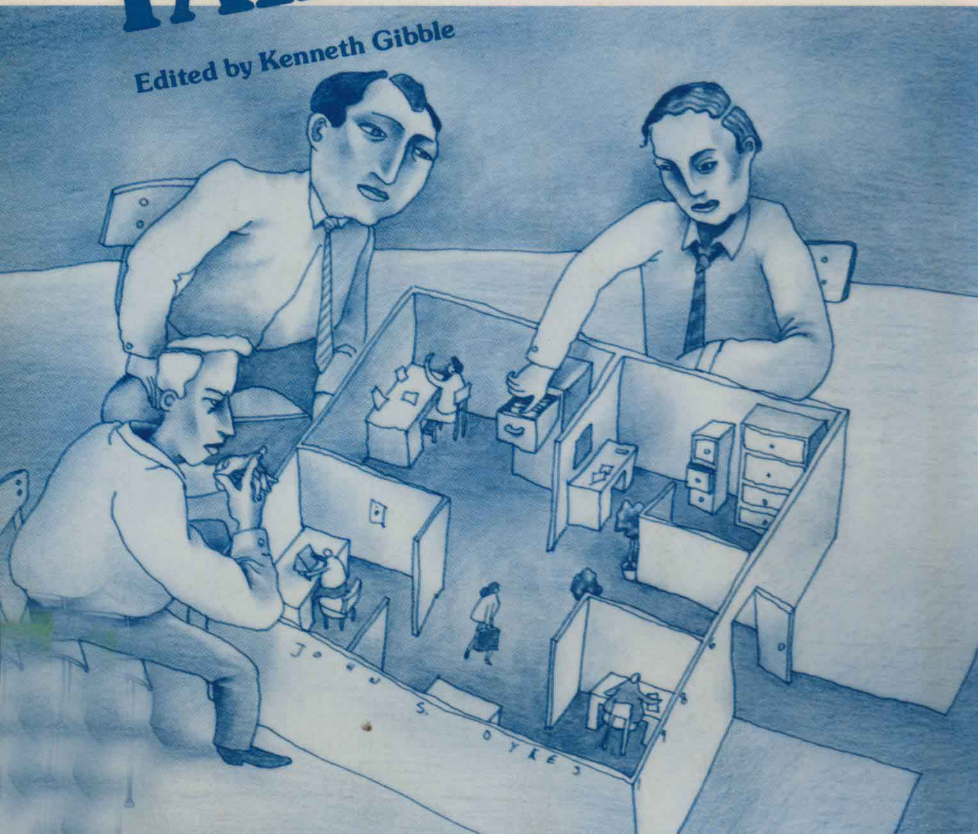
MANAGEMENT LESSONS FROM ENGINEERING FAILURES

Edited by Kenneth Gibble



MANAGEMENT LESSONS FROM ENGINEERING FAILURES

Proceedings of a Symposium sponsored by
the Engineering Management Division of the
American Society of Civil Engineers
in conjunction with the ASCE Convention
in Boston, Massachusetts

October 28, 1986

Edited by Kenneth Gibble

Published by the
American Society of Civil Engineers
345 East 47th Street
New York, New York 10017-2398

ABSTRACT

Engineering failures are not always catastrophic. More are due to improper management of contracts rather than actual physical failures. Some result in loss of life; most result in disputes that frequently lead to litigation. While these failures involve technical issues, they also involve management issues. Communication problems are often a contributing cause. The papers in this book deal primarily with failures associated with the technical quality or functional capability of the project as designed and constructed. If an engineered project cannot meet the performance criteria that it was designed for, then it must be considered a failure. If the resulting work causes a life threatening situation or economic crisis during the expected life of the project, then it is a catastrophic failure. A variety of failures is examined. The intent is to show what caused the failures, what resulted from them, and, in some instances, what could be done to prevent them.

Library of Congress Cataloging-in-Publication Data

Management lessons from engineering failures.

Includes indexes.

Contents: Facing failures / Neal FitzSimons—Quality assurance in a large firm / Charles E. Fuller—Failures / Joseph S. Ward—How do I find the information—that I needed yesterday? / Donald W. Vannoy—[etc.]

1. Engineering—Management—Congresses. 2. Reliability (Engineering)—Congresses. 3. Structural failures—Congresses. I. Gibble, Kenneth. II. American Society of Civil Engineers. Engineering Management Division. III. ASCE National Convention (1986: Boston, Mass.)

