EFFECTIVENESS EVALUATION OF OPERATOR TRAINING CONDUCTED UNDER THE PSC PROGRAM

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The Environmental Protection Agency and Harbridge House wishes to acknowledge and thank the Texas Water Quality Board's Environmental Education Program, the Texas State Department of Health's Division of Sanitary Engineering, and the North Central Texas Council of Governments for their contributions and cooperation in making this publication possible.

This report addresses only one of the many training programs currently underway in the State of Texas. Recognition should be given to the cities of the State for their outstanding record of training in the field of water quality control. In conducting and evaluating operator training in the Public Service Careers Program, it was determined that Texas, due to its comprehensive training efforts, would provide an excellent basis for conducting this study.

Despite the generous assistance of the organizations mentioned, the findings, conclusions and recommendations presented in this report remain the responsibility of Harbridge House.

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by

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EPA REVIEW NOTICE

ABSTRACT

The relationship between wastewater treatment plant operator training and plant performance in Texas was studied using three different approaches:

(i) An analysis of the performance of a sample of plants involved in Operation Cleansweep, a Texas Water Quality Board (WQB) project to clean up the poorest performing plants in the state.

(ii) A survey of WQB field supervisors and their staffs to determine which plants had improved as a result of training and why that improvement had taken place.

(iii) A statistical correlation of operator training completed and level of plant performance for a sample of 124 plants.

Plant performance was found to be greatly influenced by training in all of these studies, and this influence was found to be powerful enough to cause some plants to change from a seriously noncompliant status to a fully compliant performance – substantially as a result of training.

Once the magnitude of the performance change was calculated, a monetary value for the change was estimated using the concept that the relative cleanliness of the plant effluent was a measure of plant productivity which could be converted into a "return" on capital invested in the facility. Accordingly, poor plant performance gave very low returns, and the improved performance due to operator training yielded very high returns estimated at $91 of incremental asset value for each dollar invested in training.

Other values derived in this study include a high investment in plant per operator, over $64,000, a figure approximately six times the average industrial investment per production worker.

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PART I
CONCLUSIONS

- Three independent investigatory tracks have produced complementary results which, when taken together, prove beyond reasonable doubt that the Public Service Careers Program type of training of municipal wastewater treatment plant operators improves skills and increases plant effectiveness. However, in specific cases the use of trained operators alone may be ineffective in promoting good plant performance. The availability of adequately trained personnel alone does not ensure effective operation; however, their unavailability ensures ineffective operation.

- Use of untrained or inadequately trained operators exposes the public to a loss of the benefits from a productive public asset, in effect decreasing the return on capital invested in treatment plants. While this loss is difficult or impossible to assess precisely, certain useful, if imperfect, estimates have been made.

  (i) Risk of capital dissipation is substantial if untrained or inadequately trained operators are utilized. Based on Texas data, a conservative estimate of average plant value entrusted to each operator is approximately $64,000. Because of understaffing, individual operators are actually entrusted with capital plant of up to $160,000.

  (ii) In 19 Texas plants where training during 1971 has been identified as the substantial cause of improved plant performance, it is estimated that almost $5 million in capital dissipation has been avoided through training. The cost of training in all of these plants, at maximum estimate, was $62,715. The estimated return on each dollar invested in training in these plants in terms of capital stop-loss is $91.

  (iii) Other substantial but unmeasurable returns from training in many of the other 1,000 or so Texas plants have undoubtedly occurred. Returns from these plants plus the 19 above may be contrasted with the $690,000 in federal investment in operator training in Texas between January 1969 and December 1971.

(iv) In 19 Texas plants, BOD/TSS performance has improved in a range of 112 percent to 334 percent as substantial result of the operator training.

- Training probably increases the cost of operations and routine maintenance which are funded out of local funds. Therefore, by itself, training may not be an appealing investment to local decision-makers. However, in Texas, and in other states which provide heavy fines for noncompliant plant operation, training which moves a plant to compliance will provide a substantial stop-loss return to a locality.

- Prior to the conduct of this study, the Harbridge House project team had anticipated that operator training did have a positive effect on plant performance. However, the measurable value of such training in terms of the return on investment in that training astounded us.

PART II
RECOMMENDATIONS

This study shows the salutary effect of operator training on treatment plant effectiveness in Texas. Further, with regard to a sample of 19 established Texas plants, it indicates an extremely high return on training investment in terms of halting dissipation of capital invested in plant and in other unmeasured ways. It also shows a high plant investment per operator and thus displays the substantial risk in entrusting plant to untrained or unlicensed operators. We see no reason why the Texas findings for established plants are not valid for the rest of the United States; the extent of the return on the training dollar may vary, but even a substantially smaller return than shown in Texas remains a very excellent investment. Therefore, we recommend that EPA proceed as rapidly as possible to develop and implement programs designed to ensure training and certification for plant operators.

Anticipated federal and state capital investment in new plants during the next five years is in the billions. We can speculate that the relationship of trained operators to plant effectiveness for new plants coming on line will be similar to that for established plants as determined in this study. However, this is speculation. We recommend that further research and analyses be undertaken to establish the effect of operator training on new plant effectiveness and the return on investment in training operators for these plants.

In anticipation of a finding from such research and analyses that operator training does have the result of preventing substantial capital dissipation in new plants, we recommend that EPA take the necessary legal and administrative steps necessary to be immediately ready to make operator training and certification a condition of plant construction grants. Rapid implementation action would be prudent in order to prevent wasting of federal capital investment.

EPA should note that a requirement for training will create a demand for training. The EPA current estimate for additional operators is 43,600 in the next five years. (This is in addition to upgrade training demands for existing operators necessary to protect the present investment in plant.) This additional demand to man the new plants underscores our previous recommendation that EPA press forward with programs designed to ensure training and certification for operators.

The report notes that available evidence suggests that routine plant operation and maintenance costs increase with the use of trained operators. Since these costs are born by the localities which are generally financially hard pressed, there is likely a disincentive for localities to encourage operator training. Some states, such as Texas, have a procedure for fining localities with plants not meeting specified performance requirements. Such a fine system provides an incentive for localities to see to operator training. We recommend that EPA encourage the states to adopt and/or enforce a fine system or some other mechanism which provides an incentive to localities to train and certify all operators.

