REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
11/00/80

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
INVESTIGATION OF BASIN F SOLUTION ALTERNATIVES (DRAFT)

5. FUNDING NUMBERS

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
D'APPOLONIA CONSULTING ENGINEERS
DENVER, CO

8. PERFORMING ORGANIZATION REPORT NUMBER
81266R11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
BATTELLE MEMORIAL INSTITUTE. COLUMBUS LABORATORIES
COLUMBUS, OH

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
THIS IS A STUDY OF ALTERNATIVE SOLUTIONS FOR THE BASIN F PROBLEM. IN PARTICULAR THE FOLLOWING TYPES OF ALTERNATIVES WERE EVALUATED:
(1) FILL AND COVER BASIN F, (2) EXCAVATE CONTAMINATED MATERIALS AND TRANSPORT TO A LANDFILL, AND (3) PHYSICAL AND/OR CHEMICAL TREATMENT OF THE CONTAMINATED MATERIALS IN BASIN F. THE FIRST TASK OF THE ORIGINAL SCOPE OF THIS WORK WAS PREPARATION OF A "DECISION SCHEME TO EVALUATE METHODS OF CONTROLLING RELEASE OF CONTAMINANTS IN THE BASIN F VICINITY TO THE SURROUNDING ENVIRONMENT." COMPLETION OF TASK 1 RESULTED IN A LETTER REPORT ISSUED MAY 5, 1980 BY D'APPOLONIA.

14. SUBJECT TERMS
TREATMENT, INCINERATION, CHEMICALS, DISPOSAL, COST

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

Project No. RM80-192
Nov. 80

[redacted]

DRAFT

D'APPOLONIA
CONSULTING ENGINEERS, INC.

Report

Investigation of Basin F Solution Alternatives

Rocky Mountain Arsenal
Commerce City, Colorado

Battelle Columbus Laboratories
Columbus, Ohio

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1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

The Rocky Mountain Arsenal (RMA) is located approximately 10 miles northeast of the central business district of Denver, Colorado and immediately north of the Stapleton International Airport (Figure 1). RMA was established in 1942 and historically has either produced various chemicals and chemical-filled munitions, or demilitarized these same items. In 1946, a large portion of the manufacturing facilities was leased to private industry for the production of various pesticides. The major lessee, Shell Chemical Company, has leased a considerable portion of the facilities at RMA since 1952. Industrial waste effluents generated at RMA have been discharged into several waste storage basins located on the Arsenal grounds. The capacity of these basins has been periodically increased when chemical production was expanded.

In 1954, several farmers northwest of the Arsenal complained of damage to crops irrigated with water pumped from shallow alluvial aquifers. The suspected cause of this damage was seepage from the waste storage basins on the Arsenal. In response to this concern, the Department of the Army initiated the following actions:

- Retained an engineering firm to investigate the problem of groundwater contamination.
- Requested the U.S. Geological Survey (USGS) to study water quality on the Arsenal and neighboring farmlands.
- Contracted the University of Colorado to undertake plant, chemical, and geological investigations to identify the source of the crop damage.

These studies resulted in the construction of a new disposal basin (Basin "F", Figure 1) with a low permeability liner to prevent chemical waste seepage into the groundwater. Since 1957, all chemical wastes have been pumped into this reservoir.

In May 1974, diisopropylmethylphosphonate (DIMP) and dicyclopentadiene (DCPD) were detected in waters discharging from a bog located in the vicinity of north boundary of the RMA. DIMP is a persistent compound produced in small quantities during the manufacture of GB, a chemical warfare agent. DCPD is a chemical used in the production of insecticides. Detection of these compounds resulted in the following actions:

- RMA expanded its groundwater monitoring program.
- A dike was constructed north of the bog to eliminate off-post surface drainage from this area.
- Investigations were conducted to determine the effect of DIMP on wheat.

In December 1974, the Colorado Department of Health (CDH) detected DIMP concentrations in a water supply well near the City of Brighton. The detection of DIMP and DCPD off post prompted the CDH to issue three Cease and Desist Orders on April 7, 1975, that required (1) an immediate stop to surface and subsurface discharge of DIMP and DCPD, (2) development of a plan to preclude future discharge of the contaminants, and (3) development of a monitoring program to verify compliance with these orders. As a result of the Cease and Desist Orders, as well as the Army's recognition that contamination had resulted from past operations, an extensive program of contamination control was established. The objectives of this program were to contain and treat contaminants migrating from the Arsenal and to identify, isolate, and treat the contaminant sources.

As part of the contamination control program, analysis of groundwater from the north boundary area in the summer of 1976 revealed the presence of inorganic fluorides and three organic sulfur compounds (p-chlorophenylmethylsulfide, p-chlorophenylmethylsulfoxide, and p-chlorophenylmethylsulfone).

In 1978, dibromochloropropane (DBCP or Nemagon) was discovered in the groundwater in the vicinity of the north boundary of the Arsenal. Although these compounds were not cited in the Cease and Desist Orders, they are included in the list of compounds requiring treatment.

In pursuit of the first objective, many investigators have been involved in hydrologic investigations and the design of a containment and treatment system for a portion of the northern boundary of the RMA. These investigations resulted in the installation of the existing pilot containment system along a portion of the northern RMA boundary. This system has been in operation since July 28, 1978 and has been evaluated extensively during the past two years. Because of the system's excellent performance, it will be extended to the east and west along the north boundary so as to control the major zone of groundwater flow through the north boundary.

These systems will control the release of containments from RMA along its north boundary. However, such treatment at the boundary would continue for very long time periods unless the source of the contamination is eliminated or contained. Basin F is the closest probable source of many of the contaminants found in the groundwater in the vicinity of the north boundary. This report addresses elimination of Basin F as a contaminate source.

1.2 ORIGINAL SCOPE OF WORK

On February 16, 1980, D'Appolonia Consulting Engineers, Inc. (D'Appolonia) responded to a proposal to review Basin F control strategy. On April 14, 1980 D'Appolonia entered into a contract with Battelle Columbus Laboratories, Durham Operations, to perform the review. The first task in this review was preparation of a "decision scheme to evaluate methods of controlling release of contaminants in the Basin F vicinity to the surrounding environment". Completion of Task 1 resulted in a Letter Report being issued on May 5, 1980 by D'Appolonia. This report presented a logic model to evaluate Basin F control strategies.

Due to delays in contract initiation (two months, see previous paragraph), it became evident that the remaining information to be provided by D'Appolonia would not be available for input into the fiscal year 1981 (FY81) control scheme. Therefore, D'Appolonia was asked to hold further work in abeyance until after a decision had been made for the FY81 effort for Basin F. A new schedule for the task would then be arranged and the effort continued.

1.3 PRESENT SCOPE OF WORK

On August 22, 1980, D'Appolonia rescoped the remaining work and proposed tasks to continue study of Basin F alternative solutions. In particular, the technical feasibility and cost estimates of the following types of alternative strategies were to be determined:

- Fill and cover Basin F.
- Excavate contaminated materials and transport to a landfill.
- Physical and/or chemical treatment of the contaminated materials in Basin F.

A summary of these evaluations is provided in the following section.

1.4 SUMMARY

A review of the available literature concerning Basin F includes data which describes the composition of the materials in the Basin. However, accurate estimates of the volumes of contaminated materials and their specific heat content were not available. In order to calculate the volume of material present in Basin F, a topographic map of the Basin and various reported depths of the liquids in the Basin were analyzed. The information was refined by field observations and a contoured map of the amount of solids in the Basin was constructed. The total volume of material to six inches below the liner to be processed was calculated to be 809,800 tons. The specific heat of the liquid was measured to be 400 BTU/lb in samples obtained during the field visit.

To help in evaluating the various options, two models were used: 1) a decision flow diagram, and 2) a ranking model. The flow diagram and ranking model resulted in conclusions to either incinerate the Basin contents and landfill the residue or construct a landfill within Basin F and place the Basin contents in the landfill.

Detailed cost estimates of eight alternative excavation and landfilling options were calculated. These options ranged from simple cap and fill to landfilling of residue from an incineration process. The costs varied from approximately $5,800,000 to $9,800,000. Detailed cost estimates were also calculated for the various treatment options, including methods of incineration and wet air oxidation. The lowest cost estimate to excavate, incinerate and landfill the residue was calculated to be approximately $11,300,000 over a five year period. The estimates are very sensitive to the volume of materials, moisture content, material properties, and fuel required; therefore, these data should be determined more precisely to obtain refined cost estimates.

The compliance of any process with regulatory agencies is difficult to predict. Specifically, new rules may be issued soon concerning landfilling and air emissions from hazardous waste management facilities. These rules could have serious effects on the decisions to be made concerning Basin F strategies. Currently, processes involving both landfilling and incineration could comply with regulatory laws. However, any success with incineration would require more permits. Testing of the treatment residues and exhaust gases will probably be necessary to determine applicable permits.

The following sections provide details of the information summarized in previous paragraphs.

Respectfully submitted,

John C. Mullen
Project Manager

Roger L. Olsen
Assistant Project Geochemist

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2.0 LITERATURE REVIEW

As the first step of this project, the available reports containing information concerning Basin F were collected and reviewed. All of the reports reviewed, are listed in the Bibliography. The following reports were used extensively throughout the project:

- Buhts, R. E., N. R. Francingues, and A. J. Green, 1979, Basin F Investigative Studies, Report 1, Chemical Assessment. Waterways Experiment Station.
- Buhts, R. E., N. R. Francingues, and A. J. Green, 1979, Basin F Investigative Studies, Report 2, Historical Review, Waterways Experiment Station.
- McKown, G., and L. Taft, 1980, Alternatives for Reduction in Volume of Liquid in Basin F, Rocky Mountain Arsenal, Battelle-Columbus.
- Hildebrandt, H. F., 1978, Evaluation of the Rocky Mountain Arsenal Incinerators for Use in Basin F Disposal Scenarios, Chemical Systems Laboratory.
- Johe, D. E., and T. A. Bowen, 1980, RMA Basin A Stabilization Alternatives, Battelle-Columbus.
- Asselin, M. B., and H. F. Hildebrandt, 1978, Basin F Investigative Studies, Phase II, Disposal Evaluation, Volume 1, Chemical Systems Laboratory.
- Berkowitz, J. B., et al., 1976, State-of-the-Art Survey of Land Reclamation Technology, Arthur D. Little, Inc.
- Lawless, H. L., 1978, Preliminary Test of the Wet Oxidation of Organics in Basin F Wastewater at Rocky Mountain Arsenal, Rocky Mountain Arsenal.

The two Basin F investigative study reports, Reports 1 and 2 issued by the Waterways Experiment Station, served as the data base for the contents of Basin F (Buhts, et al., 1979). The reported characteristics and concentrations of contaminants were used as the first estimation of the total amount of materials and the treatability of the liquid and/or bottom solids. The water depth to bottom solids in Basin F which is part of the study documented in Report 1, was integrated with a 1976 topographic blueprint (RMA, 1976) of Basin F to determine the distribution and total volume of solids on the bottom of Basin F.

The alternative evaluation report by Drs. McKown and Taft (McKown and Taft, 1980) was used as the first screening of potential treatment/disposal alternatives. A tabulated list summarizing the alternatives which were evaluated in this report is provided in Table 1. The alternatives were reviewed, the favorable options listed and a number of additional schemes for disposal/treatment were added to the list of options for future consideration by D'Appolonia. Reviews were solicitated from personnel of varied disciplines so a thorough evaluation of each of the alternatives was achieved. During this evaluation, the options of freeze crystalization and spray evaporation were eliminated. Freeze crystalization was eliminated because of the high cost associated with the process (Hager, 1980). In addition, freezing is only a concentrating step and further treatment would still be required. Spray evaporation was eliminated because of air pollution concerns. A spray raft was operated during 1965 and 1966 in Basin F but was shutdown because of air pollution concerns (Buhts, et al., 1979). The options which remained for detailed investigation of feasibility and cost were:

- o Wet air oxidation.
- o Incineration (various types).
- o Fill and cap Basin F.
- o Excavate contaminated material and transport the material or ash from incineration to an off-site landfill.
- o Creation of an on-site landfill at the RMA for Basin F material or incineration ash (either Basin F or another site on RMA property).
- o Sell the material for metal recovery.

In addition, possible methods of evaporation were listed as options for volume reduction and drying of the material.

Combinations of the options provided above result in overall treatment schemes which are similar to the five scenarios proposed by the Chemical Systems Laboratory (Asselin and Hildebrandt, 1978). A brief summary of the five scenarios follows:

- Scenario 1
  - Liquid: concentration and ozonization
  - Sludge: incineration, encapsulation, and landfill
- Scenario 2
  - Liquid and Sludge: Wet air oxidation, centrifugation, concentration, encapsulation and landfill.
- Scenario 3
  - Liquid and Sludge: transport, landfill
- Scenario 4
  - Enhanced evaporation, incineration, encapsulation, landfill.
- Scenario 5
  - Enhanced evaporation, incineration, landfill.

The other previously listed references were also used to evaluate methodologies. For example, the "RMA incinerator use" report (Hildebrandt, 1978) was a valuable data source for information related to potential use of RMA incinerators for this project, overall incinerator evaluation and Basin F solids data. The Basin A report by Battelle (Johe and Bowen, 1980) served as an example and guide for some of the earthwork calculations and design at Basin F. The other reports were used for background material and/or design examples for a number of the options investigated.

3.0 DECISION MODELS

3.1 FLOW DIAGRAM DECISION MODEL

After the alternatives for treatment/disposal of Basin F had been screened to remove the unfeasible options, the remaining options were arranged into a "flow diagram" decision model. The flow diagrams are provided in Figures 2, 3 and 4. The figures depict the thought process that would be used when deciding on a plan of action relative to Basin F. A preliminary decision model was submitted to Mr. Allan McKinney of USATHMA and Mr. Donald Hager of Rubel and Hager, Inc., for review; their comments and other refinements hve been incorporated with the present form of the model.

The flow diagrams follow the anticipated direction which will be taken in evaluating the Basin F alternatives. Based on economics and legal/RMA policy considerations, a decision is made to accept an option or reject it and continue on to the next decision point. The two questions which must be answered for each of the options follow:

- Is the option 'acceptable'?
- Is the option cost effective?

Whether an option is acceptable or not is determined by the likelihood that it would satisfy environmental regulations, whether the option is a proven technology, and whether the option would be in accord with RMA policy and long range planning. A ranking methodology is applied to these criteria so each option can be measured on an absolute basis (e.g., if the option is not a positive step toward regulatory compliance, it is not acceptable), and on a relative basis (e.g., if two options equally achieve regulatory compliance but only one utilizes a proven technology, the one with the proven technology is more acceptable). Because the ranking approach requires an interaction among a number of groups, it is not fully executed for each question during the flow diagram decision process. However, such a ranking methodology was applied to specific options and is discussed in the next section (3.2).

The other question, is whether the option is cost effective. This question (in this model) assumes that costs of all of the options are known before the use of the model is begun; therefore, a decision can be made on each option without continuing through the entire model.

The first part of the model (Figure 2) is the main body which deals with options related to landfilling, hauling, filling and capping. Depending on the decision generated in the first section, three supporting diagrams (Figure 3 and 4) may be needed to complete or complement the main body of the model. The second section (Figure 3) is a continuation of the main flow of the model. This section is concerned with physical and/or chemical treatments; it deals with the use of liquid versus solid treatment and wet air oxidation.

Figure 3 contains a question concerning the caloric content of the liquid. If the material has a significant heating value (caloric content), and incineration is to be used anywhere in the treatment scheme, then that heating value should not be reduced before the incineration step. Wet air oxidation and other liquid treatments will reduce the chemical oxygen demand of the waste and thereby its heat value. They will also generate residual solids which may require incineration. Thus such liquid processes are not complete solutions as the waste stream being generated may require further treatment.