TA190.M36 1986 620'.00452 86-25949

ISBN 0-87262-572-9

Library of Congress Catalog Card No.: 86-25949
ISBN 0-87262-572-9
Manufactured in the United States of America.

FOREWORD

Gary D. Bates, P.E., M.ASCE

Vigilance is very important to the practice of engineering today. This is because of the fact that at every corner there is someone ready to challenge the work of engineers and other professionals for possible mistakes that they may commit. The increase of liability suits demands an engineer to be more vigilant in every task that he performs in fulfilling his professional services. Lack of vigilance leads to mistakes, which leads to failures, which more and more frequently lead to legal actions regardless of how large or small the failure may be.

Recognizing this, the Engineering Management Division of ASCE has chosen the theme of Engineering Failures for the Management Symposium in Boston, Mass., October 1986.

From an owner's point of view, certain projects could certainly be considered failures if the financial goals are not met. All projects must have financial justification or the appropriate benefit to cost relationship. Furthermore, many projects, especially in the private sector, are considered failures to some extent if the project is not completed on time to properly reap the expected benefits.

However, this symposium and the papers which are presented, deal primarily with the failures associated with the technical quality or functional capability of the project as designed and constructed. If the resulting work causes a life threatening situation or economic crisis during the expected life of the project resultant, due to inadequate design or construction, then this is a catastrophic failure.

A variety of failures is examined, herein. The intent is to show what caused the failures, what resulted from the failures and in some instances what could have been done to prevent the failures. Throughout the symposium, the common thread of each paper is the role that good engineering management played or should have played in each failure. Therein lie the lessons for each of us to to learn from.

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Session No. 17-S2.1

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*Manuscript not available at the time of printing

FACING FAILURES: Alleged or Actual

Neal FitzSimons, F.ASCE*

Abstract

Every practitioner, in large office or small, faces the possibility of an accusation of causing, directly or indirectly, a failure. The facts may only implicate, or the legal tactics may just entangle, but in any case the resulting embarrassment, frustration, regret, and hostility can be professionally and personally crippling. What can be done to prevent or ameliorate such a traumatic situation? This paper gives some personal ideas on coping with this problem.

"Every error comprehends a contradiction: for since he who errs does not wish to err, but to be right, it is plain that he does not do what he wishes." Thus Epictetus (AD60-138) spoke about error 1900 years ago. The problem remains that errors still occur even though we do not wish them to, but perhaps wishing is not enough. Perhaps we have to clearly understand that an error-free project is an illusion; that a conscientious effort to minimize the frequency of errors, to maximize their interdiction and to mitigate their impact is a much more realistic way to reduce one's vulnerability to the accusation of failure and to ameliorate the impact if it occurs.

Although every case involving an accusation is different, there are some useful ways to mitigate the psychological and financial impact which apply to most cases. Here are a few general rules:

1. Blame no one, including yourself, until you have made a thorough examination of the accusation.

There is a strong tendency for practitioners to blame themselves when problems develop on their project. This is unfortunate for two reasons. First, the evidence cannot be weighed properly if there is a built-in personal bias. Second, the guilt feelings associated with self-

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blame are an unnecessary psychological burden during a period when self-esteem is critical. It should be remembered that failures are normally associated with a series of circumstances and a triggering event rather than a single error.

2. Make a thorough examination of the accusation itself and the conditions associated with it.

Was harm actually done to the accuser? What was the nature of the harm? When did it occur? How much time and effort are necessary to remedy the harm? How was the harm linked to the accusation? Are others being accused? Is the accusation well defined? Do you believe that the accusation is justified? Could you have prevented the accusation? How?

3. Determine what you think was expected of you by the accuser and if these expectations are consistent with your ideas.

A practitioner is not expected to be perfect, but rather to have used due care in the course of the project. Due care, however, may mean that there was a distinct effort to assure that the quality of the products produced by the planning, analysis, design and documentation of the practitioner were sufficient to result in an acceptable project.

There are five "R's" that are implicit in a professional relationship. It is expected that the professional will be RESPECTED for his education, knowledge, experience and judgement; RESPONSIBLE for his actions to all affected by them, including, and especially the public; RESPONSIVE to the needs of the project; REASONABLE in his assumptions and decisions and RATIONAL in his prcedures for carrying out the project.

4. Understand that finding errors and omissions on a project is relatively easy; it is proving that they had a significant adverse effect on the project that is difficult. It is also difficult to show that they were not preventable.