PART III
INTRODUCTION

A. Purpose and Scope

This report presents the results of a study conducted for the Environmental Protection Agency (EPA) regarding the effectiveness and return on investment of wastewater treatment plant operator training – particularly that supported by federal funds through the Public Service Careers (PSC) and similar programs. Because of the similarity of operator training conducted under the sponsorship or influence of EPA in terms of work skills developed and substantive content, PSC program results can reasonably be imputed to other programs, and vice versa.

The effectiveness of wastewater treatment plant operator training programs in increasing the applied skills of their graduates – the first major area of investigation – can most appropriately be measured in terms of quality of plant output or effluent. This study examines the impact of training on plant performance in two ways: (i) the ability of training to improve plant performance by changing operator skills and behavior, and (ii) the influence of training in maintaining consistently high performance at already successful wastewater treatment plants.

On the basis of the conclusions drawn from this first analysis, the study proceeds to examine the return on the public investment in operator training. Although it is possible to total the monies spent on training, it is probably impossible to determine the definitive dollar return from operator training, and certainly it was impossible to do so within the resource limitations of this study. However, the public, through federal and state agencies, has made a substantial capital investment in the construction of wastewater treatment plants, and training may be viewed as an expenditure to ensure the proper utilization of these plants. These monies have been invested with the expectation that specified quantities of wastewater will be treated to specified levels of cleanliness. In this second investigation, training was therefore viewed in terms of its ability to prevent or substantially reduce faulty operations that might dissipate the public investment through delivery of an effluent of substandard quality or impairment of plant capability or productivity.

The conclusions and recommendations derived from these two investigations have been presented in Parts I and II, respectively, of this report. Section B of this part describes the various research activities that were conducted in support of these investigations. The results of the research and analysis are presented in detail in the remainder of this report, as follows:

- Part IV: The Impact of Operator Training on Wastewater Treatment Plant Performance

- Part V: The Return on the Public Investment in Wastewater Treatment Plant Operator Training

B. Research Methodology

Because a study of this nature required uniformity and compatibility of data, and because the scope of the study was necessarily limited, all of the work was performed within one state. The state of Texas was selected because it contains a particularly large number of treatment plants, has received considerable federal operator training funds, and is very advanced in its policies and procedures relating to water pollution control.

1. The Impact of Operator Training on Wastewater Treatment Plant Performance

The initial hypothesis for this portion of the study was that the relative effectiveness of training could be determined by an examination of "paired" plants that were similar in all design characteristics except that one of them was staffed by trained operators and the other staffed by untrained personnel. Upon initial investigation in Texas, this approach was rejected since it was impossible to establish pairs in which the training factor was the only independent variable affecting effluent quality. Other variables that precluded pairing included plant capacity, load, type of treatment, age and condition of the plant, and level of staffing (in comparison to design standards) – each of which tended to combine with the others in a unique way for each plant. Therefore, the approaches described below were developed and implemented.

a. **The Effectiveness of Training in Improving Performance.** Examination of the impact of training in improving performance was complicated by the lack of consistent data as the basis for a statistical sampling of plants across the state of Texas. No single source of information exists that presents training completed or level of operator certification achieved together with plant performance within Texas. Existing sources of information available from separate state agencies (described below) present time-series data for plant performance and cross-sectional data on operator certification and training as of the end of 1971. These data had to be manually looked up and cross-filed to get complete data on each plant to be studied.

Therefore, a survey of the results of operator training in all of the municipal treatment plants in Texas would have been impossible within the resources available for this study. Accordingly, an approach was sought to identify specific plants where training might well have had a specific effect and then to determine the details of that effect by "before" and "after" training analyses. The specific approach initiated was two pronged.

(1) **"Operation Cleansweep" Analysis.** First, 1971 and 1972 performance was analyzed for 16 plants whose performance had been so poor during the first quarter of 1971 that they had been summoned by the Texas Water Quality Board's (WQB's) "Operation Cleansweep" project to explain the reasons for their substandard performance and to devise possible solutions. The theory of this examination was that operator training might well have been instituted as a performance remedy in these plants.

(2) **WQB District Supervisors Survey.** To supplement this analysis, the 12 district Texas WQB supervisors were surveyed to obtain professional opinions as to which plants had benefited from operator training since 1970. Although the resulting sample of 51 plants does not necessarily include every plant in the state that benefited from training during the specified period and was not selected according to random statistical methods, it does permit an assessment of the types of plant performance and operator behavior improvements that may be realized through training.

b. **The Impact of Operator Training in Maintaining Consistently High Performance.** The effectiveness of training in maintaining consistently high performance was approached through computer analyses of relevant data on performance, certification, and training available through Texas state agencies.

Computerized data from the WQB's self-monitoring reports maintained on a monthly basis yielded plant performance data with respect to WQB-determined levels of capacity and treatment effectiveness. Training levels were derived from computerized information maintained by the Texas Department of Health which gave the name and certification level of each certified wastewater treatment plant operator, arrayed by town and certification level. Because maintenance of certification is contingent upon completion of a quota of training hours within a time period, certification was used as a surrogate for or indicator of the existence of training in this analysis.

Plants were selected from the WQB printout for which at least six months of performance data were available and which ranged in size between one and twenty million gallons per day (MGD) in design capacity. Then the number of certified operators at each level in the town in which each plant is located were counted and merged with the plant data to form a composite computerized data source relating plant performance data to operator certification levels. For the purposes of this study, it was necessary to assume that each operator listed was employed by the wastewater treatment plant in the town where he worked.

2. The Return on the Public Investment in Wastewater Treatment Plant Operator Training

An attempt was made to develop some quantitative insights into the dollar value of the benefits that can be derived from operator training. The scope of this study precluded estimation of the precise dollar value of such benefits. However, it was considered possible to develop numbers that would be useful to decision-makers considering the desirability of sponsoring and/or conducting additional operator training.

The value of training benefits was viewed from two points of view. First, the value of the capital assets entrusted to the care of individual operators in Texas was estimated on the basis of data obtained through the EPA STORET information system, the Texas Water Quality Board, and current literature. Second, the capital investment that is wasted when a treatment plant does not fulfill its BOD and TSS removal specifications was estimated on the basis of Texas WQB performance data on plants known to have experienced performance improvements following operator training.

Both of these approaches emphasize the value of operator training by comparing the relative value of training benefits to the estimated cost of training individual operators. In effect, training cost is viewed as the cost of insuring that capital investment will be used properly and effectively to produce the intended returns in terms of effluent quality.