The remaining sections of the model (Figure 4) are two "sub-flow diagrams" used to refine certain decisions to a specific action. The sub-flow diagram for evaporation alternatives is used to determine the method of evaporation (volume and water reduction) that should be specified. Except for the air pollution consideration, the decision of the type of evaporation to be implemented is strictly a function of economics and performance. The sub-flow diagram for incineration alternatives is used to select the type of incinerator. This decision will be based on which technology is best suited for the material.

The model is not intended to be an all-inclusive decision maker. There are a number of areas which require further questioning and analyses to determine if a given option is correct. Dead ends also occur in the model. Some potentially successful schemes may have been overlooked or an option may have been ruled out when it is, in fact, still a feasible option. The model has utility in organizing the thought process for this particular project. By using the model, it was possible to see which options would be potential sources of problems and complications (legal, technical and economic). For example, the most attractive option was (and is) that of selling or giving away the material for metal recovery. However, the cost of metal extraction presently exceeds the metal value of the material. The next most attractive option, from the economic standpoint, would be landfilling the material on-site without treatment. However, this option only contains and does not eliminate the problem and thus the chance of later contamination exists. At the time the model was constructed, it was felt that some form of treatment (elimination) would be the best way to deal with Basin F. Because of the complications of the wet air oxidation process (and all liquid treatments), incineration was viewed as the most attractive solution. While this early opinion did not influence the ensuing investigation for factual information, incineration has remained as a very attractive means of dealing with Basin F and its material.

3.2 CRITERIA/RANKING METHODOLOGY

Ranking of options or concepts requires a selection of criteria, each of which can be used to condense and quantify important information for decision making. There are numerous criteria and sub-criteria which apply to the evaluation of the Basin F. An example criteria list is given in Table 2. In a ranking exercise, even this list of 34 items becomes unwieldy for a judgment-type quantification of importance, risk or adequacy. Accordingly, the criteria list was condensed to four general criteria and nine sub-criteria, as shown on the Example Ranking Matrix in Table 3. All of the criteria are generally understood. However, as part of the ranking exercise, each criterion was discussed among the participants (in the ranking exercise) to effect an agreed-upon meaning in the context of the Basin F evaluation.

Given the criterion and the concepts for Basin F evaluation, a simple ranking method was employed. A value range of one to five (ranking numbers) was used to consolidate the judgment of several individuals who were generally well informed of the subject matter and who individually represented areas of expertise pertinent to the evaluation. The ranking numbers are defined in Table 3 as they apply to each criterion; the definitions are accomplished by a word description for each end of the scale and the condition that the intermediate numbers indicate a degree of sensitivity between the limits. The number one (1) always indicates least acceptable conditions; the number five (5) always indicates best conditions. The number zero (0) was given a special significance -- to indicate an abortive or unacceptable circumstance. Blank spaces indicate that a zero determination was made for a criterion, and consequently evaluations of remaining criteria did not occur.

Eight concepts for the Basin F evaluation were identified. The concept of constructing a slurry wall barrier on the northwest side of Basin F with an attendant dewatering, treatment and recharge system was included as Concept #4; this concept is already scheduled for construction (MCA). For each concept, ratings for each criterion were agreen upon; then the ratings were summed to give an overall ranking of the concept. The result of the ranking method shows two concepts to be unacceptable (#2, #3), one concept acceptable, but only providing an interim or partial solution (#4), one concept to be acceptable but cost prohibitive (#8), and four concepts to be in the same level of acceptability (#1, #5, #6, #7).

Concept "1" is noteworthy in that it shows as a low prospect for compliance and public acceptable (some evaluators may use a zero rating for these criteria); but the technical feasibility and cost criteria are rated sufficiently high to place the concept in serious consideration. Concept #2 is unacceptable because the liquid from pumping could not be discharged without treatment. Concept #3 is unacceptable because a proven technology for treating Basin F contents in place is not known.

Since Concept #4 (the slurry wall barrier concept) is to be implemented and Concept #5 is a combination of Concepts #1 and #4, they (#4 and #5) are not considered further in this evaluation. Concepts #2, #3, and #8 are not further considered for reasons identified above. Concepts #1, #6, and #7 are given detailed evaluation in the following chapters.

4.0 CALCULATION OF MATERIAL VOLUMES

4.1 INFORMATION ON BASIN F MATERIALS

The volumes of the solids and liquids in Basin F were estimated by using data from the previously published reports, observations from a site visit, and engineering judgments. Most of the reports reviewed stated the total liquid volume in the basin, the surface area of the basin and the concentration of total dissolved solids in the liquid at the time of the study. However, no accurate estimates of the amount of total solids in the basin or the distribution of those solids were available. During the literature review, all pertinent data were recorded for possible use in this material estimation process. Data from the Waterways Experiment Station (WES) (Buhts, et al., 1979) report proved to be very helpful. A Battelle report (McKown and Taft, 1980) on the available alternatives also contained information which was useful.

To accommodate an evaluation of the ultimate volume and composition of the basin liquid upon completion of the evaporation program, the following condition was accepted as given (McKinney, 1980): Enhanced evaporation would be performed for a period of two and one-half years. If during this time period, the liquid has evaporated to a point where no more water can reasonably be removed, the program will be stopped early. No standing liquid would be present at the end of the evaporation period and the condensed sludge would be approximately 80 percent solids. This assumption will be discussed later.

One of the most complicated and difficult estimations concerned the total amount of solids on the bottom of the basin. When the basin was originally constructed, a one foot layer of sand/soil was laid directly on top of the liner. The soil volume can be estimated by knowing the area of the basin (approximately 93 acres, neglecting the curvature of the basin). Thus, the volume of soil is estimated to be about 150,000 cubic yards. However, this is not the only source of solids that are presently in Basin F. Other sources of unknown quantities include wind-blown soil suspended solids which have settled out of suspension, and dissolved solids which have precipitated out. This precipitation could be due to changing pH (or other parameters), or concentrations which increased above the saturation point as the water evaporated. The WES Historical Review (Buhts et al., 1979) contained data from a 1969 study which found a distinct layer of sludge (precipitated or settled solids) which could be observed on top of the soil layer. There was no single reference which had a substantiated estimate of solids volume.

4.2 CALCULATED MATERIAL VOLUME

A shape and contour map of Basin F is depicted in Figure 5. In an effort to make an estimation for the purposes of this report, the data from a WES report (Buhts et al., 1979) was combined with an RMA topographic blueprint (RMA, 1976) of the basin. The WES study reported, among other things, the depth of liquid in the basin (i.e., depth to the solid-liquid interface). The basin was nearly full at the time of the study; containing about 200 million gallons of liquid. Knowing the volume to surface area relationship (Taft and McKown, 1980), the surface area was obtained. By trial and error with a planimeter, the elevation with the correct surface area was derived. Once the water surface elevation was known, the reported depth to solids at the sample points was subtracted from the water elevation and a "topographic" map of the solid-water interface was constructed. Using this newly constructed map and the Basin F topographic blueprint, the volume of solids was calculated. By using this method, the solids layer in the northeast corner was calculated to be extremely thick, and the thickness of layer at the southwest corner was negative. The results for these corners are probably incorrect. The remainder of the calculations around the basin are reasonable. To improve the volume estiamte, test holes were excavated in the southwest portion of Basin F during a site visit. No data could be gathered on the northwest corner because it is still covered with liquid. Therefore, estimates for this area were made. The WES Historical Review (Buhts, et al., 1979) reported that tank "bottoms", which probably contained large concentrations of solid matter, have been dumped into Basin F from the western and northwestern edges. It was estimated that the greatest depth of solids should be located at these places; a depth of four feet was chosen. The final contour map of the estimated depths of solids in Basin F is included as Figure 6. A volume of 308,000 cubic yards was calculated using the above method.

4.3 SITE VISIT

The above mentioned site visit was conducted on October 6, 1980. The objectives of the visit were to obtain liquid samples and to excavate test holes in the basin. The liquid samples were analyzed for caloric content (BTUs/ pound) and the excavated holes provided supplemental data concerning the volume of solids in the basin. Due to the need for air packs as a safety precaution, two separate trips onto the dried portions of Basin F were made to obtain the following information:

- Depth of soil/solids above the liner.
- Condition of the liner.
- Condition of the soil under the liner.
- Horizons present in the solids (i.e., saturated versus unsaturated and settled or precipitated solids versus sand, soil, or sludge).

The first trip consisted of a walking investigation along the eastern edge of the dried portion of the basin. Test holes were excavated on the eastern and southeastern edges of the basin with a shovel. The approximate test hole locations are shown in Figure 7. Samples of soil were taken at some of these locations.

The second trip started on the southwest corner of the basin and continued in towards the existing liquid. Sample holes were excavated with a shovel at 80 to 100 foot intervals from the outer edge into a point where the "ground" would no longer support excavating (see Figure 7). Samples of the excavated soil were taken at some locations. A sample of the liquid which leached from the side of test hole No. 5 was collected for BTU testing.

Observations made which are pertinent to this study and the current condition of the basin include the following:

- A salt layer has formed a thin crust over the "dried" parts of the basin and has prevented or hampered subsurface evaporation of the liquid in the soil.

- The material in areas closest to the "water" is completely saturated with liquid. A characteristic of the saturated solids (soils) is that they are black in color, as a result of the organics.

- Areas furthest away from the "water" are fairly dry and the material seems to be soil (sandy soil placed on top of the liner during construction) with little organic content (light brown color).

- The liner appears to be in good condition and there is little or no leakage in the areas where holes were excavated. The soil under the liner is dry and light brown; there is no visible evidence of contamination.

- Waste inflow was observed to be relatively small (<5 gallons per minute).

- The saturated zone of the soil in the holes excavated is not always present at elevations below the liquid surface elevation. There appears to be no consistent level at which saturated material can be found.

The results of the test hole excavations are summarized in Table 4. The observations of zones of saturation resulted in the formulation of a map (Figure 8) which approximates zones of total and partial saturation of the solids. By comparing Figures 6 and 8, zones of saturated solids can be estimated. These solids are completely saturated with the organic liquid. Such materials observed during the site visit consisted of dark gray, organic looking solids. A clear line of distinction could be observed between the saturated (black colored) and unsaturated (brown colored) zones. The volume of these saturated solids was estimated to be 224,000 cubic yards. The volume of dry solids (assumed to contain little or no liquid) was estimated to be 84,000 cubic yards.

4.4 ANALYTICAL RESULTS

Data (Buhts, et al., 1979 and Taft and McKown, 1980) show that total solids concentrations in the basin liquid were about 15,600 mg/l (15.6%) when the basin contained 200 million gallons. Organic content of the basin at the 200 million gallon volume, as measured by total organic carbon (TOC), was approximately 20,000 mg/l (2.0%). Using these data and knowing the present basin volume (approximately 80 million gallons), the amounts of solids and organics in the supernatent were calculated to be 135,600 tons of solids and 17,400 tons or organics. This calculated amount of solids agrees fairly well with the 134,000 tons calculated by the Chemical Systems Laboratory (Hildebrandt, 1978).

These calculations assume that enhanced evaporation will be able to reduce the material to 20 percent liquid. This assumption is subject of differing opinions. The best data is available in a report by L. Lojek, D. Gross and J. Hertzog (Lojek, et al., 1979). These researchers achieved between 43 and 72 percent weight loss by evaporation. Distillation at temperatures up to 128 degrees Celsius resulted in 75 percent reduction in weight. If the liquid were a sodium chloride solution, the maximum concentration (saturation) of dissolved sodium chloride would be approximately 26 percent by weight. The remaining amount of sodium chloride would have precipitated. Assuming 75 percent weight lost of the original solution which contained 16 percent total dissolved solids and 2 percent organics, the remaining solution would contain 26 percent solids (saturation of sodium chloride) and 8 percent organic. About 42 grams of sodium chloride would precipitate for every 100 grams of original solution. The final slurry would contain appreciable amounts of water. However the solution would be in a rather dense state. Therefore, the assumption that the final solution contains 80% solids is questionable. However, the assumed final volume reduction is a reasonable estimate. No attempt has been made in this report to calculate the amount of water or organics in the liquid or solid form. For most processes it does not matter if the the material is water- or organic-saturated. For this reason, and to greatly simplify the calculations, only solid and liquid volumes and weights were calculated.

4.5 TOTAL VOLUME TO BE PROCESSED

As instructed by the United States Army Toxic and Hazardous Materials Agency (USATHMA), the volumes (and weights) of material to be processed were calculated with the addition of a six inch and a six foot layer of "possibly contaminated" soil from below the liner. The preliminary volume calculations were made to include these amounts. However, refined calculations consider only six inches of soil beneath the liner. The reasons for this follow:

- Six feet of soil would approximately triple the amount of material to be processed and categorize certain treatment options as cost prohibitive.
- If contaminants have indeed leaked to six feet in depth, they may also be deeper. The soils beneath Basin F would fall into a separate category of evaluation. A drilling program is needed to determine the actual depth of contamination.

Estimated amounts of solids that would be processed in the treatment/disposal of Basin F are given in Table 5. The final result of all of the calculations shows that an estimated 809,800 tons of material needs to be processed (using a six inch layer of subliner soil).

5.0 EXCAVATION AND FILL ALTERNATIVES

5.1 ALTERNATIVES

This section addresses the excavation and landfill options, while the next section (6.0) evaluates the various treatment concepts. The following excavation and landfill options were evaluated:

1) Landfill of as-is Basin F material in Basin F (contaminated material placed at one end of basin with clay layer above and below).
2) Cap and fill Basin F (clay layer above material).
3) Off-site landfill of as-is Basin F material.
4) Off-site landfill of treated Basin F material.
5) Landfill of treated Basin F solids back into Basin F.
6) Landfill of as-is material on RMA property (but not Basin F).
7) Landfill of treated Basin F solids on RMA property (but not Basin F).
8) Sell or give away Basin F material (either as-is or treated).

A diagram of the final form of all areas affected by earthwork at RMA is shown in Figure 9 for each of the eight general options. All options except #2 includes ripping the basin liner, and loading or moving the basin's material. All options include final reclamation of the site which entails the placement of a clay liner(s) within the basin area, placement of a protective soil layer over the clay and revegetation. Depending on the place of final disposal for the material, the clay liner may be placed directly on the excavated basin area, or it may be placed on top of redeposited treated materials (or in one case the original contaminanted material). In all cases except capping and filling (Option 2), there will also be a clay underliner placed below any contaminated material or treated Basin F solids placed on-site at RMA.

5.2 DEPTHS OF REPLACED SOIL AND CLAY LINERS

The depth of the clay liners has been selected as three feet deep for the bottom layer (when used) and two feet deep for the upper layer. The choice of three and two feet is based on estimated seepage rates through the clay layers into the groundwater. When material is replaced into Basin F or placed into another on-site landfill, there is a risk of groundwater contamination. Even if incineration or another organic destruction process is used, the residue will still contain heavy metals. These metals normally will be in an insoluble and unleachable state (probably oxides). Therefore no migration would occur unless the pH was lowered drastically. However, a lined landfill will probably still be required for regulatory compliance. A 50-year time period for seepage through the liner was chosen for a realistic liner design criterion. Assuming that the clay used for liner construction has a permeability of 10^{-7} cm/sec, an approximate five foot thick layer of clay will meet the criterion. The cover soil and the material itself will increase the actual travel time.

All regulatory issues are addressed in Section 7 of this report. Specifically, new guidelines concerning landfills have recently been published in the Federal Register (October 8, 1980). These new guidelines do not mandate liner thickness but mention designs for 100 years containment and 20 feet thick clay liners. It could be anticipated that such designs may be required. Therefore the cost estimates for 100 years travel time (10 foot clay liner) and a 20 foot clay liner have been included.

When no contaminated or treated material is placed back in Basin F, a two foot thick clay layer is included with the options to minimize seepage through contaminated material that may exist below the excavation depth. The exact location and nature of these contaminants is not known but can be determined by a drilling and sampling program. Such a program may show that large amounts of contaminated material do exist below the asphalt liner. The cost of excavating these materials may be prohibitive. Therefore, a clay liner to prevent further leaching would be required.