In reviewing the merits of an accusation, it is inevitable that errors will be uncovered. As mentioned earlier, an error-free project is an illusion. However, it is necessary to determine what effect, if any did each uncovered error have on the project's quality/performance. Further, it should be ascertained the procedural reasons for each error. Why were they not uncovered before the review? Was there procedural vagueness, such as camouflaged buck-passing? Were project communications crisp? In attempting to totally prevent errors a great deal of time and effort can be expended and for no apparent gain. How can you show that you prevented an error? There is an implied balance between accepting a given probability of error for a given level of error prevention effort. However, there is also implied that there was a defined effort made.

5. A doctor that treats himself has a fool for a patient! An outside practitioner should be called in to review a project if a serious accusation is involved.

Of course, an insured practitioner should immediately inform his carrier, if a serious accusation has been received. He should also inform his attorney. Very early in the course of his review of the accusation, an independent practitioner, experienced in investigational procedures should be retained by the attorney (not directly by the accused). The independent practitioner can be expected to develop a clearer view of the situation and thus enable the attorney to better develop a better case. It should be remembered that the visibility of an error is not related to its project impact. An obscure error may have a large impact whereas a boner may have little. It is very difficult for a practitioner to re-review his own work, but an outsider, with proper orientation by the originator can often detect errors efficiently.

6. Clearly define the errors which culminated in the accusation.

Even if the accusation itself is without merit, the fact that it was made, exists. Normally an accusation is made by an accuser that has been harmed and wants recompense from the party responsible for the harm. However, the accuser often does not know what errors were the basis of the harm. Sometimes the errors were clearly made by others, but laws are interpreted so that the accuser seeks redress from someone else associated with the project. In any event, it is usually essential to be able to discover, describe and define the errors which may have led to the failure that resulted in the accusation. The standard five "W's" of the news reporter are a convenient guide to doing this: Who, What, Where, When and Why.

Although all errors are "human" errors, it is convenient to consider three levels, viz., personal, organizational, and institutional. A personal error is one directly attributable to the person committing it; "3+7=11".

An organizational error occurs when an individual, following an organizational procedure unwittingly commits an error because the procedure is not clear; or it is incorrect in the first place. If the company handbook of details is mis-read by the designer and "36A" is designated instead of "63A", the intended, this is still a personal error. However, if "63A" is limited in application and this limitation is not clearly expressed, an organizational error occurs if the designer designates it for a wrong application.

An institutional error occurs when an individual, following an institutionally accepted practice, unwittingly commits an error because the practice is inherently incorrect for the particular application, but would not be recognized as such by the profession at large. There are many historic examples of institutional errors. One famous one, is the fall of the Tacoma Narrows Bridge which was designed using the best institutional information by an experienced and respected engineer.

There are other kinds of errors which result in accusations. For example, "opulent" errors in which the practitioner overdesigns for safety because he does not have the time, money or inclination to make a proper design. Often, clients do not understand the benefits gained by more "up front" design money. They ignorantly pay more for the construction and then make accusations when they discover the false economy. Of course, the engineer may have been more diffident than forceful when agreeing to the fee involved. This error is often organizational because it is closely associated with "company policy".

Another type of error is the "stingy" error in which the practitioner underdesigns, not from the standpoint of safety, but from the standpoint of long-term maintenance, operation and longevity. This error may be institutional, because, unfortunately, safety alone seems to dominate American structural attitudes rather than safety and serviceability. It may also be "personal" due to ignorance or "organizational" due to diffidence on the part of management to give the client the full implications of a given design.

Still another type of error is the "constructability error" in which a project documents are prepared which implicitly require the contractor to construct in an awkward or inefficient way. The Kansas City walkway disaster was initially generated by an error of this kind, excessive distances to screw nuts under support washers.

Before closing, it might be useful to be reminded of the antiquity of the problem of error propagation as applied to the construction industry. About 50 B.C., Lucretius, the Roman poet and philosopher wrote "....in a building, if the rule first applied is wry (twisted), and the square is untruce and swerves from its straight lines, and if there is the slightest hitch in any part of the level, all the construction must be faulty, all must be wry, crooked, sloping, leaning forwards, leaning backwards, without symmetry, so that some parts are ready to fall, others do fall, ruined by the first erroneous measurements...."

Many practitioners are lucky, because even though they lack a well defined quality assurance program, their projects although, "ready to fall (fail)', have not fallen. Other less fortunate, had projects that did fall (fail) to the extent that accusations were made. It is hoped tha this paper may prove helpful to both categories of practitioners.

