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Project Summary

Drinking Water Cost Equations

Paul Dorsey and Robert M. Clark

The Safe Drinking Water Act of 1974 emphasizes the need to consider costs when promulgating regulations. Much concern has been expressed over these costs, particularly as they relate to technological requirements. To respond to some of these concerns, the Drinking Water Research Division of EPA's Municipal Environmental Research Laboratory sponsored a research effort to develop cost data (a base of 99 unit processes) associated with water supply unit processes. Before being considered acceptable, the costs developed by a design consultant were reviewed by a cost-estimating specialist.

With the use of the cost data developed in the original report, a general equation was developed to calculate regression estimates. With the use of this form of equation, operating and maintenance and capital costs (normalized at 8% over a 20-yr amortization period) were estimated. In addition, equations based on operating and maintenance components (number of kilowatt hours, labor hours, etc.) and construction cost components (housing, instrumentation, etc.) were developed.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report cf the same title (see Project Report ordering information at back).

Introduction

The Safe Drinking Water Act of 1974 emphasizes the need to consider costs when promulgating regulations. Frequently these regulations become translated into generalized design requiremnts for technology rather than into specific unit process designs. Concern over the cost of regulatory requirements has increased general interest in efficient unit process design, as have concerns over continuing trends in higher costs for labor, energy, materials, and other important input factors.

To respond to some of this concern over the cost of water supply, the Drinking Water Research Division of EPA's Municipal Environmental Research Laboratory sponsored a research effort to develop cost data associated with water supply unit processes. The purpose of the project was to develop operating and capital costs for water treatment processes that are sufficiently accurate for preliminary planning and flexible enough for cost effectiveness studies. Before being considered acceptable, the costs developed for 99 unit processes by a design consultant were reviewed by a cost-estimating specialist.

The full report presents equations derived from the original data and shows how these equations can be used to estimate costs for unit processes. Examples based on a standard layout for a water supply treatment plant and standard values for the input factors to the cost equations are presented.

Need for Predesign Estimates

Although seldom, if ever, are any two plants exactly the same, two plants with similar water treatment goals can be similar and can often be meaningfully compared if adjusted to a common base.

When considering concepts or designs, frequent economic appraisals are necessary to eliminate noncost-effective alternatives and to concentrate research and engineering efforts into channels leading to the most attractive end results. These economic appraisals must be made without the benefit of firm estimates based upon detailed design. When some indication of the cost of constructing a plant is required, an individual closely concerned with the development or a specialist with previous estimating experience and a reference file of cost data often prepares an estimate. The dependability of the result and the amount of time spent in developing the necessary data vary widely.

These estimates, broadly termed the "predesign" estimate, are useful for guiding research into examining the most desirable of several process or design alternatives. Only when the choice between alternatives is difficult are complete designs and price quotation needed to select the proper technology.

Cost Estimation for Research

Many water treatment processes originate in the laboratory and are tested through field-scale pilot plant studies. When a new process is considered for field-scale evaluation, the question of the cost of this process in full-scale application arises. The data presented in this paper can be used to answer this question. By disclosing the most costly features of the process, a cost estimate may suggest some specific areas for further study.

Preliminary Engineering

Preliminary engineering to translate laboratory and pilot plant data into equipment design, piping, layout, buildings, etc., can start as soon as a project appears attractive. The first step should be a detailed process flow sheet with complete material and energy balances.

Preliminary selection of types and sizes of equipment can be made from the flow sheet. In some cases the most favorable equipment can be chosen by comparing purchase prices of equipment performing the same function. In other cases the direct operating and installed costs of competitive equipment must be considered. Simple formulas can be developed to assist in making these comparisons. Such formulas and their applications are given in the full report.

Before preliminary engineering can be completed and construction can be started, all decisions must have been made between competitive processes, raw materials, plant sites, scale of production, etc. Cost considerations are extremely important in these choices. Simple factors will dictate most fundamental decisions, but somewhere in the selection process may be a choice between two courses of action in which nearly all factors must be considered in a "full-scale" estimate.

Cost estimates have their greatest utility for these kinds of decisions. In other words, after all other factors are considered, the final choice of unit processes should be based on the most economically attractive alternatives. The considerations involved are nearly the same as those for evaluating the desirability of construction.