The drilling and sampling program may also reveal only small amounts of contaminated materials below the asphalt liner. In this case, the contaminated materials could be excavated and no clay liner would be required.

A soil layer must be placed above any clay "upper" liner to protect it from drying, cracking, wind and prairie dog holes. The depth of this soil is specified to be at least five feet. The reason for the choice of five feet is to make reasonably certain that plant roots and prairie dogs do not penetrate through the clay layer. As reported by Battelle (Johe and Bowen, 1980) prairie dogs typically dig burrows three to four feet deep; thus, a five foot layer of soil would be sufficient. However, it has been reported that burrows can be dug to depths exceeding ten feet (Journal of Mammology, 1971). If leakage due to prairie dogs is a serious a problem, a layer of cement/soil mix could be laid somewhere within the five foot local soil layer. This cement and soil mix would form a barrier which may discourage burrowing. However, the cost of the layer would be quite high and should only be implemented if the problem is judged to be severe. A cement/soil layer is not included in the cost estimates.

Battelle's report on Basin A (Johe and Bowen, 1980) contains an analysis of precipitation infiltration. According to their calculations, the soil zone above the clay would be able to absorb all of the precipitation from a record storm within eighteen inches of soil (worst case conditions). Even with gravity effects, a five foot layer of soil could absorb the water before it seeped down to the clay layer. Evapotranspiration would then begin to pull the water to the surface. The result of this analysis is that no water will pond in the soil directly above the clay layers, so that no forced seepage from static pressure will occur through the liner. Assuming that the basin material or treatment process residue is sufficiently dried for landfilling, there should be very little head within that material to force contaminant seepage through the clay liner.

The only on-site earthwork option which would be of concern is the cap and fill option without the bottom clay liner. Any landfill site on RMA would have to be designed with the groundwater table in mind. The most likely site for an on-site landfill is a location with the greatest depth to groundwater. According to a Chemical Systems Laboratory report (Asselin and Hildebrandt, 1978), Section 25 is the preferred area.

5.3 COST ESTIMATES

The calculation of earthmoving costs has been based on unit costs for the various separate operations listed in the 1980 Dodge Guide (McMahon, 1979). Each of the eight concepts was broken down into its basic earthmoving operations such as scrapping, bulldozing, front end loading and hauling. These earthmoving steps are shown in Table 6 for each of the eight concepts. The volume of materials involved with each operation was then estimated. The volume of residue from any treatment process was assumed to be tow-thirds the original volume processed. The cost factors (per unit of material) were taken from the Dodge Guide and a cost for each operation was computed. Clay can be purchased from the G. W. Parfet Estate in Golden, Colorado for approximately $2.75 per cubic yard. This clay is clean (contains less than 5 percent silt and sand) and has a reported permeability of less than 10^{-7} cm/sec. The transportation costs for clay have been estimated from the Dodge Guide for the twenty mile haul distance from Golden. It is assumed that local soil can be obtained on RMA at no capital cost. The total costs (before profit) of each step of each option are listed in Table 7. The total costs (before profit) are given as 1980 dollars for standard construction. In addition to an inflation factor, a hazard pay factor should be included into the final cost. Costs of excavating and hauling large quanties of low-level radioactive contaminated soils at Rocky Flats in Golden, Colorado and INEL in Idaho (Olsen, et al., 1979) have shown that costs are 20 and 35 times more than excavating and hauling equivalent amounts of uncontaminated soil. However, such operations are very extensive as radiation monitors and decontamination facilities are required. The operation at

RMA will not be as extensive, but will still involve handling of hazardous material and possibly material that is physically difficult to handle (due to liquid content).

D'Appolonia is presently working with Canonie Construction Company on a joint venture (Canonie/D'Appolonia) at a hazardous waste site in Montique, Michigan. Canonie/D'Appolonia is building a burial vault for final disposal of 1,000,000 yd^3 of chemical wastes. Costs at the site are presently close to $13.50 per cubic yard. That cost includes all construction, earth moving and clay costs, and transportaton costs for travel distances of 1500 yards from waste to vault and 4 miles from clay source to vault.

A factor of 2.0 has chosen for calculations at RMA. Costs have been calculated by two methods. In the first method,the factor of 2.0 has been applied to all of the steps of each option, so that total cost, with a fee assumed to be ten percent, is 2.1 times the actual construction cost (Table 7). Another method to include hazard pay is to use the hazard factor only on those steps which are associated with hazardous materials. Table 7 indicates which steps are considered to involve handling of hazardous materials. The cost of these steps were doubled to estimate the extra cost associated with handling the contaminated materials. A total 1980 dollars cost, with hazard factor of 2.0 for steps associated with handling contaminated materials and a profit of ten percent of cost, is provided in Table 7.

The cost experienced by Canonie/D'Appolonia compares very favorably with our estimates for earthwork at RMA. Using the Canonie/D'Appolonia cost of $13.50 per yd^3 for 486,000 yd^3 an estimated cost for RMA is 6.6 million dollars. Our estimates for Option 6 (on-site landfill, other than Basin F, of as-is material), which is the option most similar to what is being done at Montague, is 8.3 - 13.9 million dollars. The distance between waste and vault/landfill would be about the same at both sites. Accounting for the fact that RMA would have to transport clay over 20 miles as opposed to the 4 miles of transport at Montague, these costs are very comparable. This comparison also shows that an additional factor of "cost safety" has been built into the set of estimates which use a hazard factor of 2 for all steps.

5.4 EFFECT OF CLAY DEPTH

In the October 18, 1980, Federal Register, the EPA mentioned 100 year containment times and/or twenty foot clay layers for hazardous waste landfills (see Chapter 7). Therefore, calculations were made to determine the effect of these requirements on construction costs. From calculations performed for the five foot clay layer design, every five feet of clay is equal to about fifty years of detention time. To determine the effect of the possible regulations, both a ten foot layer (approximately 100 years) and a twenty foot layer were used in cost calculations for those zones that would contain Basin F materials or residue. The final results of these alternate calculations are given in Table 8. Option 2, on the basis of cost alone, would be eliminated if thicker layers of clay would be required. Other options are not affected as drastically because they do not require as much surface area to be covered by the clay layer. This is also the reason that Option 2 costs more than any other option, even with a five foot clay layer. Option 2 spreads the material out and requires a clay liner over the entire 93 acre basin (see Figure 9). But, the other options consider placement of contaminated or treated Basin F materials within smaller areas.

One of the most economical options from an earthwork cost only is Option 8; however, as previously discussed selling/giving away Option 8 material is not reasonable. Among the remaining scenarios, the most economical earthwork options are:

- o On-site landfill in Basin F, as-is material: Option 1
- o On-site landfill in Basin F, treated material: Option 5
- o Off-site disposal: Options 3 and 4

Option 6 must also remain in consideration in the event that a landfill construction within Basin F is technically prohibitive due to the physical characteristics of the Basin F material. To determine the most economical overall action, all costs must be added. Transportation costs, treatment costs, off-site disposal costs or any other costs involved should be added to the most economical earthwork option listed above which applies to the overall action.

5.5 OFF-SITE LANDFILL COST

A number of operating hazardous waste landfills were contacted to determine (1) if landfills would accept either the as-is Basin F material or the treatment effluent, and (2) the shipping/disposal fee for this material. Only one facility exists within the Denver area, the Denver-Arapahoe Chemical Waste Treatment Facility (commonly referred to as the Lowry Landfill). Other out of state sites were also contacted to obtain more information.

The Lowry site would accept either the as-is material or the treatment residue. Lowry has concentration restrictions on material which the landfilled directly, but they will accept and treat material which does not meet these limits and then landfill it. The cost for landfilling at Lowry is $18 per ton if there is no treatment required. Treatment costs are added on an "as needed" basis. The amount of treatment required, and the cost of that treatment are determined by Lowry's operators and site chemists. Discounts are given to clients with large quantities of material to be delivered. This discount is applied to the cost of both landfilling and treatment (if required).

For the purposes of making rough cost estimates, it was assumed that as-is material delivered to Lowry would require treatment prior to landfilling. The treatment costs would probably be offset by the bulk discount so that the tipping cost would be about $18/ton as delivered. Including transportation from RMA to Lowry, the cost for 809,800 tons would be $14,600,000. Adding earthwork costs for on-site RMA work the total option cost is about 20 million dollars. This includes a hazard factor for hazardous steps only, but does not account for hazard transportation costs which would probably be quite significant.

Landfilling of treatment residue should not involve further treatment at Lowry. Assuming at tipping fee of $12 per ton (bulk discount) and a weight of 540,000 tons (2/3 of original material) the cost of landfilling, transportation, and earthwork would be $13,700,000. Cost of treatment at RMA and Basin F reclamation would increase the estimate for this option to about $25,300,000.

Costs for landfilling as-is material at sites in Idaho, Texas and Missouri are quite high due to the distance that material must be transported. Costs for transport (without a hazard factor) and landfilling range from 44 to 300 million dollars. Although these costs rule these sites out, all sites would accept either as-is or treated material.

The efficacy of off-site landfilling of the type and quantity of material from Basin F is questionable from the viewpoints of hazardous waste transportations and public acceptance.

The concern coupled with the high cost of off-site landfilling made Options 3 and 4 unacceptable. Therefore, options to be considered further are numbers 1, 5, 6, and 7. Options 5 and 7 are concepts for disposal of treated residue. These options are combined with the treatment costs to arrive at the total concept cost. These total costs are discussed in the next chapter.

6.0 TREATMENT ALTERNATIVES

6.1 REVIEW OF POLLUTION ABATEMENT TECHNOLOGIES

As indicated in Section 2.0, a thorough review was conducted of the literature made available to D'Appolonia by RMA concerning the treatment processes. With respect to this literature, as well as information gathered from other sources, the knowledge of the technologies investigated was adequate for the waste type to be treated. The treatment scenarios proposed by previous researchers (Asselin and Hildebrandt, 1978, and McKown and Taft, 1980) were also in basic agreement with D'Appolonia evaluations. Consequently, the scenarios numbered 1, 2, 4, and 5 by Asselin and Hildebrandt (see Chapter 2) and the alternatives recommended for further study by McKown and Taft were analyzed on merits of their ability to handle the waste, their costs, how well proven the technologies are, and their overall feasibility for successful and troublefree operation.

Each of the groups of treatments proposed employed one or more of three general physical treatments operations, plus a primary and tertiary process to properly condition the waste. Specifically, the three physical processes include artifical evaporation (distillation), wet air oxidation (WAO), and incineration. The following discussions address the applicability of these processes in handling a waste slurry comprised of concentrated Basin F fluids (less than 20 percent liquid content), and contaminated Basin F soils.

6.2 DISTILLATION

The applicability of distillation treatment to Basin F fluids would be primarily as a concentrating step to reduce or eliminate the water content inherent to the fluid. Initially, this option would appear quite practical, since the existing fluid mixture contains roughly 80 percent water. However, at the present time, natural evaporation of basin fluids is occuring and enhanced evaporation is planned to lower the moisture content in a more economical and timely manner. In time, should this evaporation system fail to lower the liquid content to the targeted 20 percent level (McKinney, 1980) distillation would again become an alternative. For report purposes, the latter possibility was considered. Figure 10 depicts a treatment scenario incorporating distillation (Carver-Greenfield method) as a concentrator of a partially dewater liquid. This process is slightly different from Scenario No. 1 proposed by Asselin and Hildebrandt because the feed material is a mixture of the remaining liquid and soil and the ozonation step has been eliminated.

The plan involves an intricate array of equipment that is both energy intensive and mechanically complex. Therefore, maintenance costs would probably be high. Bench scale evaporation studies were performed on Basin F fluid under the direction of Lojek (Lojek, et al, 1979) which concluded distillation was possible, but not practical on a full scale installation. A synopsis of their results follows:

- The evaporation process was extremely sensitive to the temperature at which the fluid was maintained.
- At roughly 114° Celsius, liquid phases began to stratify in accordance with apparent density differences among fluid compounds. Some solids also precipitated out of solution.
- White smokelike vapors began to form inside the boiler unit at 120° Celsius and carried over into the distillate stream.
- Product distillate from every effective distillation trial (temperatures from 105° to 135°celcius) appeared contaminated with volatile organics that carried over with the product stream. In appearance, the distillate was initially clear, then gradually turned yellow. Unpleasant odors were also noted.

Upon closely investigating these test results, it does not appear that this alternative should be further considered unless the enhanced evaporation system presently operating at the site should be proven ineffective. Even then, cost, applicability, and overall practicality would most likely preclude this scheme from full development.

6.3 WET AIR OXIDATION

The process of wet air oxidation (WAO) involves the oxidizing or decomposing of organic materials to carbon dioxide and low molecular weight compounds in a reactor containment of high temperature and pressure. By feeding a concentrated waste stream having a high specific heat content into a reactor vessel, the physical reaction would become sufficiently exothermic to maintain a reaction that would be self-sustaining. Unfortunately, the waste stream in question does not contain such a BTU content; therefore, external heat energy must be supplied.

A WAO system intended to oxidize Basin F wastes is described in Scenario No. 2 by Asselin and Hildebrandt (1978). A modified version of this scenario excluding distillation is presented in Figure 11. The feed slurry would consist of the basin liquor in its current moisture state mixed with basin sludge and contaminated soils (to six inches below the liner). No pretreatment evaporation would be necessary. The total volume of this slurry is estimated to be 160 million gallons. As shown in Figure 11, the waste and product streams need further treatment. The estimated capital and operating costs for this scenario are presented in Table 9. The total system costs, including earthwork needed to excavate the basin soils initially, plus landfilling the treatment residues were estimated at $17.7-$19.5 million in 1980 dollars depending on the landfill location.

Bench scale studies were performed on Basin F supernatant (Lawless, 1978) to determine the feasibility of wet air oxidation treatment on the organic waste. The extent of oxidation obtained from the first experimental run was roughly 78 percent of the initial chemical oxygen demand (COD) during the first 60 minutes. The author also indicated that up to 90 percent removals were likely, provided the proper operating conditions could be achieved.

Limitations to the WAO treatment option are the very high costs and the technically complicted process scheme.

6.4 INCINERATION

Incineration is commonly performed on waste materials having relatively low moisture contents, and containing a moderate to high specific heat content. In the case of Basin F materials, evaporation has begun at the site to lower the fluid's moisture value and in turn, increase its specific heat content. After enhanced evaporation, this concentrate, if blended together with the contaminated soils from the Basin F could then be incinerated for the purpose of destroying the toxic organic compounds. As a final step to follow incineration, inorganic residues could be disposed into a landfill site. However, proper caution would have to be taken to prevent leaching of metals from the residue into the disposal site soils.

Estimated waste weight loads, moisture content, specific heat content, and feed rate for a thick fluid/soil slurry have been calculated and were used for system design parameters. These values follow for the total treatment stream (based on treating 6" of contaminated soil below the liner):

- 710,300 tons solids + 99,500 tons liquid = 809,800 tons slurry
- Specific heat content: = 188 BTU/lb
- Moisture content = 10%
- Feed rate based on 5-year operation = 20 tons/hour
- One-third volume reduction (residue/feed = .66)

The specific heat of the liquid in Basin F was measured to be 400 BTU/lb. The heat content of liquid draining from saturated soil (see Chapter 3.0) was 300 BTU/lb. For the known volumes of saturated soil and liquid, the total BTU content of Basin F was calculated to be 3.8×10^{11} BTU. Some of this heat value will probably be lost during evaporation due to the high vapor pressure of some of the organic compound. A reduction of 20 percent was estimated.

A treatment scheme incorporating incineration as the fundamental process was investigated. It follows the basic formats of Scenarios 4 and 5 of Asselin and Hildebrandt (1978), with the exception that some modifications were made to the proposed flue gas treatment scheme. Various arrangements of rotary kiln incinerators were investigated which ranged in size from 3 tons/hour skid mounted set-ups to a full scale, 20 ton/hour permanent installation.