QUALITY ASSURANCE IN A LARGE FIRM

Charles E. Fuller*

Abstract

This paper will describe the formalization of the Quality Assurance Program in a large consulting engineering firm. Although Quality Assurance and Quality Control have been a part of normal project procedures in this firm for many years, an increased effort has occurred over the past two years to strengthen and tighten up the program.

The establishment of a tracking program to monitor project milestones, including preliminary and specialists reviews, the formal technical review meeting and follow-up, as well as project history and final audit will be discussed. Also the interaction between the firm's four regions as it pertains to technical standards development, master specifications and formal review of projects by utilizing the firm's most qualified people in certain areas of expertise for formal review of projects.

Background

Camp Dresser & McKee Inc. was formed in 1970 as the succeeding parent organization of the partnership formed by Dr. Thomas R. Camp, Mr. Herman G. Dresser and Dr. Jack E. McKee. The firm's initial efforts involved work primarily with New England industries and government offices with Camp Dresser & McKee quickly establishing its reputation for outstanding professional consulting engineering. The firm experienced steady growth, greatly expanding its geographical base and broadening its expertise in the environmental engineering field. The firm currently maintains offices at 30 locations in the United States as well as 10 offices in 7 foreign countries with a work force exceeding 1,500 employees. The CDM staff is thoroughly experienced in all phases of water resources planning; collection, treatment and disposal of wastewater, stormwater and industrial wastewater; public water supply, transmission, treatment and distribution; surface and groundwater hydrology; drainage, irrigation and flood control; air pollution control; and solid waste management. Members of the staff also have extensive experience in such related

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fields as systems analysis methodology, urban planning, computer applications, groundwater modeling, environmental impact evaluation, and financial management and planning. The firm currently operates in the continental United States through four regions, with the Northeast Region comprising 3 offices in 9 states, the South Region including 12 offices in 13 states, the West Region comprising 10 offices in 17 states while the Midwest Region comprises 4 offices in 9 states. In addition, Camp Dresser & McKee International Inc. operates the WASH II Project out of an office in Arlington, Virginia, while the firm of Camp Scott Furphy Pty, Ltd. (CSF) maintains 3 offices in Australia and 3 other offices in other parts of Asia. Further, the firm operates the REM II project out of its Federal Program Center in Annandale, Virginia, with the hazardous waste work coordinated with the EPA regions.

The responsibility for administering the quality assurance program rests with each of the four regions as an outgrowth of the initial development of the program which was undertaken by Corporate Technical Development (CTD). The Regional Technical Development (RTD) is fully responsible for compliance, monitoring and actions necessary to correct non-compliance. In addition, RTD is responsible for the development and upgrading of all regions specific procedures. Each region is provided with a Regional Technical Director (RTD) whose responsibility it is to see that the program is carried out in his region. Because of the vast geographical extent of the West and South Regions, the RTD for each of these regions is provided with an assistant in each of the local offices to carry out the routine monitoring and auditing activities, with matters of a more technical nature such as reviews scheduled for periodic visits to each office by the RTD. The RTD responsibility for the Midwest Region is carried out by a single individual who covers the program requirements in the 4 offices. The Northeast Region is by far the largest region within the firm with nearly one-half of the company's 1,500 employees located in the 3 offices in Boston, New York City and Edison, NJ. An assistant to the RTD handles the individual technical review of most projects as well as scheduling group technical reviews for the New York/New Jersey offices. Responsibility for the quality assurance program in the Boston office rests with the writer who, along with the other three RTD's, is responsible for:

1. monitoring all quality assurance procedures
2. review of technical communications
3. coordinating development of new office standards and guidelines
4. organization of and a permanent member of the Technical Review Committee (TRC) for the review of projects.

It is pertinent at this point to define the terms Quality Assurance and Quality Control for purposes of this discussion. Quality assurance includes all activities undertaken to establish requirements and ensure compliance thereto which result in the provision of services to our clients which fully meet their expectations as well as the requirements of the contract. These activities can be further subdivided into two categories; the Quality Control procedures being those specific control procedures undertaken by staff engaged in a particular project, while the Quality Assurance being the timely overview by authorized staff to ensure that such control procedures are being followed to the extent appropriate to meet contract requirements and satisfy client expectations. This paper deals with the quality assurance activities which make up part of each project.