Approval of Construction

In the final analysis, the decision of whether to build a treatment facility involves many factors that must be weighed judgmentally:

1. total capital outlay,
2. estimated operating costs,
3. terminal production costs,
4. amount of water to be produced per year,
5. quality specifications required,
6. processes to be used,
7. amount of waste generated,
8. location of the plant, and
9. support facilities required.

Many times misunderstandings in comparative costs can be eliminated by following the steps outlined above. For example, two treatment plants, one with sludge handling facilities and one without, can have quite different costs.

Understanding which design variables have the greatest impact on cost is often important. The equations presented in this report can therefore frequently be used to perform sensitivity tests.

Reliability of Estimates

The factors affecting the reliability of cost estimates include availability of basic data, state of development, definition of scope, the time expended on analysis, and experience of the analyst. Figure 1 illustrates the effect these factors can have on capital costs for projected and actual facilities. These same factors apply to estimating operating costs as well. Table 1 summarizes the characteristics, purpose, and reliability of five basic types of cost estimates.

Development of Cost Data

Data for this study were derived from a carefully designed research project study to establish water supply unit process cost curves on a consistent and understandable basis. The study focused on (1) processes for removing from potable water those contaminants included in the National Interim Primary Drinking Water Regulations (NIPDWR) and (2) development of construciton and operation and maintenance cost curves for these processes. The final data base contained cost curves for 99 unit processes and a computer program for retrieving, updating, and combining the cost data. Characteristics of these data are described in the following sections.

Derivation of Cost Curves

The construction cost for each unit process considered in the original research project is presented as a function of the process design parameter that was determined to be the most useful and flexible under varying conditions. Variables such as loading rate, detention time, or other conditions that can vary because of designer's preference or regulatory agency requirements were used. For example, for granular activated carbon (GAC), concrete contactor construction cost curves are presented in terms of cubic feet of contactor volume; this approach allows various empty bed contact times to be evaluated. Contactor operation and maintenance cost curves are presented in terms of square feet of surface area because operation and maintenance requirements are more appropriately related to surface area than to contactor volume. Reactivation facility cost curves are presented in terms of square feet of hearth area for the multiple hearth furnace and pounds per day of reactivation capacity for the other reactivation technologies considered. This approach provides greater flexibility in the use of the cost curves than if the costs were related to water flow through the treatment plant.