3. Validity of Study Conclusions

This report is a first in its attempt to make a quantitative assessment of the effectiveness of wastewater treatment operator training and to determine the cost effectiveness of such training. Despite the limitations of the research data base, the conclusions appear very strong that training can have a key role in improving performance if properly utilized and in maintaining consistently high performance where good performance has been previously established. In addition, regardless of the measure of value that is used, the economic return from training in relation to its cost is enormous. It is expected that a broader scale investigation either within the state of Texas or throughout the country would only add further evidence in support of these conclusions.

PART IV
THE IMPACT OF OPERATOR TRAINING ON WASTEWATER TREATMENT PLANT PERFORMANCE

The response of an operator to formal training and the response of plant performance to a newly trained or updated operator tend to be unique to each combination of operator and plant. In this respect, it is difficult to develop a formula which will express across the board the impact that operator training may be expected to have on plant performance. Therefore, in this report, training was viewed from two perspectives:

- Ability to improve faulty performance.
- Ability to sustain high levels of performance.

In some cases, training can be identified as the only factor influencing performance, while in others it acts in combination with other stimuli (such as WQB pressure or new plant construction).

A. The Impact of Training in Improving Wastewater Treatment Plant Performance

In an effort to gain an impression of the impact training might have on performance, an examination of the Water Quality Board's "Operation Cleansweep" and a survey of 12 WQB district supervisors were conducted.

1. Operation Cleansweep

a. **Overview.** Operation Cleansweep is the WQB's on-going project to upgrade the performance of Texas plants not complying with Texas' standards of operation. The Board holds monthly hearings on water quality problems and in the first three months of 1971 brought 16 plants to testify as to the nature of their performance problems and any corrective action that was either planned or under way. These 16 plants all were drawn from five of the 12 WQB districts in Texas; these five districts have a total population of approximately 720 discharging plants, as revealed on the self-monitoring reports filed monthly with the WQB.

We have traced the histories of these plants subsequent to the hearings to determine to what extent training may have had an influence in performance improvement, where such improvement occurred, and to estimate the nature of the training benefits. The problems which brought the plants there and the suggested remedial actions were identified from the minutes of the hearings; the subsequent history of each of the plants has been gained through interviews with the surveillance staff in charge of these investigations and the performance monitoring system of the Water Quality Board.

The 16 case histories developed during this investigation are presented in subsection b, and the findings that emerged from the Operation Cleansweep study are summarized in subsection c.

b. Operation Cleansweep Case Histories

- *Case 1*

Town 1 had two severely overloaded plants and was summoned before the WQB twice in the first quarter of 1971. One part-time uncertified operator was in charge of both plants under the supervision of a licensed municipal utilities director. Just prior to the hearing, a WQB inspector had found in both plants poor effluent quality, poor maintenance and operating practices, mechanical reliability problems, high infiltration of the collection system unnecessarily loading the plant, a high frequency of bypassing and sewer overflows, and a failure to submit self-monitoring reports and to report overflow incidents as required.

At the time of the hearing, the town officials agreed to explore the possibility of joining a large river basin authority as a means of taking some of the load off its two small plants.

Since the hearing this town has become self reporting and has managed to get the river basin authority to take a small part of the load from one plant and consider its application for membership, but the two small plants are still overloaded. There was some improvement in effluent quality in the balance of 1971, largely as a result of the prodding and close supervision of WQB officers, but performance was still below specification. Training has not been a factor in this situation to date.

- *Case 2*

The plant in Town 2 also lacked a certified operator and had a high rate of infiltration and mechanical reliability problems when called before the Board. Subsequently, the hiring of two properly trained and licensed operators, the installation of lab equipment, and the enforcement of the town's industrial waste ordinance (resulting in the closing of the major offending industrial facility) have all contributed to dramatic improvement in the plant's performance in 1971. The plant is now compliant with WQB specifications. There is no way to distinguish the influence of training from that of better enforcement of the waste ordinance in this case, but WQB officials have commented that without the trained personnel in place, the necessary lab work and enforcement activities could not have been carried out.

- *Case 3*

This city's small plant was severely overloaded, and the results of the WQB hearing indicated that the plant should both augment and upgrade its facility. The town has not voted the necessary financing for these changes, but the operators at the plant have managed some improvement in effluent quality. The potential for training impact after addition of new facilities is strong.

- *Case 4*

This plant was determined to have poor quality effluent and needed to augment its facilities to remedy an overloaded condition. Despite this problem, censure by the WQB, and a change in management, in early 1971 a bond issue for construction failed to pass. During the rest of 1971, the plant managed to maintain an essentially constant biological oxygen demand (BOD) and total suspended solids (TSS) output despite increasing overloading. The potential for training impact after addition of new facilities is strong.

- *Case 5*

This small plant was consistently operating in noncompliance with its permitted BOD and TSS levels. After being called before the WQB, it hired a consulting engineering firm in April, and in October dramatic performance improvement brought both BOD and TSS performance to compliance levels. Training did not appear to affect this situation directly.

- *Case 6*

In the hearing before the Water Quality Board, this plant's poor performance was attributed to defective mechanical procedures and faulty or inadequate equipment. Following the WQB citation, a new board of directors was appointed that committed itself to resolving the plant's performance problems. Subsequently the mechanical operations improved, with an attendant improvement in effluent quality, and the board of directors applied for a construction grant to enlarge the facility. Although training was not applied directly in the resolution of this plant's problems, the deficiencies noted by the WQB in its citation – requiring improvements in mechanical processes and equipment – are the types of improvements that might have been initiated automatically by a properly trained operator. The potential for training impact after addition of new facilities is strong.

- *Case 7*

This plant was not chlorinating its effluent sufficiently, but in other respects its performance was satisfactory on BOD and slightly high on TSS. An increase in chlorination in April 1971 cured the problem. Performance on both BOD and TSS improved steadily through 1971, largely as a result of operator training, particularly for the lead operator in this plant.

- *Case 8*

Like Case 7, this plant was not sufficiently chlorinating its effluent. At the end of August 1971, however, heavier chlorination began, and that problem has been resolved. BOD performance was not a serious problem at this plant, but suspended solids performance was noncompliant. During the year, operators of this large plant received increased training and managed a noticeable improvement in TSS measures, although they are not yet in compliance; some plant renovations are required before full compliance can be achieved.

- *Case 9*

This plant was not overloaded in 1971 (except for a one-month seasonal peak), and its performance is well within the compliance range. However, it was brought before the Board because of a serious and worsening problem with suspended solids removal. Because the problem is caused by industrial waste, the city has been told to pass and enforce an industrial waste ordinance. It is expected that this measure will cure the problem and that training is not a factor in this case.