The TRC was established at CDM in 1968 for the purpose of reviewing all report and design projects to ensure that proper engineering principles were being applied to these projects as well as cost effective solutions being recommended. The design project was required to be brought before the TRC during the early stages, before the drawings were sufficiently under way, so that any changes deemed necessary could be made without incurring excessive costs. The report or study type project was brought before the TRC when the study was sufficiently well along that analyses of the alternatives had been completed and recommendations formulated. As the firm continued to grow in size, as well as the scope and size of projects also increased, it became obvious that the TRC in and of itself alone was not enough to ensure the degree of quality assurance and quality control necessary to maintain the firm's reputation. It was learned that sometimes the committee's comments were not heeded or the direction taken by project personnel was different than that given by the TRC in its review of a given project. Consequently, the QA program was established which continues the TRC, but sets same into a more formal structure. The TRC is probably one of the most important review gates in the overall review procedures for a project: however, it is not to be misconstrued as the entire review effort on a project. The detailed checking which follows constitutes probably the single most important part of project review.

The Quality Assurance Program for Report and Design Phase Projects

The Quality Assurance Program for both report and design phase projects comprises three types of project activities, start-up, execution and conclusion. The project start-up activities include the establishment of a QA Work Plan including a QA budget and the generation of sufficient information to enable an entry audit to be made for the project. The project execution activities include scheduled reviews for the project, the computations and utilization of technical standards for the project, the checking of computations, any special considerations and the development of a project history for the project. Project conclusion activities include the storage of project related data as well as the filing of the project history and the QA sign off form. Let us first look at the QA Work Plan.

QA Work Plan - This is required on all projects with a cost in excess of $10,000 and should be established immediately following notice to proceed on a project. The project work plan is developed by the project manager and reviewed by the RTD with such submission and review constituting an entry audit for the project. The work plan includes such items as:

1. Synopsis of contract work, scope and objectives
2. Table of Organization
3. Schedule of Milestones and Reviews
4. Identification of the expected input from specialists, consultants as well as any anticipated client interactions or funding agency interactions.
5. Time and cost budgets for QA program.

The work plan also includes a budget which allows for complete implementation of all QA activities. Items included in the QA budget include costs for the work plan preparation and monitoring, costs for necessary reviews and costs for preparation of materials for permanent storage. A schedule of milestones and reviews for a given project should spell out the appropriate staff or specialists to be involved with a series of review dates usually consisting of the following:

Review Gate 1 - Preliminary
Review Gate 2 - Specialists Review
Review Gate 3 - Technical Review Committee (TRC)
Review Gate 4 - Optional Final TRC
Review Gate 5 - Extensive Final Review

Let us briefly review the QA Work Plan submitted for the MWRA Moon Island Phase II Feasibility Study, dated October 25, 1985. Review of this document reveals that the contract work, scope and objectives are outlined, the Table of Organization set forth in chart form, the communication procedures for the project detailed and the schedule of QA milestones and deliverables also detailed. The work plan also indicates special research and field data, specialists' input, client interactions, funding agency interactions, special requirements for codes and enforcement agencies, steps necessary to implement all QA procedures and finally, project budget and QA budget. A typical response to a work plan is included also and described in Review of Work Plan - Worcester, Mass. - Future Water Supply Study, dated April 24, 1986. This review confirms the gates that have been established for the project as well as provides a review of the QA budget for review of the project. The monitoring of on-going projects in this office is accomplished by the establishment of a tracking system which lists each project as well as the established gate reviews and dates thereof with the tracking schedule checked each month to ensure that review gates are accomplished according to schedule in a timely fashion. All projects which comprise a formal TRC are subjected to an intermediate audit with the timing of such dependent on whether or not the project involves a report or study or a design. The final audit for each project establishes whether or not the project has complied with the gate reviews scheduled in the original QA Work Plan, the record of the TRC meeting as well as the response memo to the minutes of the TRC meeting and a confirmation of such items as checking of computations, file maintenance and completion of the project history. (This is all indicated on attached form.)

This paper has attempted to describe the formalization of the quality assurance program in a large consulting engineering firm. Although quality assurance and quality control have been a part of normal project procedures in this firm for many years, an increased effort over the past two to three years to strengthen and tighten up the program has enabled us to provide our clients with a more well-designed project. Further, the establishment of a tracking program to monitor project milestones, including preliminary and specialist reviews, the formal TRC meeting and follow-up as well as intermediate and final audits has given us the opportunity to ensure our clients of a well engineered project.