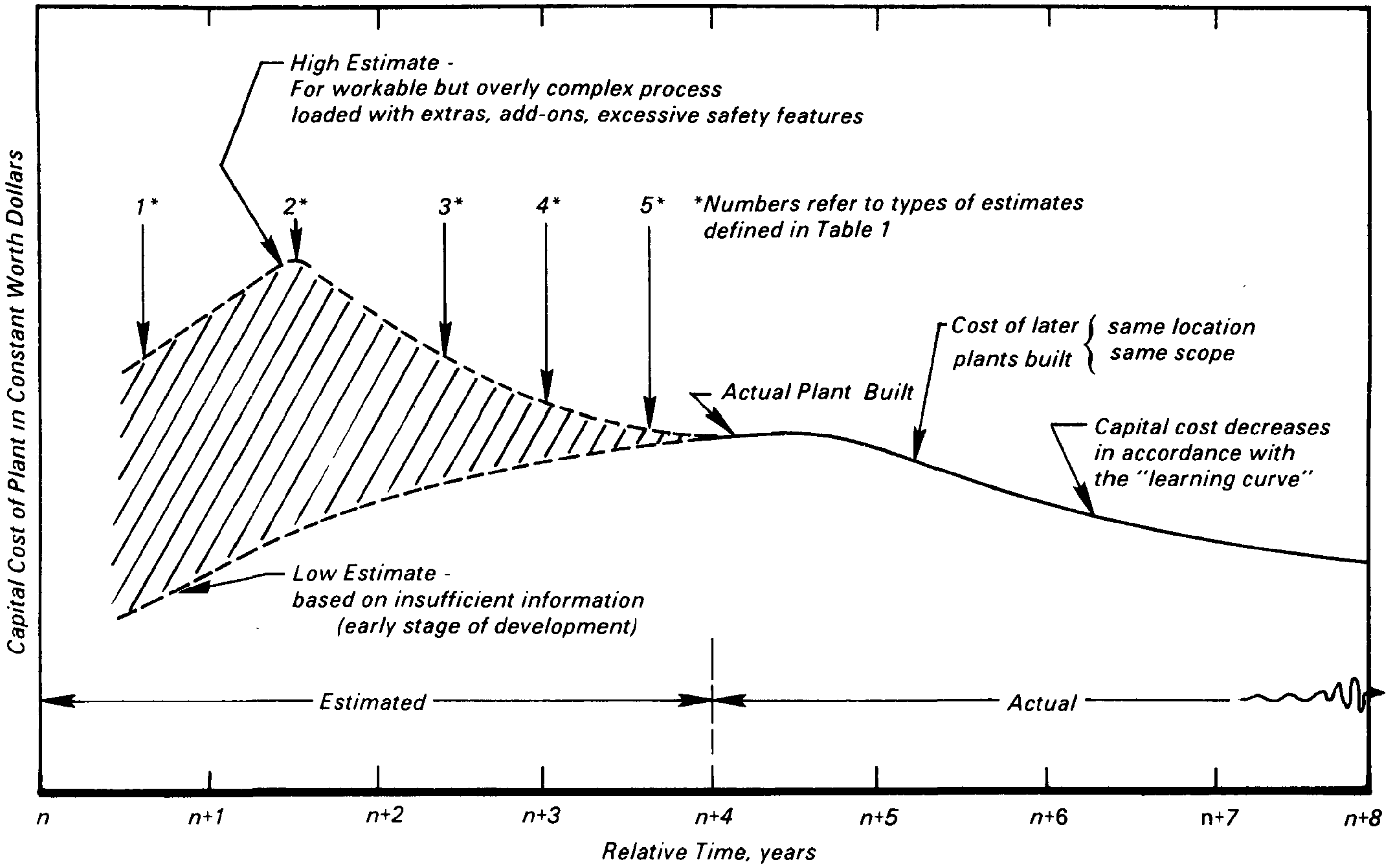

Figure 1. *Effect of various factors on projected and actual capital costs.*

Figures 2 and 3 show typical construction cost curves and some of the operating and maintenance cost components for pressure carbon contactors. A feature common to many of the curves is a decrease in slope of the curve at smaller size ranges; Figure 3 illustrates this effect. This feature is significant in deriving the equations.

Methods Used to Develop Cost Curves

The construction cost curves were developed with the use of equipment cost data supplied by manufacturers, cost data from actual plant construction, unit takeoffs from actual and conceptual designs, and published data. An approach similar to that utilized by a general contractor in determining a construction bid was then used to check these cost curves. Any discrepancies that existed between the initial estimate and the second estimate were then resolved.

Construction Cost Components

The costs for eight principal construction components were developed and then aggregated to give the construction cost for each unit process. The eight components are (1) excavation and sitework, (2) manufactured equipment, (3) concrete, (4) steel, (5) labor, (6) pipe and valves, (7) electrical and instrumentation, and (8) housing. These categories also provide enough detailed information to permit accurate cost updating.

The construction cost curves are not the final capital cost for the unit process because these curves do not include costs for general contractor overhead and profit, administration, engineering and legal fees, fiscal determinations, and interest during construction. These items are more directly related to the total cost of a project than to the cost of the individual unit processes. Therefore, if more than one unit process is required, they are more appropriately added after the costs of the individual unit processes are totaled.

Operation and Maintenance Cost Components

Operation and maintenance requirements were developed for building-related energy, process energy, maintenance material, and labor. The separate determination of building energy allows for regional variations. Energy requirements are presented in kilowatt-hours per year for electricity, standard cubic feet per year for natural gas, and gallons per year for diesel fuel. Labor is presented in hours per year, allowing local variations to be incorporated into the operation and maintenance cost calculations. Maintenance material cost, given in dollars per year, does not include the cost of chemicals. Chemical costs are added separately as shown in later examples.