- *Case 10*

This plant was and still remains seriously noncompliant on BOD and TSS, and it began self-reporting only late in 1971. At the time that

EXHIBIT I
SUMMARY OF OPERATION CLEANSWEEP CASE ANALYSIS

Case	Problem	Solution Selection	Apparent Influence of Training	Potential Influence of Training
1	Overloading, others	Offload	None	None
2	Poor operation	Hiring of trained operators	Strong	N/A
3	Overloading	Augment facilities	None	Strong
4	Overloading	Augment facilities	None	Strong
5	Poor operation	Consulting engr.	None	None
6	Inadequate equipment	Augment facilities	None	Strong
7	Low chlorine, non-compliant TSS	Chlorination and training	Moderate	N/A
8	Low chlorine, non-compliant TSS	Chlorination and training	Moderate	N/A
9	Heavy industrial waste load	Industrial waste ordinance	None	None
10	Poor operation	Training	None	Strong
11	Poor operation	Hiring of trained operators	Strong	N/A
12	Deteriorated plant	New plant	None	Strong
13	Overloading	Regional affiliation	None	None
14	Overloading, infiltration	Consulting engr.	None	None
15	Poor operation	None taken	None	Strong
16	Poor operation	Chlorination	None	None

supervisors of the WQB. These men have surveillance responsibility for monitoring plant performance and supervising or enforcing the solution of individual pollution control problems. Typically they are professional engineers and have engineers, former senior wastewater treatment plant operators, and biological scientists on their staffs. They report to one statewide authority, but they and their staffs have a close and professional view of plant operations at the local level.

The initial contact for this survey was made by memo from WQB headquarters, followed by a telephone contact seeking specific information on a case-by-case basis. Generally the WQB supervisors gave us their impressions of plants which had benefited from training without referring to specific data on personnel in their districts who had been recently trained. Some supervisors from the larger districts assembled notes summarizing the collective impressions of their subordinates; others provided direct answers based upon their own knowledge, and still others, while voicing strong support for training as beneficial in many ways, did not describe specific case examples from their districts. Where the number of cases described appeared to be large and the supervisor wished to submit a return memo in lieu of a telephone contact, this was accepted. In addition, actual visits were made to two district supervisors with particularly interesting or long answers.

The cases emerging from this survey reveal both the unique situations and the common patterns which exist in plant response to training. Each case is described in subsection b, and a summary analysis and relevant conclusions are presented in subsection c.

b. Cases of Training Benefits Cited by WQB District Supervisors

- *Case 1*

Plant 1 is a new plant which was off to a bad start with an operator who did not understand how to run it. Following training, however, and some assistance from a consulting engineer, the operator's attitude and interest dramatically improved. Since the plant was new, effluent quality had not been low but would have degraded over time if the initial operator attitudes and knowledge had not been improved.

- *Case 2*

The performance of this plant was dramatically improved as a result of a combination of operator training and support from water quality inspectors who have assisted the town in gaining control over the industrial waste from a food processing plant. As a result of training, the operator was sensitized to the problem and was able to work with the surveillance agency to collect the data necessary to effectively enforce its industrial wastewater ordinance.

- *Case 3*

As a result of training, the operator of this older plant has given it a face-lifting and now practices greatly improved maintenance procedures. Unfortunately, because of the plant's age, its performance has not been improved.

- *Case 4*

As a result of his training, the operator in Case 4 realized that his plant was not physically capable of making its target. Nevertheless, in order to get the best possible performance out of his facility, the operator overhauled the plant and has managed to arrest the performance degradation that had been taking place. In addition, in order to avoid loading up the receiving waters with inordinately high BOD and TSS loads, he has developed a revenue-producing irrigation use for part of the plant effluent. Realizing also that a new plant was the only long-term satisfactory solution, this operator has spoken at meetings and has taken other actions to help the town to get a bond issue passed for a new plant.

- *Case 5*

As a result of training, this operator's attitude and "housekeeping" practices have greatly improved. Because the plant is a no-discharge plant – that is, the effluent, if any, does not enter public waters – the performance could not be assessed.

- *Case 6*

Operating difficulties and neighborhood complaints of foul odors have been eliminated by the operator in Case 6 since he completed training. Prior to the training, the operator was shutting down aeration blowers at night to save money – thus rendering the treatment process anaerobic. Blowers now run full time. Actual plant performance could not be assessed because the plant is a no-discharge installation.

- *Case 7*

Following training, this operator has acquired a new laboratory for his plant, beautified its grounds, become concerned over compliancy, and joined the required statewide self-monitoring program, in addition to improving effluent quality. Prior to training, the plant operator had not been submitting reports and, in fact, had been discharging effluent into the *wrong* stream (of two that ran close to the grounds), in violation of the plant's waste control order (WCO).

- *Case 8*

As a result of training, the operator in this plant set up his own laboratory. The training has created more interest in and understanding of plant operations. Although the flow figures indicate that the plant is operating at or slightly above its WCO specification, BOD performance has dramatically improved (although somewhat at the expense of TSS performance).

- *Case 9*

Training has given this plant a certified operator and has enabled him, with the support of some plant redesign, to greatly improve BOD and TSS performance. Although the redesign of the plant was accomplished professionally, the operator himself supervised the rebuilding operations.

- *Case 10*

Training provided this plant with a certified operator who set up a new lab for his plant. Due to the seasonal loads on this plant and occasional failures to report performance, it is not possible to detect a change in performance.

- *Case 11*

This municipality has instituted a policy of having all of its operators trained to at least the lowest certification level. As a result of the new policy and the resultant efforts to train all operators, strong improvement in BOD performance has been noted and the plant is now fully compliant on both BOD and TSS.

- *Case 12*

Training provided this plant with a certified operator who has improved both BOD performance and plant appearance. He has also assumed the responsibility for his own lab work.

- *Case 13*

Training provided for the certification of an operator at this plant. With his new knowledge, the operator has been able to dramatically improve his BOD performance and make some improvement in his TSS performance.

- *Case 14*

Since this operator returned from training, he has exhibited greater enthusiasm for his job and plant performance has improved on both BOD and TSS.

- *Case 15*

This plant has a laboratory which was unused prior to operator's attending a training program. Following the program, he is now performing his own lab work. Although plant performance was satisfactory at the outset, further improvement in plant performance has been noted.

- *Case 16*

Training has helped the supervisor of this plant move up to a B certificate and has influenced him to plan for the establishment of a plant laboratory. Although TSS performance has continually been satisfactory, BOD levels are now compliant, and performance on both measures has been improving steadily since the completion of training.