Interaction Between the Regions

The success of a good quality assurance program in a firm with over 1,500 employees depends on communication between the various regions. The written memo offers an excellent way to solicit input from personnel in other regions while the Regional Technical Directors (RTD's) communicate frequently by telephone and in person when technical reviews or other business efforts cause the RTD to travel to another regional office. Twice each year, usually in February and October, RTD meetings are scheduled for the purpose of discussing quality assurance and technical development efforts, goals, and to report on progress as well as problems. These meetings are usually held on a rotating geographical basis or at a location which can be combined with a technical meeting, seminar or convention which is being attended by certain members. Quality assurance items often include discussion of the development of appendices to the QA-1 Manual which are suitable for each region. These appendices include such subjects as technical review committee procedures, project auditing procedures, development of the project history or directives for storage of project records. The monitoring of progress with regard to development of work plans, audits, and responses to technical review committee minutes are usually discussed at these meetings.

Technical standards within the firm include the development of a series of ten manuals which depict design procedures and include guidelines for process design including the design of water and wastewater treatment plants. Responsibility for the development of these manuals has been divided amongst the various regions and, at the present time, four manuals have been completed with four more manuals at various stages of completion with the outlines developed for the remaining manuals. The Northeast Region is also currently developing its own set of Master Specifications with these specifications scheduled to follow the CSI format. The responsibility for development of Master Specifications for certain product lines is spread amongst the regions with the end product shared by each region. Our computer aided drafting and design (CADD) system is developed around a system marketed by Intergraph which has been adapted to enable more widespread use throughout the company, particularly in the areas of mechanical and piping design. Standards and standard details have also been developed and distributed for widespread use throughout the firm.

Technical communications include memos developed within the various regions to advise personnel of technical matters, material and equipment suitability, experiences which should benefit future designs, and actions by state or federal agencies that may impact on the design of other projects. The firm also retains the services of a number of technical consultants for input to various projects either on a retainer or part-time basis. We are constantly upgrading our list of consultants to meet the requirements of projects currently under way.

Goals To Be Achieved

The institution of a meaningful quality assurance program at CDM has resulted in a greatly improved record of compliance of all major projects with the formal guidelines set forth as a framework for this program. Consequently, we have already been able to realize the achievement of certain goals as follows:

1. An opportunity to improve our success rate in satisfying our clients by improving the quality of our finished product.

2. An opportunity to improve our investigation/study/design/constructed facility by better planning in the initial stages, thereby leading to earlier selection of preferred alternative with more effort directed to its development.

3. An opportunity to effect some cost savings on certain projects, particularly in the construction phase, while improving our overall engineering effort and making more efficient use of same.

4. As a consequence of achieving the above, the opportunity to further ensure the already low number and magnitude of professional liability claims against our firm.

CAMP DRESSER & McKEE INC.

MEMORANDUM

To: C. E. Fuller

From: C. R. Johnson

Subj: Quality Assurance Work Plan
for
Massachusetts Water Resources Authority
Moon Island Phase II Feasibility Study

Date: October 25, 1985

This memorandum fulfills requirements for CDM's QA work plan on the above-noted project.

1. Synopsis of Contract Work Scope and Objectives

The objective of the Phase II Study is to assess the feasibility of constructing a combined sewer overflow control facility on Columbia Point adjacent to the Calf Pasture Pumping Station, or on Moon Island. The facility will control existing combined sewer overflows BOS-081, 082, 083, 084, 085, 086, and 087 in South Boston. An integral part of the study will include investigations to determine the feasibility of replacing the function now served by the Calf Pasture Pumping Station in providing hydraulic relief for the Columbus Park Headworks. The end product of the work will be a report that decribes the study and presents recommendations and preliminary design information for the facility. Recommendations for short-term improvements to the Calf Pasture and Moon Island facilities are not an objective of this study.

The work will be performed in twelve major tasks

Task 1. Data Collection and Review
Task 2. Alternative Identification
Task 3. Alternative Screening and Evaluation
Task 4. Sewer and Tunnel Inspection
Task 5. Subsurface Investigations
Task 6. Public Participation
Task 7. Coordination and Agency Meetings
Task 8. Environmental Information Document
Task 9. Water Quality Analysis
Task 10. Institutional Assessment
Task 11. Recommended Plan
Task 12. Report Preparation

2. Table of Organization

The project organization is shown on Figure 1, and this emphasizes responsibilities for quality control.