	80	70	61	52	51	29	15	13	5	3	1	0
USARC	245	217	205	196	171	152	118	110	54	32	30	5	3	0	0
USMA	23	11	11	11	7	7	6	6	0	0	0	0	0	0	0
Total	3308	2531	2249	1984	1677	1380	1060	951	478	220	177	69	43	22	0