Figure 12 illustrates a flow chart of the system that appeared most feasible to combust the waste slurry described above. Some critical features that should be considered when the system is actually designed follow:

- Flue gas will be acidic and corrosive from HCl gas. Thus, piping materials should be selected accordingly.
- Without the heat exhanger loop, stack gasses will necessitate cooling prior to or during wet scrubbing (from 1,700° to 900° Fahrenheit minimum).
- Residence time in the kiln should be 60 minutes at 1,600° Fahrenheit.
- Residence time in afterburner should be two seconds at 2,100° Fahrenheit.
- Fuel requirements are directly proportional to feed moisture content.
- The refractory must be designed to withstand corrosion and molten salts.

Cost estimates were made for the following two types of incineration systems:

- One full size rotary kiln installation.
- Seven skid mounted, three ton/hour rotary kiln units.

The estimated total life time cost of each system based on 1980 dollars is shown in Table 9. These estimates reveal that the group of seven, three ton/hour rotary kilns is the most cost-effective system. This system has the additional advantage that one of the seven units could be installed as a pilot plant system. The system could be tested to remove the "bugs" before the remaining six units are purchased. It is also extremely important to test the refractory to maximize its compatibility with the waste. In particular, the high salt content may be a problem. If the refractory is not selected correctly, two to three changes would be required per year. However, with proper selection, the refractory should last much longer. For costing purposes, two refractory changes were estimated for each incineration alternative over the lifetime of the project.

As indicated in Table 9, the fuel cost (Operating Cost) is a major cost over the life time of the project. Approximately 15 million BTU/hour will be required to fuel the incinerators if the feed has a 20 percent moisture content. If the moisture content could be lowered to 10 percent, the required fuel input would be reduced to approximately 10 million BTU/hour. Therefore, methods to reduce the water content may be very cost effective. The costs for fuel shown in Table 9 are based on Public Service's Company's present commerical, interruptable rate of $4.17 per million BTUs for natural gas. There is no noninterruptable commercial service available. Due to the high cost of natural gas, the cost of using coal was also calculated. Current cost range from $1.05 per million BTU for Wyoming coal to $1.15 per million BTU for high grade Colorado coal. These costs include rail transportation to Denver. Therefore, a considerable savings could be achieved by use of coal. However, higher capital and maintenance costs would be necessary with a coal fired incinerator. Regulatory compliance would also be a major consideration with a coal fired incinerator. A feasible compromise might be to increase the specific heat content of the input waste stream by adding crushed coal directly to the input stream. The present specific heat content of the input waste stream was not considered in the cost estimates because it represents only 1.5 percent of the total heat required.

All cost estimates are based upon the use of a rotary type incinerator. Multiple hearth and fluidized bed incinerators were also investigated.

For the type of waste being processed, multiple hearth furnaces would probably be very inefficient. The high salt content of the process stream would preclude use of a fluidized bed incinerator because the bed would probably be "gummed-up" by the molten salt.

Some of the cost estimates provided in Table 10, Denver, Colorado, were furnished by L. Lefholz of Environmental Enterprises, Inc. In addition to these cost estimates, the Lurgi Corporation and C. E. Raymond Company were also contacted. All companies gave qualified "rough" estimates. The estimates by Lurgi and C.E. Raymond are provided in Table 11. The cost estimates obtained from previous studies are also shown in Table 11. These costs do not include excavation and landfilling.

In comparison to WAO, incineration is the most cost effective option of treatment. Incorporating the incineration treatment cost with the most economical earthwork options, for disposal of treated residues, gives the following results:

Option 5:	Treatment and landfill residue in Basin F	$11,289,644
Option 7:	Treatment and landfill residue in new on site landfill	$13,120,580

7.0 REGULATORY CONSIDERATIONS

7.1 REGULATED OPERATIONS

Any action taken by the Rocky Mountain Arsenal to treat or dispose of the material in Basin F will cause that action to be carefully studied from a regulatory standpoint. Because of the hazardous type of material that is involved, the Resource Conservation and Recovery Act (RCRA) and its detailed regulations will apply to any actions taken, just as it applies to the basin and its material in its present state. In addition, other statutes, ordinances, regulations and standards will be applicable to some of the options.

This chapter is intended to serve as an identification of permitting feasibility and complexity for potential treatment and/or disposal options. Refinement of the permitting evaluation will be appropriate when the treatment processes are evaluated in more detail. These evaluations will include more precise characterization of the waste materials and emission/residue streams from the treatment processes. It will probably be necessary to determine these characteristics by bench or pilot plant studies.

Because the actual implementation of any of the options will not be until fiscal year 1984, additional regulations will be in existence by that time. As new regulations are proposed between now and 1984, they could have a dramatic impact on the plan of action at Basin F. For example, new regulations may be issued in the near future by the Environmental Protection Agency (EPA) concerning (1) air emissions from hazardous waste management facilities, and (2) design and operation of land disposal facilities. The implications of these proposed rules are discussed in the incineration and landfill sections.

The kinds of hazardous waste management activities which are presently regulated by the EPA are those which result in:

- o Emissions of regulated non-hazardous air pollutants.

- o Emissions of regulated hazardous air pollutants.
- o Discharges of wastewater from a "point source" into Colorado surface or ground waters.
- o Storage, treatment, or disposal of hazardous wastes in containers, tanks, surface impoundments, piles or landfills.
- o Spills, leakage, etc. of contaminants which may pollute surface or underground waters.
- o Employment of incinerators, thermal treatment, or chemical, physical or biological treatment.
- o Underground injection of solids, gases, or liquids.

Air emissions are regulated under the federal Clean Air Act and the Colorado Air Pollution Control Act. Wastewater discharges are regulated under the Clean Water Act and the National Pollutant Discharge Elimination System (NPDES), as administered by the State of Colorado. Pollutant spills or leakages which are not NPDES-regulated discharges are regulated under the Colorado Water Quality Control Act. All other proposed activities are regulated under the RCRA, as presently administered by the EPA. Underground injection will be regulated by the State of Colorado if it is applied to any of the Basin F options.

7.2 INCINERATION

The rotary kiln, multiple hearth and fluidized bed methods each have the potential to emit both hazardous and non-hazardous air pollutants. Currently, incineration of waste containing PCB's should have an afterburner with a 2 second dwell time at 2100°F (Hildenbrandt, 1978). Proposed EPA regulations are expected to include air emission standards for many more hazardous compounds*. These standards would be specifically aimed at incineration processes. With the addition of a lime wet scrubber

*EPA announced its intent to regulate emmissions from HWM facilities in the October 3, 1980, Current Developments issue of the BNA Environment Reporter. However, specific regulations and standards for incinerators and other emissions have not yet been proposed.

on the exhaust stream from the afterburner, organic and inorganic contaminants in the exhaust should be destroyed (oxidized) or removed (precipitated). Therefore, the standards to be proposed should be met if the system operates as expected. <u>However</u>, the proposed standards should be <u>carefully</u> examined when they are published.

Furthermore, not only do incinerators work at less than ideal efficiency, the feed material in the case of the RMA is a complex mixture of materials which are difficult to degrade. As a result, incinerator manufacturers will not guarantee the performance of their equipment with regard to meeting the current air emission standards. Manufacturers feel that, with proper design and operation, the standards can be met most of the time. However, they will not accept liability for periods of non-compliance. The current regulatory permits and compliances needed are:

- o Emissions permit.
- o Compliance with present National Emission Standards for Hazardous Air Pollutants (NESHAPS) for mercury and radionuclides; possible compliances with future hazardous air pollutant standards including arsenic and nemagon
- o Compliance with RCRA requirements for disposal of ash residue (see Landfill Requirements) from incineration.

7.3 WET AIR OXIDATION

The wet air oxidation process would be used on a liquid slurry of Basin F material. Wet air oxidation (WAO) would have waste streams of treated solids, treated liquid, and possibly exhaust air (depending upon the exact process selected). Because the WAO process is not a complete treatment by itself, additional treatment steps will be required before the liquid would be suitable for discharge to public waters. Also, the solids which remain (from settling) would require further treatment before they could be considered totally treated. Because of the complexity of the overall treatment system, a number of regulatory considerations are involved, including:

- NPDES permit and compliance with effluent guidelines for discharge water.
- Possible compliance with National Emission Standards for Hazardous Air Pollutants for, mercury and radionuclides.
- Possible need for compliance with future hazardous air pollutant standards including arsenic and nemagon.
- Compliance with RCRA requirements for disposal of solid residue (see Landfill Requirements) and thermal treatment.
- An emissions permit from the State of Colorado.

7.4 ON-SITE LANDFILL

The options involving on-site landfills have to be designed to conform to applicable landfill regulations as well as earthmoving and possible transport regulations. The regulatory considerations for these options are:

- Compliance with RCRA landfill requirements including:
  - operating requirements
  - closure and post-closure plans
  - preventing mixture of incompatable wastes
  - compliance with special requirements for corrosive, ignitable, reactive, toxic and liquid wastes
- Air emissions notice and/or permit from the Colorado Department of Health.
- Compliance with Adams County Landfill Requirements.

A landfill can be designed and operated to meet present RCRA requirements (see Table 11). However, the EPA has proposed to make these requirements considerably more stringent (Federal Register, October 18, 1980) due to groundwater considerations. Possible EPA requirements, not yet formally proposed, could include the following:

- No run-on or run-off to or from facility.
- No commingling incompatible wastes.

- o Restrictions on liquid waste disposal.
- o No "ponding" of liquids.
- o Stable facility cover.
- o 20-foot clay liner.
- o 10^{-7} cm/sec permeability.
- o 98% reduction of leachate contaminant concentrations.
- o 100-year containment.
- o Minimize risk of groundwater and surface water contamination.
- o No degradation below health/environmental standards.
- o Maximize public confidence.
- o Holistic, site-specific analysis for permitting (soils, hydrology, etc.).
- o Encourage innovative hazardous waste management approaches.
- o Downgradient water supply contamination unacceptable ("non degradation standard").

Thus, landfills with five-foot clay liners would not comply with anticipated design standards. But until more stringent standards are actually proposed, landfill design standards remain uncertain. They will almost certainly have to be negotiated with the EPA and the Colorado Department of Health. The bottom line consideration will be non-degradation of groundwater.

7.5 OFF-SITE LANDFILL

Final disposal of Basin F material at an off-site secure landfill will involve excavating, loading, transporting, and possible treatment at the Arsenal. As a result of these different operations, a number of regulations would apply to this option. The regulatory considerations are:

- o Possible fugitive dust permit from Colorado Department of Health.

- o Air emissions notice and/or permit from Colorado Department of Health.
- o Compliance with RCRA transportion requirements.
- o Compliance with Department of Transportation regulations.
- o Local county or municipal approvals.

7.6 CONCLUSIONS

Current technology can probably meet existing and contemplated regulations and standards. However, the possibility exists that new technologies will have to be developed to meet requirements that are presently unknown. This is because requirements, especially under RCRA, are a "moving target" that is not altogether predictable. Thus the objectives of any technological program must be focused on:

(1) Elimination or minimization of hazardous air emissions, and

(2) Elimination or minimization of groundwater and surface water contamination.

8.0 RECOMMENDATIONS AND CONCLUSION

8.1 RECOMMENDATIONS FOR FURTHER STUDY

The estimated costs for the various treatment and landfilling options are based on several assumptions. Therefore, the cost estimates would be more reliable if data could be collected to resolve the assumptions. In particular, the volume estimate of material in Basin F can be improved by analyzing core obtained from drilled holes. The holes should be at regular intervals (grid pattern) across the basin. Analyses of contaminants should be performed at regular depth intervals. It is very difficult to "drill" on the basin due to the saturated nature of the soils and the large amount of liquid present. However, Shelby tube samples could easily be collected on the dry portions of the basin. A coring machine could also be mounted on pontoons to core the portion of the basin which still contains liquid. The details of the exact sampling and analyses procedures should be worked out and implemented as soon as possible.

As soon as the contaminants have been analyzed, a three-dimensional excavation plan should be prepared. The depth and location of the "cut-off grade" should be determined. That is, a depth of excavation should be calculated to a certain contamination level in the soil. The most feasible excavation scheme should then be planned. During excavation of contaminated soil, a preknowledge of the location of contaminants would prevent excavation and treatment of uncontaminated materials. This knowledge may save large amounts of money because only the contaminated materials would be processed. Another consideration is the application of advanced programs for geostatistically modeling the location of contaminants between boreholes, thereby arriving at an optimum "mining plan". Such programs can also be used to select optimum locations of drill holes, thereby reducing the number of holes needed.

Machines to excavate contaminated material have also been specifically designed to minimize the generation of fugitive dust (Olsen, et al, 1979). Such a machine is shown in Figure 13. The rotary auger is an "off the shelf" item. The only modifications are the flight conveyor and auger shield. One of the main advantages is that the rotary blade is continually against the face of the excavated bank; therefore, the contaminated soil is not exposed to the open atmosphere. The machine is also highly maneuverable, capable of being ajusted precisely (within ±2 inches). This also prevents excess uncontaminated materials from being excavated. The details of such an excavation method should be investigated.

It is very important to determine or more accurately project the physical characteristics of materials that may be handled in an excavation/landfill option. Determination of physical characteristics for the materials in Basin F is especially important to the final evaluation of using the basin as the landfill site or for handling/transporting the material to treatment or to a landfill at a location different from Basin F. Standard soil classification and strength tests would be appropriate to perform on a select number of samples obtained during the drilling program. This information will be most important for effective planning, design, equipment selection and costing refinements.

The costing of the treatment/landfill options are based on an estimated one-third reduction of Basin F material volume and weight in the process stream. The effectiveness of the various incinerators should be tested. Bench scale test should be performed to determine the ash quantity for various incinerators and to select the correct refractory. The composition and leachability (toxic extract procedure) of the ash should also be determined. These tests could directly effect the cost estimates. Tests should also be performed to quantify the characteristics of the exhaust gases and vapors produced from an afterburner and scrubber. The chemical and physical characteristics of the solid produced from a bench scale scrubber should also be determined. These characteristics will be very important in the following areas:

- Determining regulatory permits that may be required
- Obtaining regulatory permits
- Designing more cost effective processes

- o Determining technical feasibility
- o Estimating accurate costs

The planned tests on enhanced evaporation should proceed. Any reduction in the total volume of materials to be treated will be cost effective. Exclusive of any volume reduction, a decrease from 20 percent to 10 percent moisture has the potential to save approximately $850,000 in fuel costs over the life time of the project. The potential savings will be even larger as fuel costs increase. Evaporation tests would also enable detailed examination of the exact composition of the residue.

Table 13 summarizes the previously discussed recommendations for further study. "Order of magnitude" cost estimates are provided. Beyond these recommendations, and upon selection of the option, consideration should be given to test excavations and placements of Basin F materials and pilot plant sized test of the treatment option.

8.2 CONCLUSIONS

Approximately 809,800 tons of material from Basin F will be excavated and processed. This estimate is based on excavation to a depth of six inches below the liner and assumes enhanced evaporation will take place for the next two and one-half years. Using this weight of material, the following options are the most cost effective:

OPTION	COST	NOTES
1) Landfill of as-is Basin F material in Basin F (contaminated material placed at one end of the basin within clay liners	$ 5,614,644	See Table 7
2) Incineration of contaminated materials with residue landfilled into Basin F	$11,289,644	See Table 10

Both options consider final disposal of materials or treatment residues in Basin F. The option of landfilling the materials or residues on RMA property but not in Basin F should also be considered. These are Options

6 (as-is material) and 7 (treated material) in Chapter 5.0. These options are approximately $2.0 million more expensive than landfilling in Basin F. These landfilling options may be more viable if the materials are difficult to handle and if the contaminated materials exist much deeper than six inches below the liner, which may prohibit construction staging within Basin F.