- *Case 17*

The operator of this plant has made a notable improvement in his knowledge as well as in plant performance. BOD levels, which were originally satisfactory, are now well within required levels, and TSS has been brought from a substandard level to well within the compliance range.

- *Case 18*

Training upgraded the license of one operator at this plant, as well as providing him with an opportunity to improve his reading and writing abilities, which were originally marginal. In addition, plant maintenance has been improved. Performance change could not be assessed because the plant is a no-discharge facility.

- *Case 19*

Training provided this plant with one upgraded operator and six newly certified operators. Although plant performance has been consistently compliant, the training has given the operators the skills to improve maintenance.

- *Case 20*

Training programs have allowed seven operators to upgrade their licenses and two more to become certified. Although the supervisor of the plant claims to see no performance improvement, the WQB self-monitoring report shows an improving but still-noncompliant effluent.

- *Case 21*

Through training, this large plant managed to upgrade 19 operators in pay and status. Unfortunately, because the plant is a no-discharge installation, differences in performance could not be observed, but better housekeeping and maintenance around the plant have been noted.

- *Case 22*

The plant also upgraded its operator through training, and an improvement in maintenance and housekeeping has been noticed. Performance improvement could not be assessed, however, because this plant is a no-discharge facility.

- *Case 23*

Maintenance and housekeeping at this no-discharge plant improved as a result of training. No performance change could be measured.

- *Case 24*

This plant has a certified C operator who takes every chance to go to the courses offered, attend meetings of local operators, and assist neighboring operators, despite the fact that he has town duties in addition to wastewater treatment plant operation. The performance of this plant is remarkable in the low BOD levels it has achieved, and the operator managed a significant improvement in TSS performance during 1971.

- *Case 25*

By hiring two trained and licensed operators and enforcing its industrial wastewater ordinance, this plant managed a sufficient improvement in both BOD and TSS performance to progress from noncompliant to compliant status. (This case is a sample plant as Case 2 of the Operation Cleansweep Survey.)

- *Case 26*

Through training, the operator of this plant gained certification. This man achieved compliant operations early in 1971 and continued to improve BOD performance throughout the year.

- *Case 27*

This town abandoned its old plant and hired a new full-time certified operator to replace the three garbage collectors who had been tending the old plant on a part-time basis. The new trained and certified operator has been able to improve his performance consistently, bringing BOD and TSS effluent levels down to exceedingly low levels.

- *Case 28*

In the two years before being called before the Water Quality Board, this plant had not had a certified operator and had been experiencing BOD levels in excess of 170, with TSS at 66 in early 1969. At this time, sludge banks were observed regularly in the stream into which the plant effluent was discharged. The hiring of a different but still unlicensed operator in 1970 improved operations somewhat, but performance still fluctuated and sludge beds were cleaned inconsistently.

The present operator was unlicensed when hired but had a letter in training – the equivalent of a license prior to completion of sufficient experience to qualify for certification. Following several months of work, he attended a technical operations and maintenance training school for six weeks. Following training, plant operations improved from noncompliant to well within compliance levels on BOD, although TSS is still noncompliant.

- *Case 29*

Through training of its operators, this plant, although overloaded, has managed to achieve compliant BOD and TSS performance most of the time. It does, however, have some equipment design problems which cause excessive bypassing to occur.

- *Case 30*

As a result of training, this operator converted his plant from a discharging to a no-discharge installation by adding a pond to catch the effluent – thereby avoiding discharging the effluent into public waters.

- *Case 31*

Training of one of the two operators in this facility has improved BOD performance from noncompliant to compliant. TSS performance has no compliance specification and does not appear to have changed in the period during which BOD performance has improved.

- *Case 32*

This older plant achieved compliant performance as a result of operator training (although the operator has not yet qualified for certification). Following his training, the operator greatly improved BOD performance, which had been noncompliant. He also made some improvements in TSS, which had already been satisfactory as a result of a generous limit in the plant's permit. A big improvement in housekeeping has been noticed.

- *Case 33*

An older licensed operator in this plant was replaced by a newly trained and licensed man who cleaned up the plant and equipment thoroughly and improved BOD performance from noncompliant to compliant. Data on TSS performance were not available.

- *Case 34*

As a result of training, this plant's operators – previously uncértified – are now licensed. Plant performance has steadily improved on BOD to within compliance levels and remained steady on TSS, which is still slightly substandard.

- *Case 35*

As a result of training, the operator of this plant received certification and demonstrated an improved attitude and motivation toward his work. Following training, he improved the appearance and general maintenance of the plant. Because the plant is a no-discharge facility, specific performance figures are not available.

- *Case 36*

In this large plant, previously uncertified operators gained certification, and certified operators upgraded their licenses as a result of training. Improved general maintenance has been observed, and the plant's performance on both BOD and TSS has changed from noncompliant to well within compliance limits.

- *Case 37*

Training in this case enabled an operator to gain certification, and he has exhibited increased interest and motivation. No performance information on this plant was available because it is not self reporting.

- *Case 38*

The acquisition of certification by the operator of this plant after training has led him to show improved motivation and interest in his work. Since completing training, he has improved or renovated parts of the plant, and BOD (already compliant) and TSS performance appear to have improved somewhat, although the WQB has not yet specified a TSS compliance standard for the plant.

- *Case 39*

This plant's operator achieved certification and exhibited improved motivation after receiving training. He improved general maintenance around the plant and has brought BOD performance into compliance. TSS performance has improved but still remains noncompliant.

- *Case 40*

This plant's operator, as a result of training, upgraded his license and has been exhibiting stronger motivation and higher morale. In addition, the plant performance has improved on both BOD and TSS, although the plant is still noncompliant on both measures.

- *Case 41*

This plant has had its operator certified through training. In addition to showing increased motivation, he has improved maintenance and has raised BOD performance from noncompliant to compliant – somewhat at the expense of TSS performance (for which WQB had not specified a target).

- *Case 42*

At this plant, new operators gained certification and at least one operator upgraded his license. Both motivation and BOD performance have improved, although BOD performance was originally compliant. TSS performance is somewhat noncompliant and has remained virtually unchanged.

- *Case 43*

The operator of this no-discharge plant received a new operator certification and displayed improved attitude and morale following training. Performance improvement could not be determined, because of the no-discharge nature of the plant.