In the original study, for the majority of the 99 unit processes, three separate

Table 1. *Definition of Five Basic Types of Estimates of Total Plant Cost*

Estimate Type (each has several designations)	*Characteristics*	*Purpose*	*Usual Reliability*
1. Order-of-magnitude ratio	*Rapid. Very rough.*	*Preliminary indication. Check on result by more detailed method.*	*About + 30% to -60%*
2. Study (commonly a so-called factor estimate)	*Flow diagram, material and energy balance, type and size of equipment.*	*For generalized evaluations. Guidance for further investigation. Basis for process selection. R&D guidance.*	*± 30%*
3. Preliminary budget authorization	*In addition to above, surveys and some engineering of foundations, transportation facilities, buildings, structures, lighting, etc.*	*Basis for decision to undertake detailed engineering. Sometimes basis for budget authorization. Can be for generalized evaluation, but usually for site specific installation.*	*± 20%*
4. Definitive project control	*More detailed engineering, but usually short of complete specifications and working drawings. Requires experienced estimating organization and substantial outlay.*	*Sometimes the basis for budget authorization. Provides improved estimate of project to be built. For site specific installations.*	*± 10%*
5. Detailed firm contractor's	*Complete site surveys, specifications, working drawings.*	*Made to control cost of project being built. For site specific installations.*	*± 5%*

graphs were used to present construction and operation and maintenance curves. The first graph presented the construction cost, the second graph presented energy (electrical, natural gas, and diesel fuel) and maintenance material requirements, and the third graph presented labor requirements and total operation and maintenance cost.

Updating Construction Cost Curves

For many engineering purposes, a single cost index such as the Engineering News Record (ENR) Construction Cost Index (CCI) can be used to update construction costs. When this approach provides sufficient accuracy, a single index is certainly the simplest and easiest approach. In the case of water treatment construction costs, especially those for carbon treatment, use of the CCI is not always recommended because the construction components used in its development are not related to those required for water treatment plants. For example, the CCI does not include process equipment or electrical equipment for instrumentation and control. For water treatment plants, the use of several other indices is often recommended, for example the Bureau of Labor Statistics (BLS) indices in conjunction with the ENR Building Cost Index and Skilled Labor Wage Index.

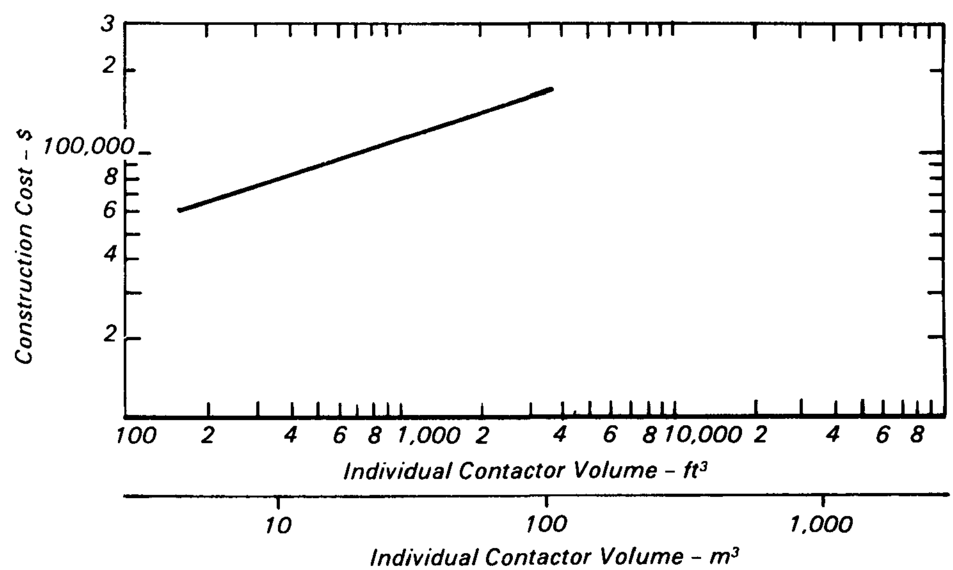

Figure 2. *Construction cost for pressure carbon contactors.*

Table 2 shows the indices recommended for application to each of the eight construction cost components representing the major items of material and labor affecting the cost of water treatment plant construction. This approach allows updating to be done proportional to changes in the cost of each component. These eight construction cost components represent the major items of material and labor affecting the cost of water treatment plant construction.