The above selection of options for consideration was determined through two types of decision processes:

- o decision flow diagram
- o ranking model

Several criteria were used in each decision process, including the most explicit criteria, cost. The final two options discribed above involve different approaches to the Basin F problem. In particular, the landfill of as-is material is a "control or contain" solution while treatment of the material and landfill of the residue is substantially an "eliminate or decontaminate" solution. Although these two different approaches were evaluated in the ranking model, a decision between these approaches can only occur with the incorporation of RMA planning and policy objectives. The final selection may also depend upon local, state and federal regulation that will be implemented in the next three years. Currently, either process option could comply with regulations. The treatment approach would, however, involve more permitting steps.

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TABLE 1

SUMMARY OF RECOMMENDATIONS ON ALTERNATIVES
BATTELLE'S "ALTERNATIVES FOR REDUCTION" REPORT

ALTERNATIVE	BATTELLE'S COMMENTS ABOUT USE ON BASIN F MATERIAL:	BATTELLE'S RECOMMENDATION
Steam Distillation	Works only on waste streams with insoluble and/or volatile compounds	N.F.C.
Electrodialysis	Has problems with high organic contents	N.F.C.
Reverse Osmosis	Osmotic pressure required is too high	N.F.C.
Ultrafiltration	Insufficient technology	N.F.C.
Extraction	Does not reduce volume	N.F.C.
Encapsulation and Storage	High cost, no volume reduction, deep well disposal uncertain	N.F.C.
Freeze Cyrystal-lization	Single stage purity approximately 90-99%	Evaluate
Activiated Carbon and Resin Adsoprtion	Not appliable on such high concentrations	N.F.C.
Clay Adsportion	Possible as a second step, needs testing	Evaluate
Multiple Hearth Furnace	High water and inorganic content inhibit burning	N.F.C.
Fluidized Bed	Could be used on organic fraction after screening	Evaluate
Rotary Kiln	For use with solid and mixed waste, not liquid	N.F.C.
Microwave Plazma	Undeveloped	N.F.C.
Photolysis	Will not meet objectives	N.F.C.
Molten Salt In-cinerators	New and unstudied, will not work with high salt and water content	N.F.C.
Pyrolysis	Low "burnable" content in waste	N.F.C.
Liquid Incinerators	May be useable on liquid condensates from evaporation	Evaluate
Chemical Fixation	Possible only after substantial dewatering	N.F.C.
Hydrolysis and Other Chemical Treatment	Large R & D required, high cost	N.F.C.
Catalytic Dechlorina-tion and Reductive Degradation	Catalyst poisoning, residual toxicity	N.F.C.
UV/Ozonation	High cost, no comparably sized operation	N.F.C.
Wet Air Oxidation	High clean-up, only air and water required	Evaluate
EVAPORATION:		
Reduced Rainfall Area and Plant Influx	Rework dry areas and get evaporation area equal to precipitation area	Evaluate
Evaporators	Simple evaporator may have applications, not multiple	Evaluate
Submerged Combustion	Air pollution	N.F.C.
Evaporation Ponds	Additional land required	N.F.C.
Surface Area Enhance-ment	Pump liquid over dry portions-no artificial surfaces	Evaluate
Spraying and Aeration	Spraying causes sociopolitical problems, aeration not possible	Evaluate (spraying only)
Evapotranspiration	Plants will not grow	N.F.C.
Solar Still	Support and structures would be very large	N.F.C.
Biological Treatment (any type)	Organisms could not live on Basin F material	N.F.C.

N.F.C. - No Further Consideration

TABLE 2

EXAMPLE CRITERIA LIST FOR
BASIN F EVALUATION

- o Legal/Regulatory Criteria
  - Water Quality
  - Air Quality
  - Hazardous Waste
  - Land Use
  - Construction
  - Water Rights
- o Environmental Effects
  - Groundwater Contamination
  - Surface Water Contamination
  - Soil Contamination
  - Atmospheric Contamination
  - Esthetics
  - Public Health
  - Plant/Animal Effects
- o Technical Criteria
  - Available Technology
  - Constructability
  - Failure Probability
  - Difficulty of Operation
  - "Worst Case" Failure
  - Repair and Maintenance
  - Predictability
- o Objective Criteria
  - Eliminate Source
  - Contain Source
  - Treat Source
  - Control Source
- o Cost Criteria
  - Equipment
  - Construction
  - Operation
  - Maintenance
  - Cost Effectiveness
  - Operational Life
- o Social Criteria
  - Public Confidence
  - Zero Discharge
  - Zero Emissions
  - Ultimate Closure
  - Problem Isolation
  - Solution Permanence

SAMPLE RANKING MATRIX

BASIN F CONCEPTS	REGULATORY COMPLIANCE: AIR	REGULATORY COMPLIANCE: WATER	REGULATORY COMPLIANCE: RCRA	TECHNICAL FEASIBILITY: DATA ADEQUACY	TECHNICAL FEASIBILITY: METHODOLOGY	COST: CAPITAL	COST: O & M	ENVIRONMENTAL COMPATIBILITY: ULTIMATE TO PARTIAL SOLUTION	ENVIRONMENTAL COMPATIBILITY: PUBLIC ACCEPTANCE	Σ	NOTES
(1) Cap and Fill	4	5	1	4	5	4	5	1	1	30	
(2) Cap, Fill and Dewater		0								0	
(3) In-Situ Treatment, Cap and Fill					0					0	
(4) Slurry Wall Barrier, Dewater, Treat, Recharge	4	3	2	3	2	5	3	1	2	25	Does nothing relative to contaminated materials in basin
(5) Slurry Wall Barrier, Dewater, Treat, Recharge, Cap and Fill	5	4	3	3	4	2	5	1	3	30	
(6) Excavate, Landfill	5	4	2	3	5	3	5	2	3	32	
(7) Excavate, Incinerate, Landfill	4	4	3	3	4	2	2	4	4	30	Excavate 6" below liner; 5' clay liner in landfill
(8) Excavate, Decontaminate, Landfill	4	5	3	2	2	1	1	5	5	27	Acid wash cost offset by metal recovery

	RANKING NUMBERS	REGULATORY COMPLIANCE	TECHNICAL FEASIBILITY: DATA ADEQUACY	TECHNICAL FEASIBILITY: METHODOLOGY	COST	ENVIRONMENTAL COMPATIBILITY: ULTIMATE TO PARTIAL SOLUTION	ENVIRONMENTAL COMPATIBILITY: PUBLIC ACCEPTANCE
	1	Expected extreme difficulty in obtaining permit to construct/operate	Virtual lack of raw data	Questionable application and no process history for the concept	Very high cost relative to other concepts	Temporary or interim solution; not additive to final solution	Likelihood of strong public objection
DEGREES OF SENSITIVITY BETWEEN #1 AND #5	2 3 4	↕	↕	↕	↕	↕	↕
	5	No problem expected in obtaining permit or no permit required	Adequate data available for planning and design	Method definitely applicable	Low cost relative to other concepts	Complete elimination or isolation of contaminant from the environment	Favorable public sentiment

NOTE: "0" indicates [illegible]

TABLE 4
SUMMARY OF BASIN F TEST HOLE EXCAVATIONS

TEST HOLE NO.[1]	DEPTH TO LINER (in.)	DEPTH OF ORGANICS (in.)	CONDITION OF: LINER	CONDITION OF: SOIL BELOW LINER	COMMENTS
1	>24	--	--	--	Liner was not reached but material was not saturated within the first two feet
2	>24	--	--	--	
3	>24	--	--	--	
4(2)	20	20	Good	Clean	Material was saturated (organics & water)
5(2)	20	20	Good	Clean	Material was saturated (organics & water)
6	--	--	--	--	The material was fully saturated (water and organics) and holes could not be safely dug to the liner
7	9	0	Good	Clean	The organic layer was at the bottom of the hole, nearest the line.
8	12	3	Good	Clean	
9	15	10	Good	Clean	
10	18	12	Good	Clean	
11	12	3	Good	Clean	
12	20	18	Good	Clean	
13[2]	20	20	Good	Some Darkening[3]	
14	--	--	--	--	The material was fully saturated (water and organics) and holes could not be safely dug to the liner

NOTES:

(1) The areas of all sample holes, except 6 and 15, were covered with a thin "crust" of salt which prevented complete drying of material below the surface.

(2) After the hole was dug, liquid seeped from the walls of the hole (seepage occurred only at specific layers in the holes, not uniformly).

(3) Probably a sign of some degree of leakage through the liner.

TABLE 5

AMOUNTS OF MATERIAL IN BASIN F

SOURCE	TOTAL (TONS)	SOLIDS (TONS)	LIQUIDS (TONS)	ORGANICS[1] (TONS) (SOLIDS AND LIQUIDS)
Supernatant	169,500	135,600	33,900	17,400
Bottom Solids	517,900	457,400	60,500	?
Liner	5,800	5,800	--	5,800[2]
Subtotal	693,200	598,800	94,400	23,200+?
Subsurface Soil to be Included:				
6" Layer	116,600	111,500	5,100	?
12" Layer	233,300	223,200	10,100	?
6' Layer	1,400,000	1,339,100	60,900	?
TOTAL:				
With 6" of Soil	809,800	710,300	99,500	23,200+ ?
With 12" of Soil	926,500	822,000	104,500	23,200+ ?
With 6' of Soil	2,093,200	1,937,900	155,800	23,200+ ?

(1) Organics were calculated only for reference. They are already included in the other columns as either solids or liquids.

(2) The liner can be classified as organic because of its material make-up.

TABLE 6

UNIT OPERATIONS OF EARTHMOVING OPTIONS
BASIN F
ROCKY MOUNTAIN ARSENAL

OPTION 1

1. Bulldoze, pile material
2. Place lower clay liner and internal dike
3. Place material onto clay liner
4. Place upper clay liner
5. Place soil layer
6. Revegetate

OPTION 2

1. Spread out and compact material
2. Place clay liner
3. Place soil layer
4. Revegetate

OPTION 3

1. Bulldoze, pile material
2. Load material for transport
3. Place clay liner
4. Place soil layer
5. Revegetate

OPTION 4

1. Bulldoze, pile material
2. Load material for treatment
3. Load residue for transport
4. Place clay liner
5. Place soil layer
6. Revegetate

OPTION 5

1. Bulldoze, pile material
2. Load material for treatment
3. Place lower clay liner and internal dike
4. Place residue onto clay
5. Place upper clay liner
6. Place soil layer
7. Revegetate

OPTION 6

1. Bulldoze, pile material
2. Load material for transport
3. Place clay liner at "F"
4. Place soil layer at "F"
5. Revegetate "F"
6. Excavate new site
7. Place lower clay liner
8. Place material onto clay liner
9. Place upper clay liner
10. Place soil layer
11. Revegetate new site

OPTION 7

1. Bulldoze, pile material
2. Load material for treatment
3. Place clay liner at "F"
4. Place soil layer at "F"
5. Revegetate "F"
6. Excavate new site
7. Place lower clay liner
8. Place residue onto clay liner
9. Place upper clay liner
10. Place soil layer
11. Revegetate new site

OPTION 8

1. Bulldoze, pile material
2. Load material for transport
3. Place clay liner
4. Place soil layer
5. Revegetate

NOTE: Material refers to Basin F contents, liner and 6-inch sub-liner soil layer.

Residue refers to material remaining after treatment.

TABLE 7

EARTHWORK [illegible] FOR TREATMENT/DISPOSAL OPTIONS
TASK BREAKDOWN
BASIN F
ROCKY MOUNTAIN ARSENAL

STEP	OPTION 1	2	3	4	5	6	7	8
1	$ 304,560 (609,120)(1)	$ 151,180 (302,360)	$ 456,840 (913,680)	$ 456,840 (913,680)	$ 456,840 (913,680)	$ 456,840 (913,680)	$ 456,840 (913,680)	$ 456,840 (913,680)
2	747,220	4,695,000	92,340 (184,680)	92,340 (184,680)	92,340 (184,680)	92,340 (184,680)	92,340 (184,680)	92,340 (184,680)
3	92,390 (184,780)(1)	1,035,000	1,878,000	61,560	546,900	1,878,000	1,878,000	1,878,000
4	1,878,000	30,300	1,035,000	1,878,000	61,560	1,035,000	1,035,000	1,035,000
5	1,035,000		30,300	1,035,000	1,878,000	30,300	30,300	30,300
6	30,300			30,300	30,300	223,100	149,500	
7						607,220	406,900	
8						92,340 (184,680)	61,560	
9						406,900	269,180	
10						223,100	149,500	
11						6,510	4,350	
CAPITAL COST OF CLAY	$ 1,151,750	$ 2,063,000	$ 825,000	$ 825,000	$ 1,063,750	$ 1,270,500	$ 1,122,000	$ 825,000
SUBTOTAL	$ 5,239,170	$ 7,975,580	$4,327,480	$4,379,040	$ 4,129,690	$ 6,322,150	$ 5,655,470	$4,327,480
(SUBTOTAL)(2)	($ 5,636,170)	($ 8,125,660)	($4,866,660)	($4,928,310)	($ 4,678,870)	($ 6,963,670)	($ 6,204,650)	($4,866,660)
TOTAL(3)	$11,526,174	$17,546,276	$9,520,456	$9,633,888	$ 9,085,730	$13,908,730	$12,442,034	$9,520,456
(TOTAL)(4)	($ 6,763,404)	($ 9,750,792)	($5,839,992)	($5,913,972)	($ 5,614,644)	($ 8,356,404)	($ 7,445,580)	($5,839,992)

(1)Values in parentheses are actual costs multiplied by a 2.0 hazard factor. These values are calculated for those steps which involve direct handling of raw Basin F material (hazardous material).

(2)Sum of the individual step costs using hazard costs in parentheses for the hazardous steps.

(3)Total includes 20% profit, overhead and contingencies, and 2.0 hazard factor for all standard step costs.

(4)Total includes costs, with hazard factor for hazardous steps only and 20% for profit, overhead and contingencies.

TABLE 8

OPTION COSTS FOR VARIOUS CLAY DEPTHS[1]

OPTION	FIVE FT.[2]	TEN FT.[2]	TWENTY FT.[2]
1	$ 6,700,000	$ 8,500,000	$12,000,000
2	$ 9,800,000	$17,900,000	$34,000,000
3	$ 5,800,000	$ 5,800,000[3]	$ 5,800,000[3]
4	$ 5,900,000	$ 5,900,000[3]	$ 5,900,000[3]
5	$ 5,600,000	$ 6,800,000	$ 9,100,000
6	$ 8,400,000	$10,100,000	$13,600,000
7	$ 7,400,000	$ 8,600,000	$10,900,000
8	$ 5,800,000	$ 5,800,000[3]	$ 5,800,000[3]

NOTE: All costs rounded to nearest hundred thousand dollars.

(1) All costs include hazard factor for hazardous steps <u>only</u>.

(2) 5, 10 or 20 feet layer only where material (raw or treated) is buried; cover layers for Basin F, if not used as a landfill, are always 2 feet thick.

(3) Because these options do not involve any landfilling there is no change in design or cost.