- *Case 44*

Training provided both new and upgraded operator certificates for the operators at this plant. Aided by new treatment facilities, these operators have maintained consistently a very high quality effluent on both BOD and TSS.

- *Case 45*

Training allowed the operator of this plant to upgrade his certificate. As a result, he displayed notably higher morale and motivation and made improvements in plant maintenance. He improved BOD performance from noncompliant to compliant; TSS performance had no specification but appeared to be getting slightly worse.

- *Case 46*

An upgraded operator certificate and improved maintenance and attitude were the benefits of training for this plant. Effluent quality had been satisfactory and remained consistently good.

- *Case 47*

Upgrading of an operator certificate and the certification of a new operator were achieved as a result of training. Attitudes improved and BOD performance, which had been somewhat erratic, settled down to a position well within the compliance range. TSS performance has remained compliant.

- *Case 48*

Following training, this plant's operator became newly certified and exhibited an improved attitude toward his work. He renovated parts of the plant and generally improved maintenance. Erratic BOD and noncompliant TSS performance settled down to values well within compliance ranges.

- *Case 49*

This plant's operators became newly certified and motivation improved as a result of training. Maintenance procedures improved, and plant renovation was undertaken. BOD performance, which was borderline compliant, improved to well within compliance tolerances. TSS performance was not specified in the permit and did not change significantly.

- *Case 50*

The operator of this plant – who had already been effective prior to his recent training – has begun to do his own lab work. Performance figures show some recent degradation in both BOD and TSS, but it could not be determined whether this was an actual decline in performance or the result of operator inexperience with lab procedures.

- *Case 51*

This plant hired a properly trained and certified operator who made strong progress in cleaning up the effluents – making it compliant on TSS. The plant was originally compliant on BOD but has further improved its performance on this measure. (This case is the same as Case No. 11 in the Operation Cleansweep Survey.)

c. **Findings from the District Supervisors Survey.** Among the 51 cases cited by the district supervisors as demonstrating performance improvement through training, a number of common patterns were observed. These are categorized in Exhibit 2.

In nearly all of the cases – 48 of 51 – training served to boost operator morale, attitude, or motivation for his job. Such changes are rated as "General Improvement" in Exhibit 2.

Attitude changes alone have yielded significant benefits. As one town manager put it, "I can get honest and informed answers from operators who are more sure of themselves. They can tell me their problems, and they can work more effectively with the consulting engineers when they need to be called in to solve plant expansion or design problems. Without the knowledge gained from operator training, these men are embarrassed and defensive about their operation of the plant and consequently much harder to understand and work with."

A second aspect of the better attitude is a generally cleaner plant. One of the most frequent comments heard was that the operator, or supervisor, upon his return from school, had policed the grounds and brightened up the plant through washing, painting, and renovating the buildings and other facilities.

In the "Other Improvement" category on Exhibit 2, at least seven plants had decided to carry on their own lab work as a result of operator attendance at a lab school. This is the only area of substantial operating cost reduction resulting from training that was observed during the study. It was reported by a number of WQB representatives and plant operators that lab work, when performed by an outside source, costs, on an average, about $600 per year on a contract basis. If the trained operator performing his own laboratory work spends as much as $100 per year on supplies and equipment, he will be saving most of this contract amount – a sum representing a substantial and ongoing return on investment in his laboratory training.

Two plants which appeared in the "Other Improvement" category have managed to employ some innovative tactics to benefit their operations. One was converted to a no-discharge plant by the addition of a pond, and the other found a market in irrigation for its

EXHIBIT 2
SUMMARY OF WQB SUPERVISOR SURVEY CASE ANALYSIS

Case	Became Compliant	Improved Effluent Quality	General Improvement	Other Improvement	Comment
1	–		X	–	
2	–	X	X	–	
3	–		X	–	
4	–	X	X	X	Developed irrigation market source for effluent
5	–	*	X	–	
6	–	*	X	–	
7	–	X	X	X	Independent lab capability
8	X	X	X	X	
9	–	X	X	–	
10	–	**	X	X	Independent lab capability
11	X	X	X	–	
12	X	X	X	X	Independent lab capability
13	–	X	X	–	
14	–	X	X	–	
15	–	X	–	X	Independent lab capability
16	X	X	X	X	Independent lab capability
17	X		X	–	
18	–	*	X	–	
19	–		X	–	
20	–	X	X	–	
21	–		X	–	
22	–	*	X	–	
23	–	*	X	–	
24	–	X	X	–	
25	X	X	X	–	

*No-discharge facility.
**Self-reporting data not complete.

EXHIBIT 2 (Cont'd)

Case	Became Compliant	Improved Effluent Quality	General Improvement	Other Improvement	Comment
26	X	X	X	–	
27	–	X	X	–	
28	X	X	–	–	
29	X	X	X	–	
30	–	*	–	X	Conversion to no-discharge facility
31	X	X	X	–	
32	X	X	X	–	
33	X	X	X	–	
34	–	X	X	–	
35	–	*	X	–	
36	X	X	X	–	
37	–	**	X	–	
38	–	X	X	–	
39	X	X	X	–	
40	–	X	X	–	
41	X	X	X	–	
42	–	X	X	–	
43	–	*	X	–	
44	–		X	–	
45	X	X	X	–	
46	–		X	–	
47	X	X	X	–	
48	X	X	X	–	
49	X	X	X	–	
50	–		X	X	Independent lab capability
51	X	X	X	–	

*No-discharge facility.
**Self-reporting data not complete.

effluent. These approaches benefit the public because the effluent no longer enters public waters, but they do not directly indicate plant performance improvement as a result of training.

Of the 51 plants mentioned by the WQB district supervisors as having experienced training benefits, 10 were either no-discharge facilities or reported inadequate effluent data during 1971 to permit quantitative performance assessment. Of the remaining 41 plants, 33 experienced marked improvement in effluent quality; 17 of the plants whose effluent improved also became compliant on both BOD and TSS following operator training, as indicated on Exhibit 2. (Two of the plants that improved effluent quality and became compliant had been called before the WQB as part of Operation Cleansweep in the first three months of 1971.)

Summarizing these results, of 51 plants which were identified as having benefited noticeably from training:

(i) Two cited for noncompliance by Operation Cleansweep in early 1971 became compliant; 15 more not cited by the WQB improved their operations from noncompliant to compliant. A total of 33.3 percent of the sample became compliant on both BOD and TSS following training.

(ii) Thirty-three (64.7 percent of the sample), including all 17 in (i) above, experienced improvement in effluent quality.