The principal disadvantages in using multiple indices are the lack of geograph-

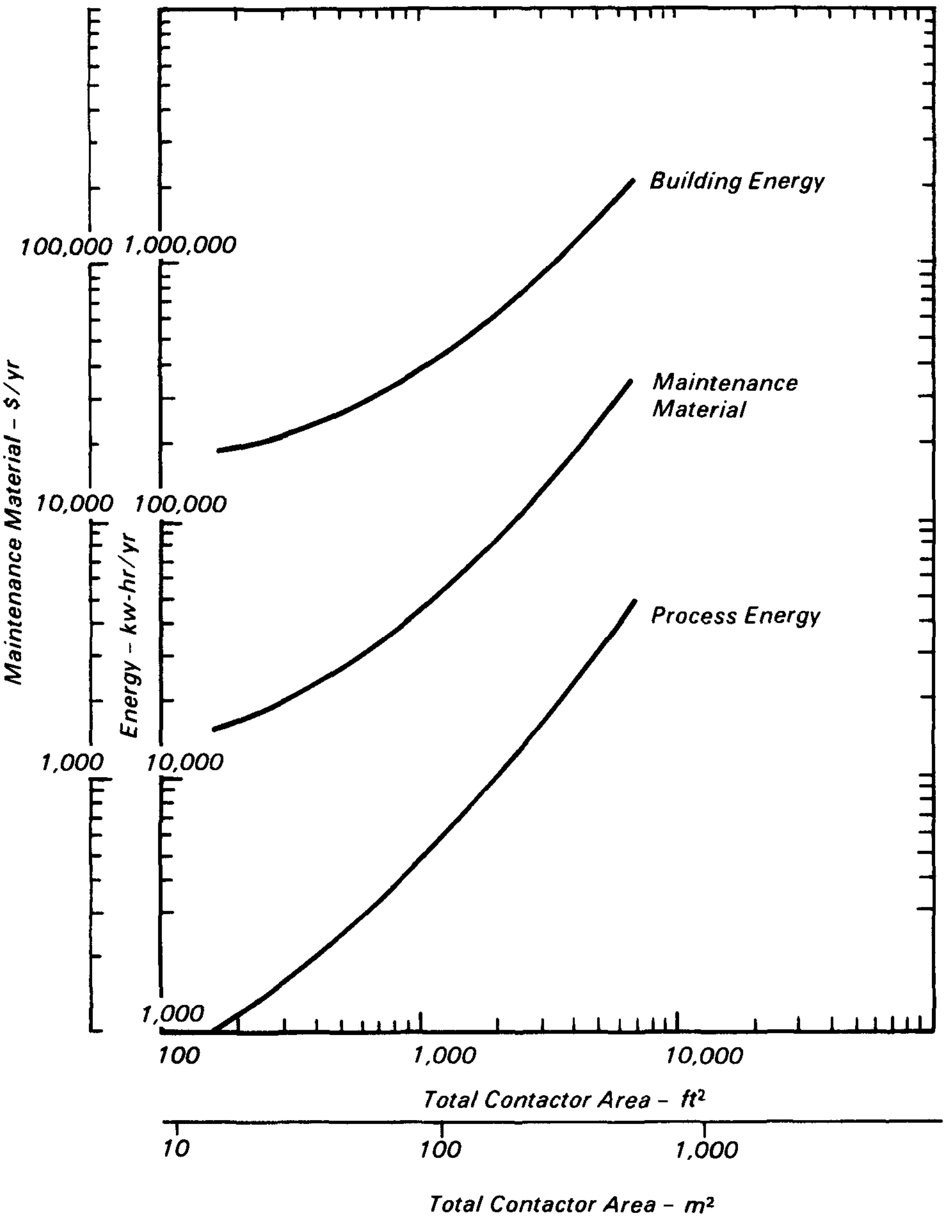

Figure 3. *Operation and maintenance requirements for pressure carbon contactors: building energy, maintenance material, and process energy.*

ical specificity of the BLS indices and the additional effort involved in using seven additional indices rather than a single index. The approach used to develop the cost data provides the user with a choice of updating procedures: (1) The individual cost indices can be applied to the components, and the component costs can then be added to obtain the unit process cost. (2) As an alternative, the total unit process cost can be updated in a single step by applying the ENR Construction Cost Index to the sum of the eight cost components.