TABLE 9

WET AIR OXIDATION SCENARIO COSTS

I.	W.A.O. COSTS(1)	
	(Including mixing of feed material)	
	Capital Cost	\$ 6,500,000
	Operating Cost @ \$0.03/gal for 160 x 10^6 gal(2)	\$ 4,800,000
II.	CENTRIFUGE SEPARATOR(3)	
	Capital Cost	\$ 105,000
	Operating Cost @ \$8,000/year for 5 years	\$ 40,000
III.	LIME CLARIFICATION(3)	
	Capital Cost	\$ 60,000
	Operating Cost @ \$4,000/year for 5 years(4)	\$ 100,000
IV.	BIOLOGICAL DEGRADATION(3)	
	Capital Cost	\$ 150,000
	Operating Cost @ \$20,000/year for 5 years(4)	\$ 100,000
V.	FILTRATION (SAND FILTERS)(3)	
	Capital Cost	\$ 60,000
	Operating Cost @ \$5,000/yr for 5 years(4)	\$ 25,000
VI.	REVERSE OSMOSIS	
	Capital Cost	\$ 150,000
	Operating Cost @ \$10,000/yr for 5 years(4,5)	\$ 50,000
	SUBTOTAL	\$12,060,000
VII.	EARTHWORK COSTS (LANDFILL)	
	a. Residue returned to Basin F (Option 5)	\$ 5,614,644
	b. New Landfill on Site (Option 7)	\$ 7,445,580
	TOTAL SCENARIO COST:	
	Returned to Basin F	\$17,674,644
	New Landfill	\$19,505,580

(1) Zimpro Inc., 1980

(2) 80 x 10^6 gal liquid + 390,000 yd^3 solid = 160 x 10^6 gal slurry

(3) U.S. EPA, 1980

(4) Approximately 65 x 10^6 gal of liquid will be treated

(5) Shargraw, 1979

(6) See Table 7, (Using hazard factor for "hazardous" steps only)

TABLE 10

COST ESTIMATES FOR INCINERATION

I.	LARGE SCALE (20 TON/HOUR) ROTARY KILN[1] (including afterburner and scrubber)	
	Capital Cost	$ 5,500,000
	Labor Cost ($75,000/year for 5 years)	375,000
	Maintenance Cost[2] ($160,000/year for 5 years)	800,000
	5 Year Operating Cost: 20% Moisture (10% Moisture)	2,550,000 (1,700,000)
	SUBTOTAL	$ 9,225,000 (8,375,000)
II.	SEVEN 3 TON/HOUR ROTARY KILNS[1] (including afterburner and scrubber)	
	Capital Cost ($250,000 x 7)	$ 1,750,000
	Labor Cost ($75,000/year for 5 years)	375,000
	Maintenance Cost[2] ($200,000/year for 5 years)	1,000,000
	5 Year Operating Cost: 20% Moisture (10% Moisture)	2,550,000 (1,700,000)
	SUBTOTAL	$ 5,675,000 (4,825,000)
III.	EARTHWORK COSTS	
	a. Resideue Returned to Basin F (Option 5)	5,614,444[3]
	b. New On Site Landfill (Option 7)	7,445,580[3]
	TOTAL	
	Large Scale Kiln (20% Moisture)	
	Returned to Basin F	$14,839,644
	New Landfill	16,670,580
	Seven Kilns (20% moisture)	
	Returned to Basin F	11,289,644
	New Landfill	13,120,580

(1) Environmental Enterprises, Inc., 1980

(2) Includes two charges of refractory of 5 years at $250,000 per charge plus 5% of capital for remaining maintenance and supplies.

(3) Using hazard factor for "hazardous" steps only, see Table 7.

TABLE 11

SUPPLEMENTAL COST ESTIMATES FOR ROTARY KILN INCINERATION

I. C.E. RAYMOND COMPANY/COMBUSTION ENGINEERING

Capital	$ 6,000,000
Operation and Maintenance (O&M) ($400,000/year for 5 years)	2,000,000
TOTAL	$ 8,000,000

II. LURGI CORPORATION

Capital	$5-10,000,000
O & M	2- 4,000,000
TOTAL	$7-14,000,000

III. ASSELIN AND HILDEBRANDT

Capital	$ 4,540,000
Operating ($648,000/year for 3.6 years)	$ 2,332,800
TOTAL	$ 6,872,800

Note: All costs are based on 20 ton/hour feed rate

TABLE 12

RESOURCE CONSERVATION AND RECOVERY ACT
ADMINISTRATIVE STANDARDS

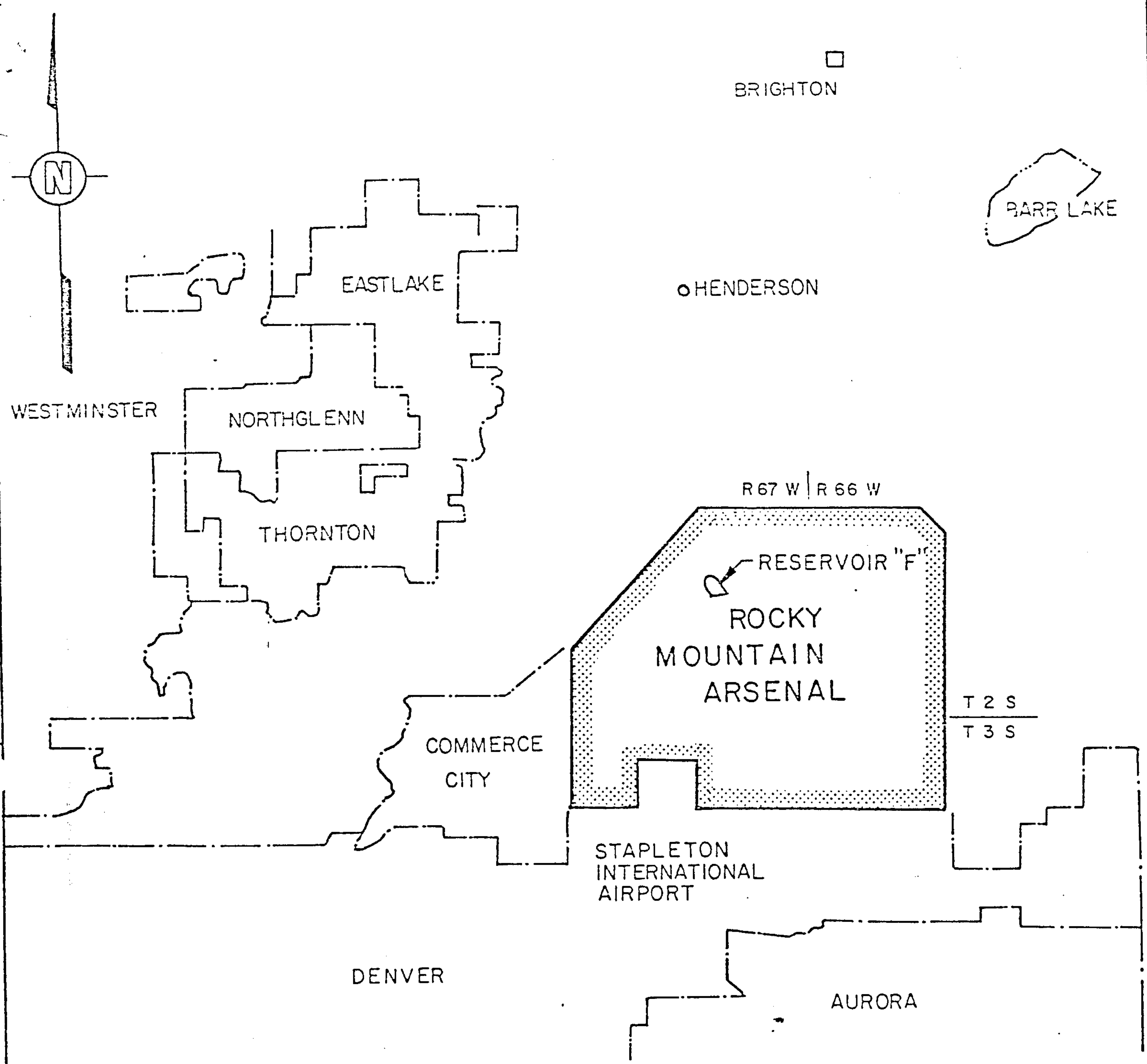
- MANIFEST SYSTEM, RECORD KEEPING, REPORTING
- GROUNDWATER MONITORING
- CLOSURE/POST CLOSURE
- POST CLOSURE CARE
- FINANCIAL REQUIREMENTS
- SECURITY
- INSPECTION REQUIREMENTS
- PERSONNEL TRAINING
- PREPAREDNESS AND PREVENTION
- CONTINGENCY PLAN/EMERGENCY PROCEDURES

TABLE 13

SUMMARY OF RECOMMENDATIONS FOR FURTHER STUDY

PRODUCT OF STUDY	TESTS OR ACTIVITIES PERFORMED	ESTIMATED COSTS ($)
1. Volume of Contaminated Soil and Excavation Plan	Core Holes on a regular grid pattern plus geo-statistical modeling	150,000-250,000
2. Contaminant Characterization	Physical and chemical analyses of selected contaminant samples	25,000-75,000 (physical) 75,000-150,000 (chemical)(1)
3. Preliminary Constructability and Equipment Evaluation (assuming completion of studies 1 and 2)	Office analyses and simple field tests	15,000-30,000
4. Process Selection and Regulatory Compliance Evaluation	Incineration bench scale tests for characteristics of residues, exhaust gases, and vapors	75,000-100,000
5. Selection of Refractory	Research on various refractories	10,000

(1)Assumed analyses performed at RMA.



SCALE

2 0 2 4 MILES

FIGURE 1

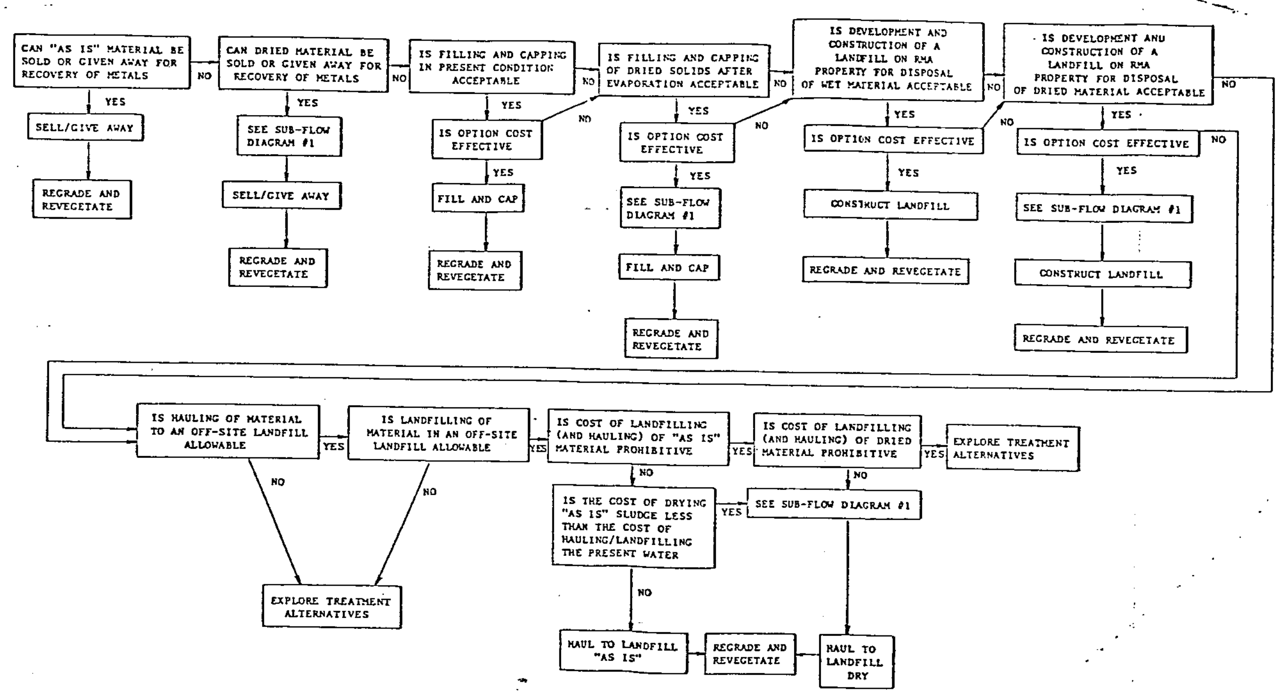
VICINITY MAP

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

D'APPOLONIA

DRAWN BY	S.L.T.	7-5-79
CHECKED BY	DBT	10/23/80
APPROVED BY	JCM	11/14/80
DRAWING NUMBER	RM80-192 A1	



NOTES:

1. "MATERIAL" REFERS TO THE BASIN F CONTENTS, THE ASPHALT LINER, AND A LAYER OF SOIL BELOW THE LINER.
2. SUB-DIAGRAM "I IS INCLUDED IN THIS REPORT AS PART OF FIGURE 4.
3. TREATMENT ALTERNATIVES ARE DEVELOPED IN ANOTHER SECTION OF THE DIAGRAM INCLUDED AS FIGURE 3.

FIGURE 2

DECISION FLOW DIAGRAM

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

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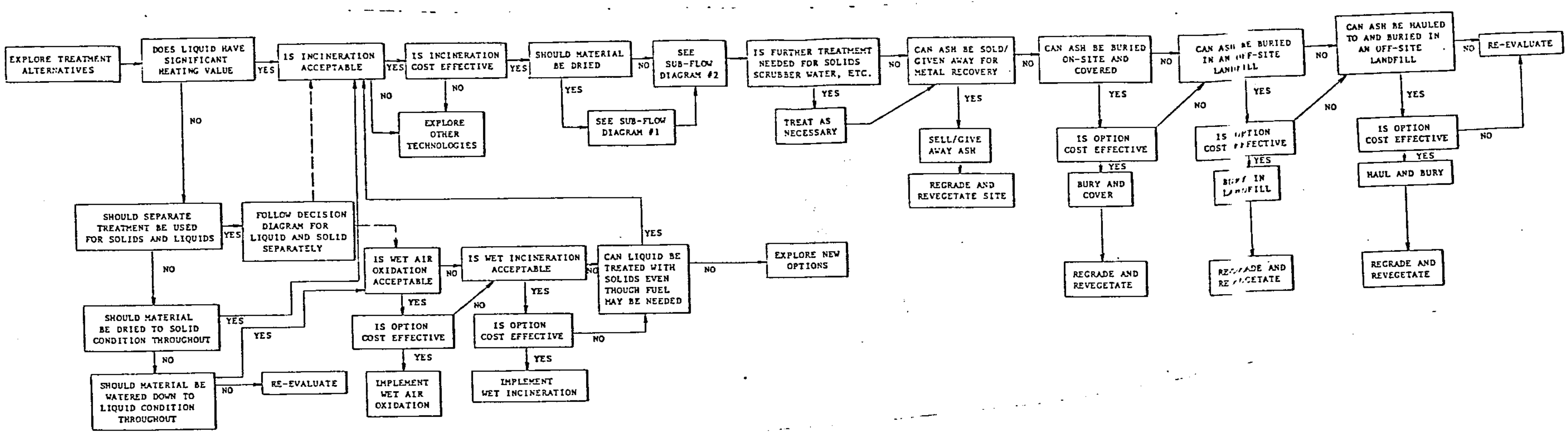
TREATMENT ALTERNATIVES



NOTE:

SUB-DIAGRAMS #1 AND #2 ARE INCLUDED IN THIS REPORT AS FIGURE 4.