(iii) A total of 48 plants – 94.1 percent – experienced "General Improvements" of noticeable proportions.

(iv) Nine plants – eight of which experienced at least one of the above benefits – experienced "Other Improvements" (including two that modified their plants to prevent them from discharging effluent into public streams).

(In this summary, the total benefits listed exceed 51 in number because of multiple effects experienced by individual plants.)

B. The Impact of Training in Sustaining High Wastewater Treatment Plant Performance

The influence of training as a factor in sustaining high levels of treatment plant performance was explored through a computer correlation analysis for 124 wastewater treatment plants between levels of performance of various factors representing number of operators employed and number of trained and certified operators who exercised a direct influence over the operations of each plant.

1. Correlation Data Base

Three types of data were acquired for correlation in this analysis:

- Plant performance.
- Operator staffing.
- Operator training (certification).

The Texas WQB maintains a "self-monitoring" system to which every plant licensed by the state that discharges effluent into a public stream or waterway must report monthly. These reports contain information on many items of plant performance, including maximum and average flow experienced by the plant; bypassing activity, if any; the percent of effluent discharged to public waters; and the maximum and average BOD and suspended solids in the effluent in parts per million. The report from each plant is fed into a WQB computer which produces printouts of plant performance data over a running 12-month period for all plants, both municipal and industrial. (This investigation concerned itself only with municipal plants.) A typical entry for one plant in the WQB is shown in Exhibit 3.

As a basis for selecting a sample for the correlation analysis, four criteria were established:

(i) Size between 1.0 and 20 million gallons per day design capacity.

(ii) Accurate performance data available for at least six months of 1971.

(iii) Operator staffing information independently available (see below).

EXHIBIT 3
TYPICAL PLANT ENTRY IN WQB SELF-MONITORING COMPUTER REPORTS

REPORT DATE	DAYS DISC	DAYS BYPASS	VOL-MAX BYPASSED	FLOW-MAX MG/DAY	FLOW-AVE MG/DAY	VOL RELEASED	BOD MAX	BOD MOAVE	TSS MAX	TSS MOAVE	CHL-RES MIN	CHL-RES MOAVE	STA MIN	STA MOAVE	S-SOL MAX	S-SOL MOAVE	SPEC PROV
GALENA PARK CITY OF					10831-01		PLANT NO 1										
01-71	31	00		.400	.330	100	9	9	18	15	2.0	2.0	50*	60*	*	*	NA
02-71	28	00		.600	.340	100	8	8	14	11	2.0	2.0	37	53			NA
03-71	31	00		.500	.350	100	7	6	9	7	2.0	2.0	37*	58*	*	*	NA
04-71	30	00		.350	.300	100	29	23*	41*	30*	2.0	2.0	37*	50*	*	*	NA
05-71	31	00		.440	.300	100	26	21*	38*	27*	2.0	2.0	37*	40*	*	*	NA
06-71	30	00		.360	.280	100	13	8	21	15	2.0	2.0	21*	37*	*	*	NA
07-71	31	00		.340	.250	100	6	6	6	4	2.0	2.0	21*	40*	*	*	NA
08-71	31	00		.310	.225	100	14	10	6	5	2.0	1.4	21*	40*	4*	3*	NA
09-71	30	00		.400	.250	100	8	5	7	6	1.0	2.0	50*	55*	*	*	NA
10-71	31	00		.300	.250	100	4	4	11	8	2.0	2.0	60*	65*	*	*	NA
11-71	30	00		.500	.250	100	8	8	10	7	2.0	2.0	50*	65*	*	*	NA
12-71	31	00		.320	.250	100	2	2	7	6	1.0	2.0	50*	65*	*	*	NA
REQUIREMENTS					.700		30	20	30	20	1.0	1.0	95	95	2	2	

(iv) Operator training (certification) data independently available (see below).

A total of 124 plants out of a state population of over 1,200 discharging facilities fulfilled these four requirements.

Operator staffing information – the number of operators employed full or part-time – was taken from manpower surveys performed for the Environmental Protection Agency and Department of Labor in 1971, and certification data were taken from the Texas Department of Public Health records. Certification data were used, in this study, as a surrogate or indicator of operator training because of the direct connection between the two under Texas licensing regulations and the lack of readily usable data on training itself.

In Texas, operators are certified at four different levels, as shown in Exhibit 4. The B, C, and D operators, to maintain their certificates, have to have achieved the directly related training shown under "Renewal Provisions" in Exhibit 4. Thus, a D operator has to have an average of five hours per year training; a C, 6 2/3 hours; and a B, 10 hours simply to maintain their status. Furthermore, the training that is accepted for credit under this plan is approved by a professional committee within the state which insists that the training be directly related to job responsibilities, not just generally applicable. The operators who have currently valid certificates can therefore be considered to be trained – and in fact recently trained – operators. Those who do not possess certificates, of course, may be partially trained, and those who do have them may be trained above the minimum levels – in effect on their way to a higher level. Therefore, although the existence of a certificate is not a precise measure of the level of training, it is, we feel, a reliable indicator of the existence of training.

2. Computer Correlation Analysis

The computer correlation study, based upon the inputs above, revealed that both staffing and training did influence plant operations and that it influenced some types of plants more than others. Heavily loaded plants were apparently affected more than lightly loaded ones, and activated sludge plants more than biological filter plants.

The first step in the analysis was the calculation of a correlation matrix to determine which parameters of performance, staffing, and training seemed to be related. In the matrix, a series of correlation

EXHIBIT 4
OPERATOR CERTIFICATION REQUIREMENTS IN TEXAS

Class	Requirements								Renewal Provision
A	Education	Masters Degree		Bachelor Degree		2-year College		HS or GED	
	Experience	4 yrs.	or	5 yrs.	or	6 yrs.	or	8 yrs.	NONE
	Training	160 hr.		160 hr.		160 hr.		160 hr.	
B	Education	Bachelor Degree		HS/GED					
	Experience	1 yr.	or	3 yrs					50 hours in 5 years
	Training	60 hr.		100 hr.					
C	Education	1-year College		HS/GED		HS/GED		HS/GED	
	Experience	2 yrs.	or	3 yrs.	or	2 yrs.	or	1 yr.	20 hours in 3 years
	Training	0		0		20 hr.		40 hr.	
D	Education	HS/GED		Less than HS/GED		Less than HS/GED			
	Experience	0	or	1 yr.	or	0			10 hours in 2 years
	Training	10 hr.		0		20 hr.			