Updating Operation and Maintenance Costs

Operation and maintenance costs are updated somewhat differently than are construction costs. To update energy and labor costs, the prevailing unit costs for energy and labor are used. Maintenance material costs that do not include chemicals are best updated with the use of the new Producer Price Index for Finished Goods.

Data Manipulation

In the original project, a computer program was developed to allow costs to be retrieved, updated, and analyzed. The computer program and data file that contain the construction costs and operation and maintenance requirements are presented in the full report.

A number of other factors can be varied in addition to the indices used for updating: (1) the operating parameter for the process, (2) sitework and interface piping cost, (3) special subsurface requirements, (4) standby power requirements, (5) general contractor's overhead and profit percentage, (6) engineering costs, (7) land cost, (8) legal, fiscal, and administrative costs, and (9) interest during construction and capital cost amortization.

The computer program, written in Fortran, was designed to operate on the PDP-11/70 computer system. Although a compact and efficiently written program, it still requires a relatively large amount of memory and must be compiled on a specific computer before it may be used.

To improve the usefulness of the cost data, a series of analytic equations were developed for each of the unit processes considered in the full report where the equation development is described.

Estimates of Construction and O&M Cost Components

Often in updating or checking cost estimates, it is useful to know the quantities of the individual components that makeup these estimates. In the following sections, a methodology is presented for providing these kinds of estimates.

Construction Cost Components

The report presents construction cost distribution factors based on the following components: excavation; manufactured equipment; concrete; steel; labor; pipe and valves; electrical and instrumentation; and housing. For example, the construction cost for Chlorine Feed-Cylinder Storage is as follows: 0% excavation, 50% manufactured equipment, 0% concrete, 0% steel, 6% labor, 4% pipes and valves, 6% electrical and instrumentation, and 34% housing. These factors are useful for updating

Table 2. Indices for Construction Costs

Cost Component	*Type of Index*	*October 1978 Value of Index*
Excavation and sitework	*ENR Wage Index (Skilled Labor)*	*247*
Manufactured equipment	*BLS General Purpose Machinery and Equipment - Code 114*	*221.3*
Concrete	*BLS Concrete Ingredients - Code 132*	*221.1*
Steel	*BLS Steel Mill Products - Code 1013*	*262.1*
Labor	*ENR Wage Index (Skilled Labor)*	*247*
Pipe and valves	*BLS Valves & Fittings - Code 114901*	*236.4*
Electrical equipment and instrumentation	*BLS Electrical Machinery and Equipment - Code 117*	*167.5*
Housing	*ENR Building Cost Index*	*254.76*

costs when various factors escalate at different rates. They can also be used to compare cost estimates from different sources.

Operating and Maintenance Components

Operating and maintenance components used in developing these cost curves are: process electricity in kilowatt hours per year; maintenance material in dollars per year; labor in hours per year; building energy in kilowatt hours per year; natural gas in standard cubic feet per year; and diesel fuel in gallons per year. Equations have been developed so that the amount of each component is estimated based on the magnitude of the process variable.

Computer Program

A computer program was written to provide the capability for easy cost calculation, and examples have been developed in the full report.

Summary and Conclusions

Cost estimating can serve a number of purposes. Predesign estimates can be used to compare the cost of two treatment plants with similar water treatment goals. These types of estimates can be used to choose the most cost effective treatment alternative. Cost estimating for research can be used to assist in making choices among new and developing technologies and to suggest specific areas for future research. Reliability of cost estimates is important to make proper judgments with regard to the type of basic cost estimate to be considered.

The full report presents a series of cost equations for conventional water treatment unit processes that are accurate to approximately three significant figures. The equations, within their level of accuracy, can be used for making engineering cost estimates.

*The EPA authors **Paul Dorsey** and **Robert M. Clark** (also the EPA Project Officer, see below) are with the Municipal Environmental Research Laboratory, Cincinnati, OH 45268.*

The complete report, entitled "Drinking Water Cost Equations," (Order No. PB 83-181 826; Cost. $16.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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