FIGURE 3

DECISION FLOW DIAGRAM
TREATMENT ALTERNATIVES

PREPARED FOR

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COLUMBUS, OHIO

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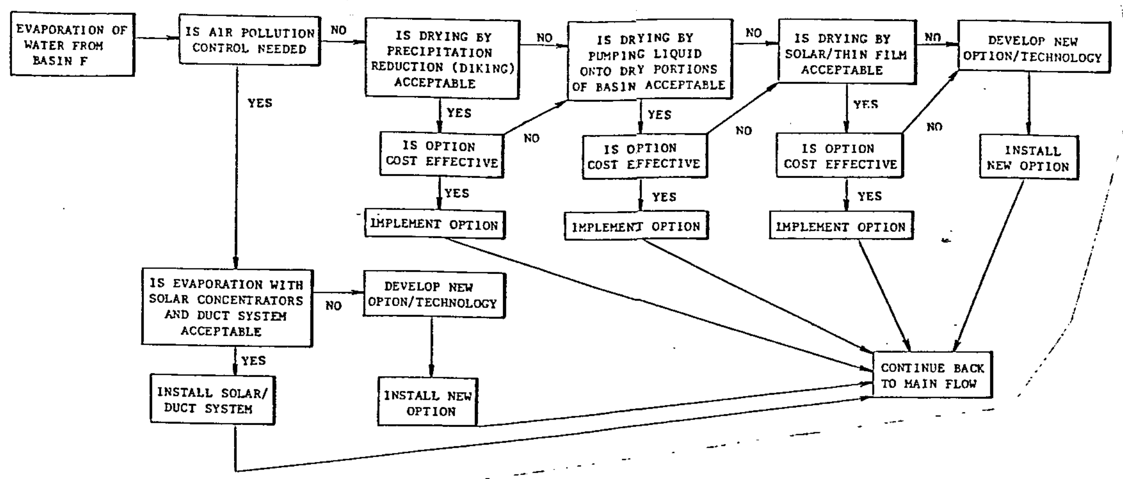
DECISION FLOW DIAGRAM
SUB-FLOW DIAGRAM #1
EVAPORATION ALTERNATIVES



DECISION FLOW DIAGRAM
SUB-FLOW DIAGRAM #2
INCINERATION ALTERNATIVES

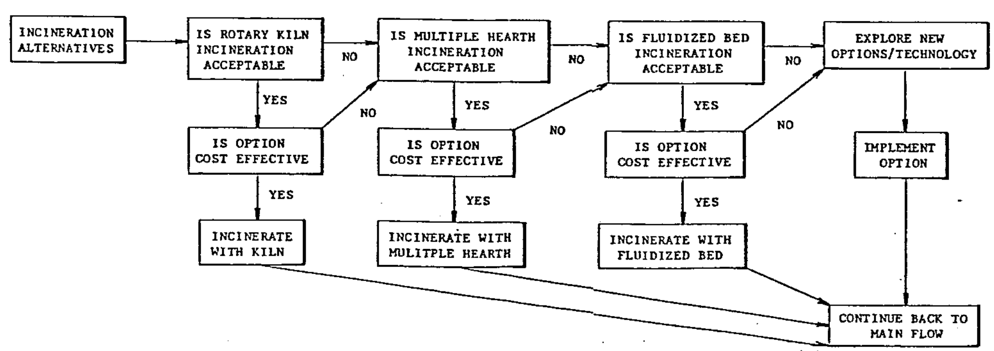


FIGURE 4

DECISION FLOW DIAGRAM
SUB-FLOW DIAGRAMS

PREPARED FOR

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COLUMBUS, OHIO

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DRAWN BY	R. Bricker	8 Nov. 80	CHECKED BY	DGT	11/14/80	DRAWING NUMBER RM80-192
			APPROVED BY	Jcm	11/14/80	

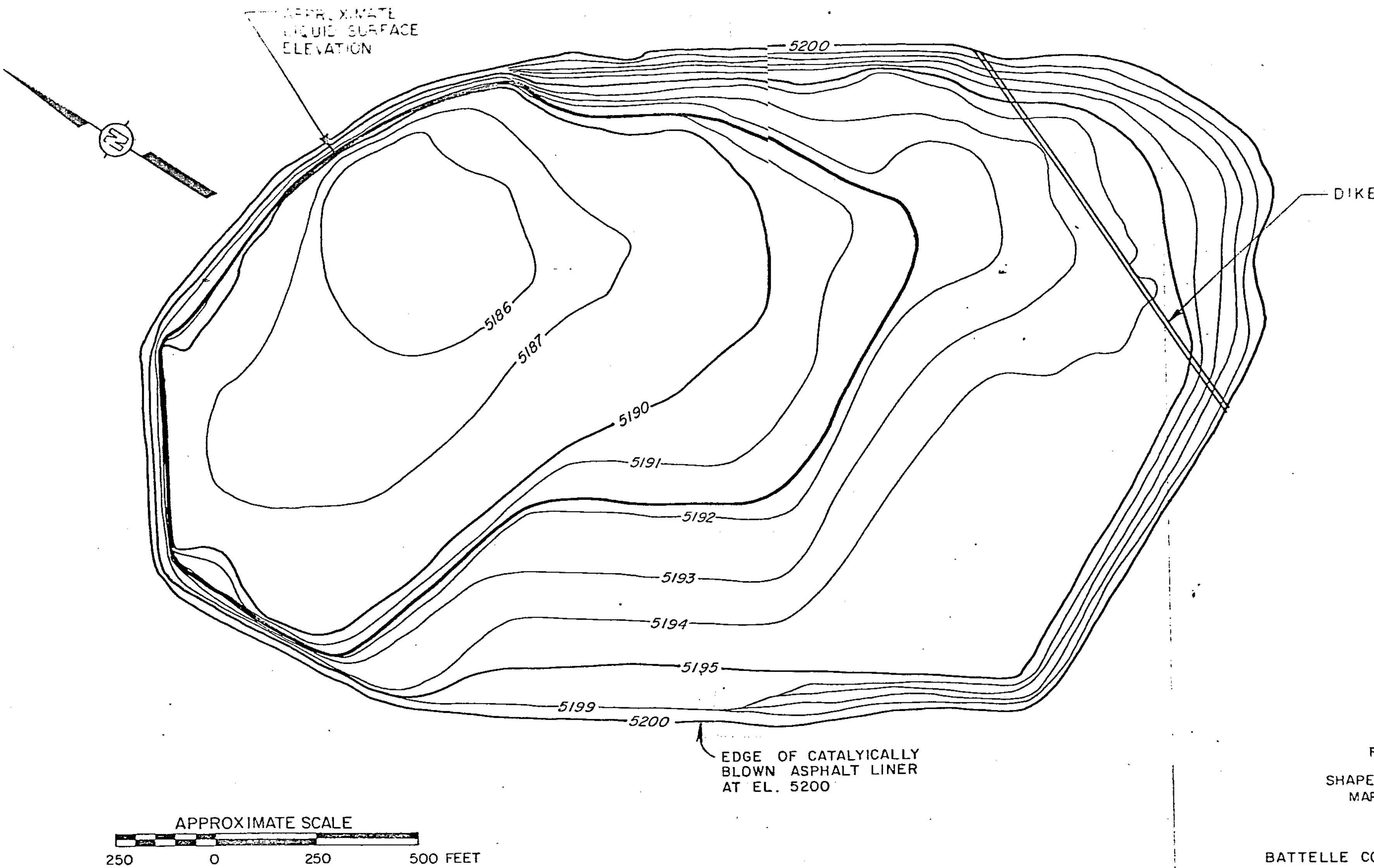


FIGURE 5

SHAPE AND CONTOUR
MAP OF BASIN F

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

D'APPOLONIA

REFERENCE:
ROCKY MOUNTAIN ARSENAL DRAWING E11-10-1,
ENTITLED: CONTAMINATED WASTE AREA,
DATED: 9-23-76, SCALE: 1" = 100'.

DRAWN BY	S.L.T.	CHECKED BY	DGT	10/23/80	DRAWING NUMBER	80-192
	10-27-80	APPROVED BY	JCM	11/14/80		

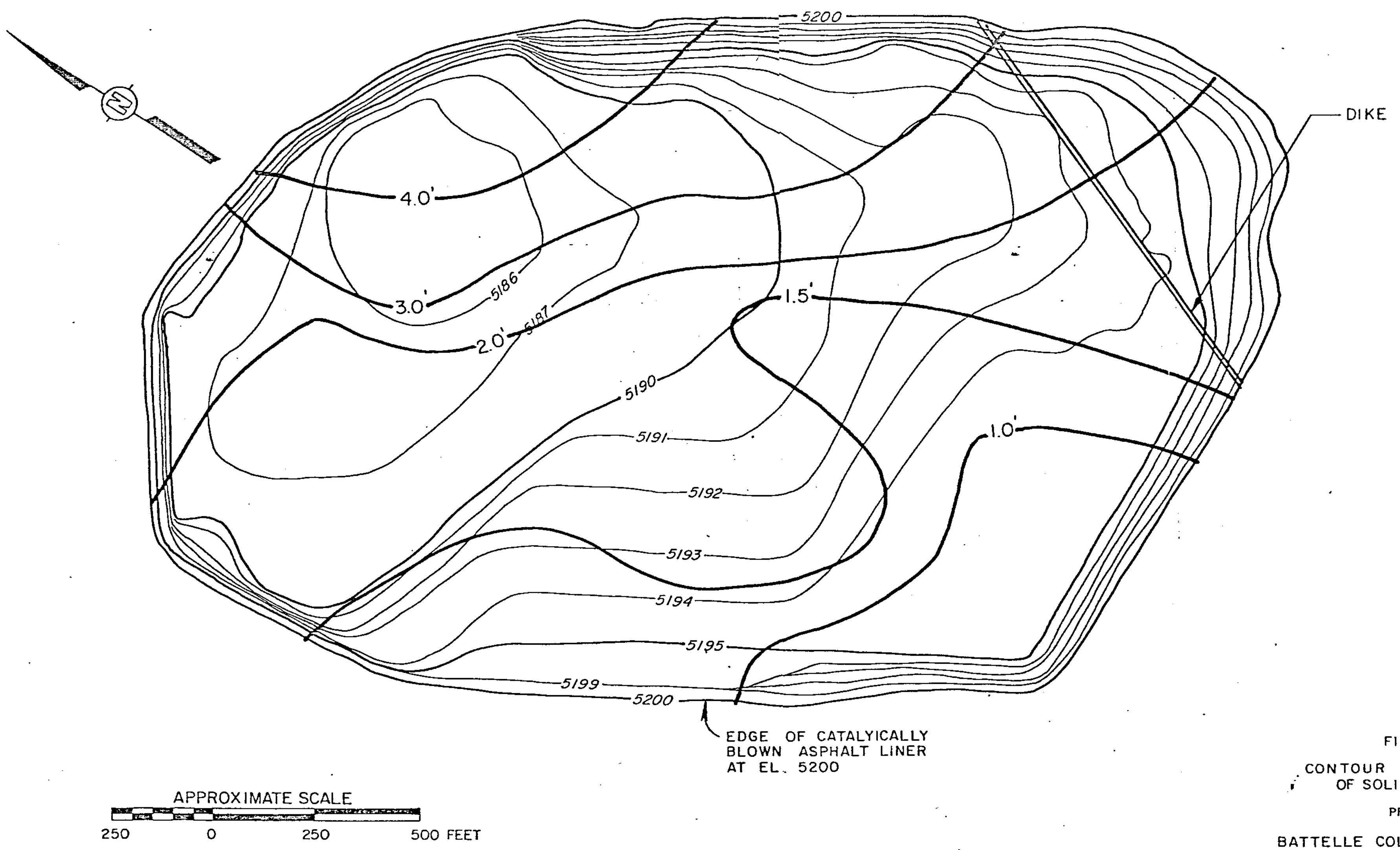


FIGURE 6

CONTOUR MAP OF DEPTHS OF SOLIDS IN BASIN F

PREPARED FOR

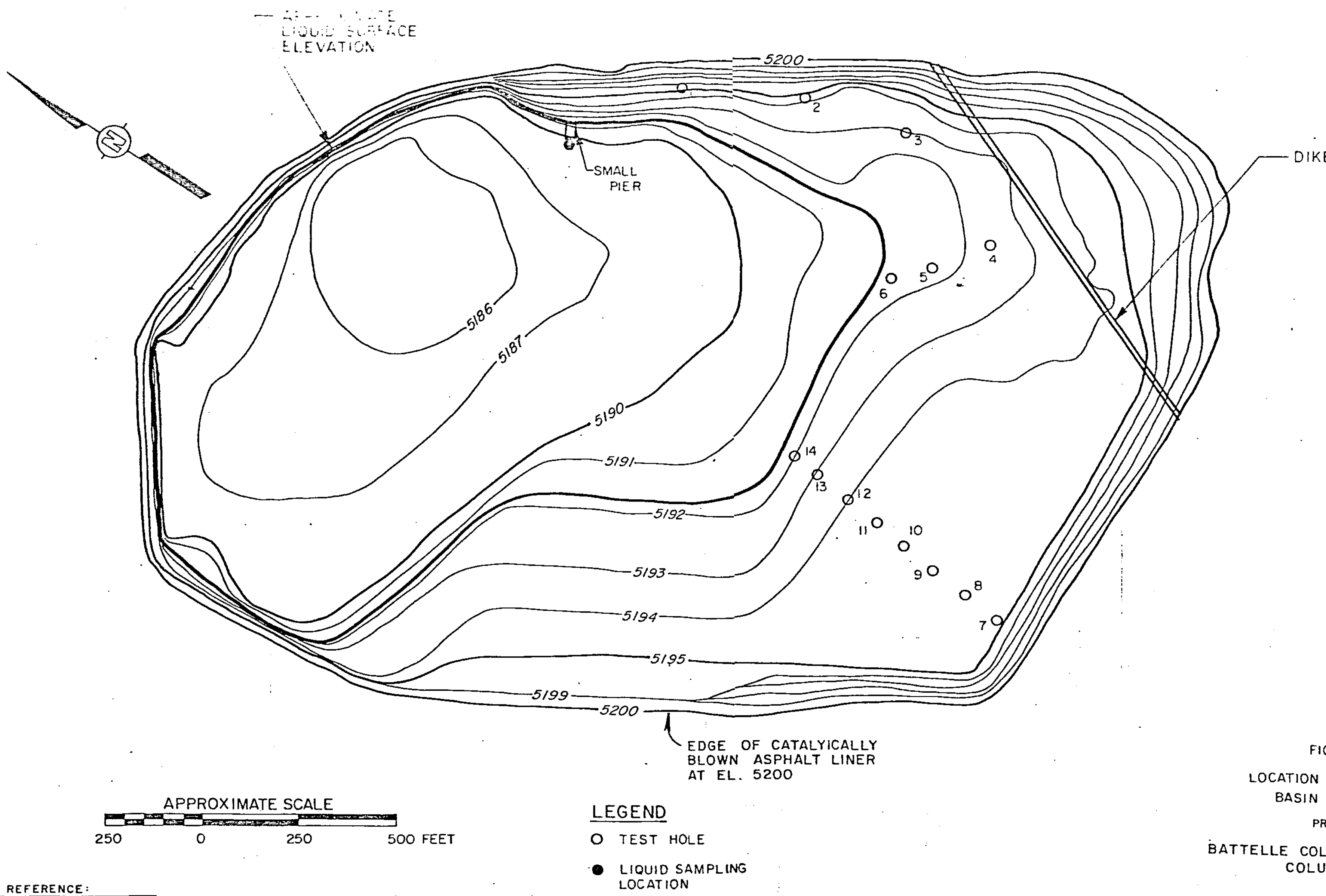
BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

D'APPOLONIA

NOTE: FIGURE SHOWS ESTIMATED DEPTH (IN FEET) OF SOLIDS AT THE BOTTOM OF BASIN F.

REFERENCE:
ROCKY MOUNTAIN ARSENAL DRAWING E11-10-1,
ENTITLED: CONTAMINATED WASTE AREA,
DATED: 9-23-76, SCALE: 1" = 100'.

DRAWN BY	S.L.T. 10-27-80	CHECKED BY / APPROVED BY	DST / JCM	10/27/80 / 11/11/80	DRAWING NUMBER



REFERENCE:
ROCKY MOUNTAIN ARSENAL DRAWING E11-10-1,
ENTITLED: CONTAMINATED WASTE AREA,
DATED: 9-23-76, SCALE: 1" = 100'.

DRAWN BY	S.L.T.	CHECKED BY	DGT	10/23/80	DRAWING NUMBER
	10-27-80	APPROVED BY	JCM	11/14/80	

FIGURE 7

LOCATION OF TEST HOLES
BASIN F SITE VISIT

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

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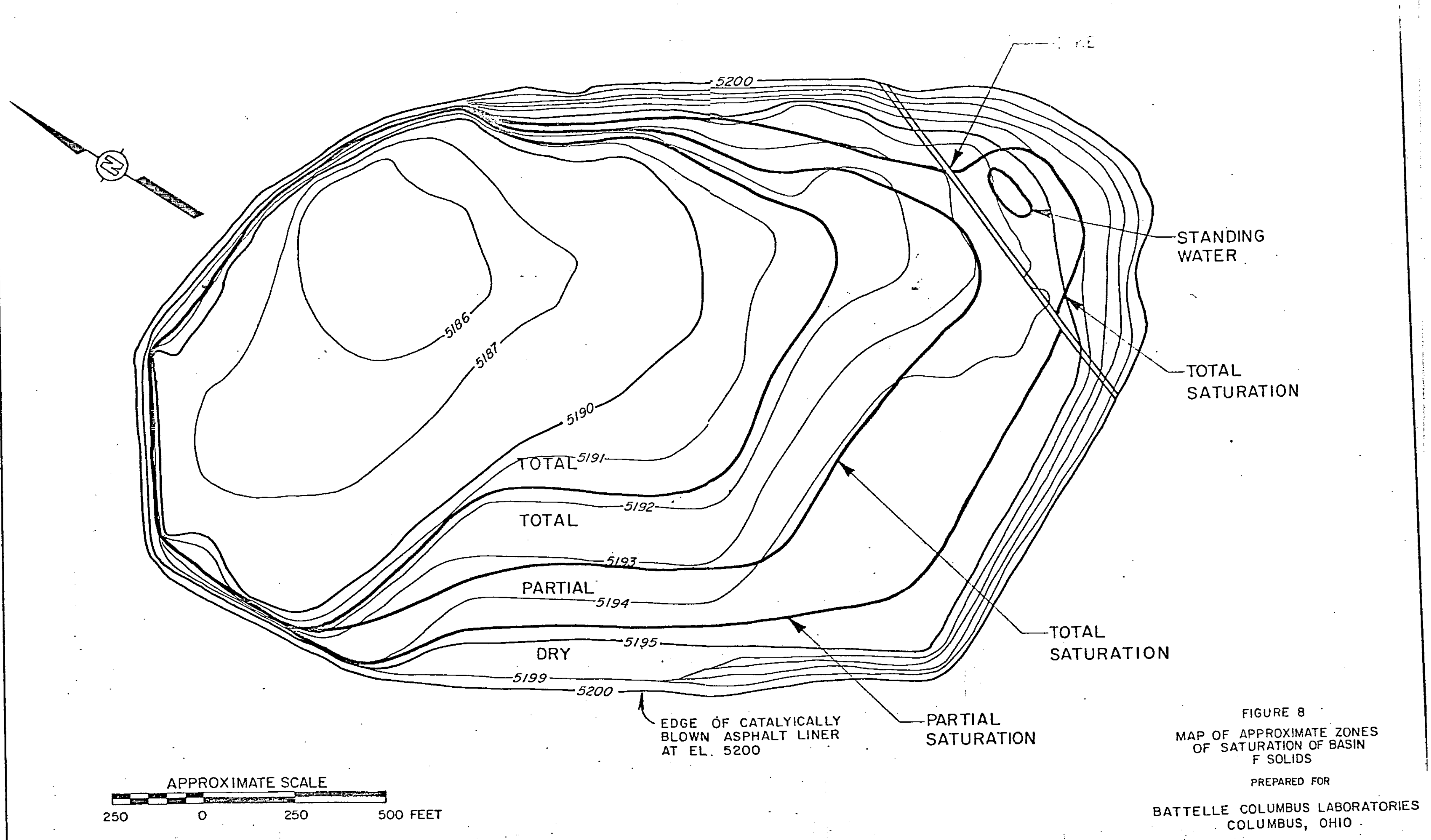

REFERENCE:
ROCKY MOUNTAIN ARSENAL DRAWING E11-10-1,
ENTITLED: CONTAMINATED WASTE AREA,
DATED: 9-23-76, SCALE: 1" = 100'.

FIGURE 8

MAP OF APPROXIMATE ZONES OF SATURATION OF BASIN F SOLIDS

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

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Y	10-27-80	APPROVED BY	JCM	11/14/80	NUMBER

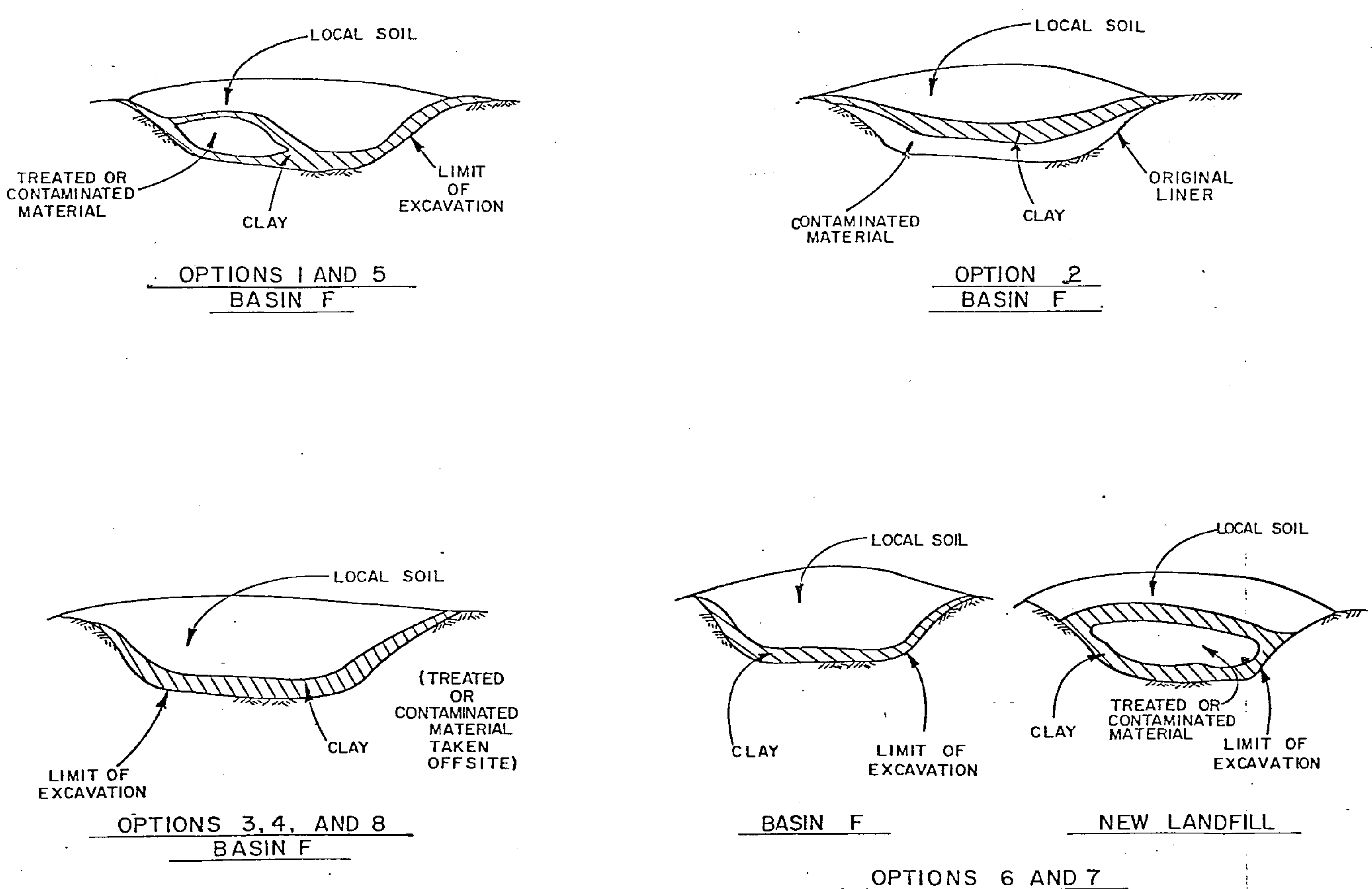

FIGURE 9

FINAL SHAPE OF EARTHWORK PROJECTS ON THE ARSENAL

PREPARED FOR

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COLUMBUS, OHIO

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DRAWN BY	D. J. R. 11-13-80	CHECKED BY APPROVED BY	DGT JCM	11/14/80 11/14/80	DRAWING NUMBER	RM80-192-B1

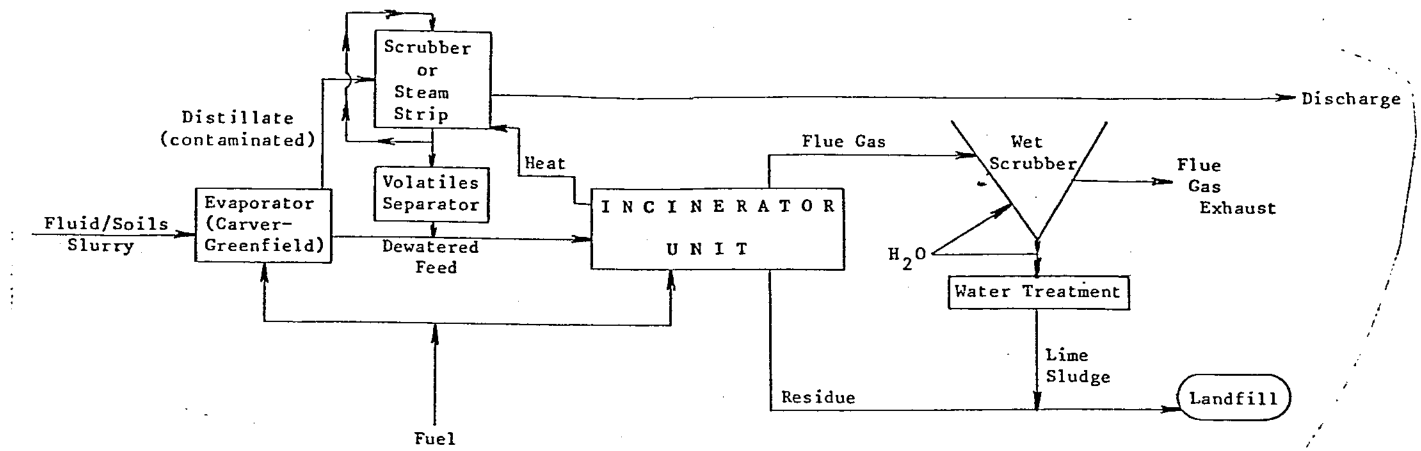

FIGURE 10

SCHEMATIC DIAGRAM OF DISTILLATION AND INCINERATION PROCESS

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

D'APPOLONIA

DRAWN BY	R. Bricker	CHECKED BY	PST	11/14/80	DRAWING NUMBER	RM 80-192-
	8 Nov. 80	APPROVED BY	JCM	11/14/80		

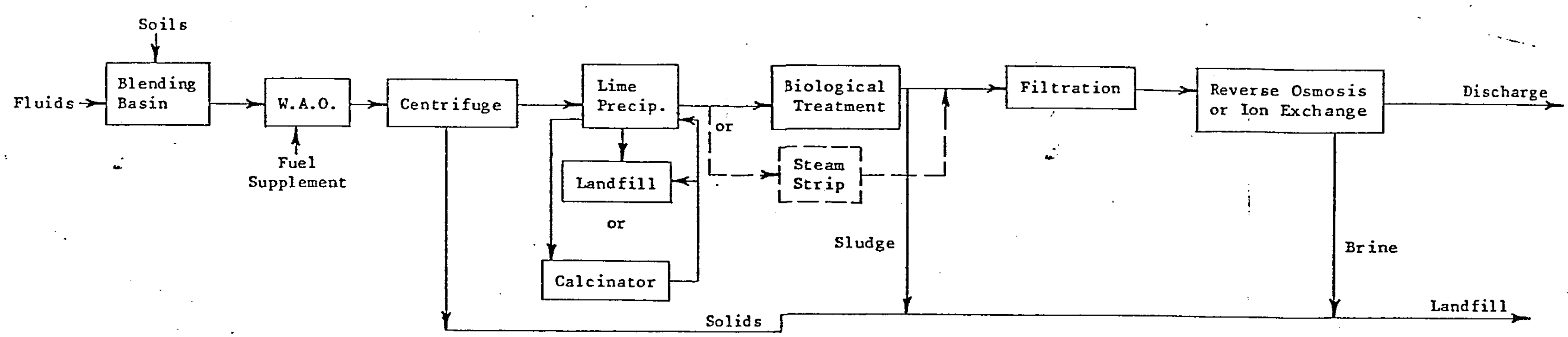

FIGURE II

SCHEMATIC DIAGRAM OF WET AIR OXIDATION PROCESS

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

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DRAWN BY	R. Bricker	CHECKED BY	DBT	11/14/80	DRAWING NUMBER RM80-192-11
	9 Nov. 80	APPROVED BY	JCM	11/14/80	

DRAWING NUMBER RM80-192 A2

DRAWN BY	CHECKED BY	APPROVED BY	
R. Bricker	DGT	JCM	11/14/80
10 Nov. 80			11/14/80

LEGEND:

1 PRIME MOVER
2 AUGER & FLIGHT CONVEYOR POWER SOURCE
3 AUGER EXCAVATOR
4 AUGER SHEILD
5 FLIGHT CONVEYOR
6 DISCHARGE SPOUT

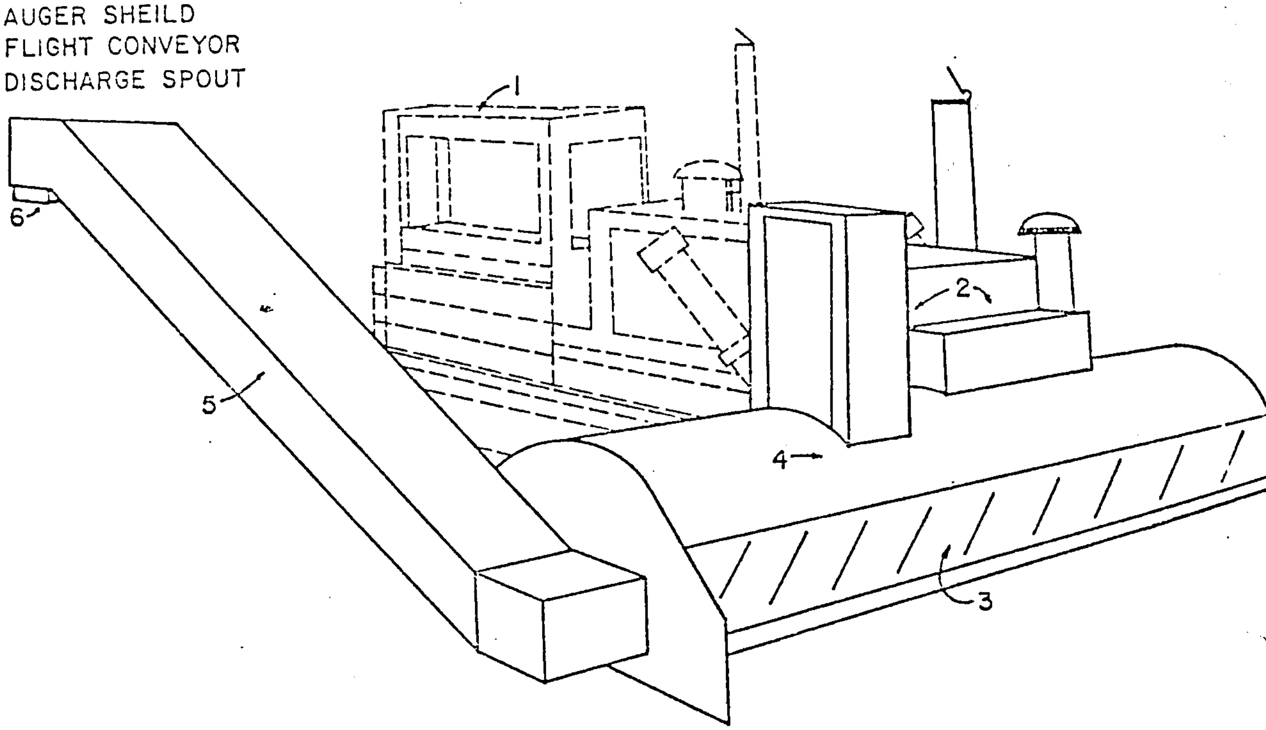

FIGURE 13

AUGER EXCAVATOR

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

D'APPOLONIA

REFERENCE:
OLSEN, et al, 1979