Source: Texas State Department of Health, Division of Sanitary Engineering, *Rules and Regulations Covering the Certification of Water Utilities Personnel,* adopted by the Texas State Board of Health, September 12, 1966, revised June 8, 1969, and December 12, 1971.

coefficients was calculated which indicated the apparent relationship existing between pairs of parameters. If a nearly perfect linear correspondence existed, the coefficient approached + 1.0000; if very little relationship existed, the coefficient approached 0.0000. For purposes of this analysis, we have assumed that strong correlations exist where the coefficient is 0.7 or more, that weak to moderate relationships are represented by coefficients between 0.4 and 0.7, and that no meaningful relationships exist if coefficients are below 0.4. A positive coefficient indicates that the variables are moving in the same direction and a negative one that the variables are moving inversely to one another.

The parameters of performance, staffing, and training used in the analysis include the following:

PER 1 – BOD performance; the inverse ratio of BOD achieved to BOD permitted, resulting in a higher number as performance improves.

PER 2 – TSS performance, calculated like PER 1.

LOADING – Plant load; the average flow divided by the WCO-permitted flow, resulting in a fully loaded plant exhibiting 1.0, overloaded plants more than 1.0, and underloaded plants less than 1.0.

OPL – Operator staff; the number of operators (whether or not certified) per plant.

INT – Staffing intensity; the number of operators (whether or not certified) divided by the average flow.

T_1, T_2, T_3, T_4 – Certified operators; the number of operators per plant at the D, C, B, and A levels, respectively.

T_{1A}, T_{2A}, T_{3A}, T_{4A} – Certified operator intensity; the number of operators certified at each level divided by the *permitted* flow.

T_{1B}, T_{2B}, T_{3B}, T_{4B} – Certified operator intensity, calculated as above but divided by the *average* flow.

T_{1C}, T_{2C}, T_{3C}, T_{4C} – Certified operator density; the number of certified operators at each level, divided by OPL, the number of operators employed.

T_{Req}, T_B, T_C – The values for the sum of certified operators at all levels divided, respectively, by permitted flow, average flow, and operators employed.

T_{IND} – Training index; an index of the numbers of certified operators, weighted according to average training hours required for each level of certificate, divided by permitted flow $\frac{T_1 + 2T_2 + 4T_3 + 8T_4}{\text{Required Flow}}$

The A sample matrix presenting correlation coefficients for overloaded trickling filter plants between various pairs of these and other factors is presented in Exhibit 5. Coefficients used in later analyses are flagged.

The computer correlations yielded the data shown in Exhibits 6, 7, 8, and 9. Exhibit 6 shows to what extent performance, represented by PER 1 and PER 2, correlates with staffing levels, as represented by INT. Applying the above criteria for identifying the strength of correlations from these data, we find that there appears to be a weak to moderate correlation between number of operators and performance in overloaded trickling filter plants and in fully loaded "other" plants (at least in the removal of suspended solids). On the other hand, the performance of activated sludge plants operating at more than 50 percent of rated load and moderately loaded "other" plants appears to be inversely correlated (at weak to moderate strength) with number of operators. These findings suggest that overloaded biological filter plants and fully loaded other plants are more labor intensive than activated sludge plants and that the addition of labor in those plants, whether or not trained, will help performance to a degree.

Exhibit 7 shows the correlation coefficients for T_{1A}, T_{2A}, T_{3A}, T_{4A}, and T_{Req} with PER 1 and PER 2. These represent the extent to which performance correlated with the number of certified operators at each of the four certification levels and in relation to total permitted gallons of flow per day. From these data, it can be seen that certified operators appear to be slightly more influential (as judged by the frequency of positive correlations observed) in the operation of activated sludge plants (7 positive correlations above 0.4) than in the operation of either trickling filter (4 positive

EXHIBIT 5
SAMPLE COMPUTERIZED CORRELATION MATRIX
(For Overloaded Trickling Filter Plants)

CORRELATION MATRIX: Performance Parameters (→ PER 2, PER 1)

Rows FLO through T4A: Exhibit 7 Figures; rows TREQ through T4B: Exhibit 8 Figures

	FLO	REQ	BOD	TSS	OPL	LAB	S	T1	T1A	T2
	T2A	T3	T3A	T4	T4A	TREQ	TB	BODREQ	TSSREQ	PER 1
	PER 2	TIND	TIND 1	LOADING	INT	T1B	T2B	T3B	T4B	
FLO	1.0000	0.9898	0.8459	0.9197	0.8377	0.6827	0.8184	0.0	0.0	0.5903
	-0.4647	0.2095	-0.3238	0.5696	0.2919	-0.4998	-0.4994	0.0463	0.5651	-0.2036
	0.0564	-0.3653	-0.4328	0.1122	-0.2253	0.0	-0.4436	-0.3313	0.2388	
REQ	0.9898	1.0000	0.8393	0.9078	0.8699	0.7340	0.8431	0.0	0.0	0.6552
	-0.4198	0.2364	-0.3024	0.5128	0.2498	-0.4633	-0.4504	0.0823	0.6174	-0.1760
	0.1187	-0.3440	-0.4010	0.0005	-0.1516	0.0	-0.3821	-0.3066	0.2102	
BOD	0.8459	0.8393	1.0000	0.9621	0.6968	0.5616	0.7372	0.0	0.0	0.5567
	-0.4053	0.3042	-0.2653	0.6139	0.3507	-0.4057	-0.4105	0.0390	0.3203	-0.4370
	-0.1499	-0.2745	-0.3601	0.0146	-0.2532	0.0	-0.3800	-0.2773	0.2974	
TSS	0.9197	0.9078	0.9621	1.0000	0.7054	0.6705	0.7465	0.0	0.0	0.5624
	-0.4463	0.3456	-0.2146	0.5717	0.3060	-0.3785	-0.3848	0.0272	0.3999	0.3437
	-0.1680	-0.2433	-0.3179	0.0256	-0.3171	0.0	-0.4287	-0.2222	0.2470	
OPL	0.8377	0.8699	0.6968	0.7054	1.0000	0.5721	0.9144	0.0	0.0	0.5613
	-0.4762	0.1775	-0.3048	0.5340	0.3326	-0.4802	-0.4398	0.2453	0.5730	0.0219
	0.3340	-0.3370	-0.4161	-0.0573	0.2862	0.0	-0.3942	-0.3021	0.3099	
LAB	0.6827	0.7340	0.5616	0.6705	0.5721	1.0000	0.5594	0.0	0.0	0.5554
	-0.2973	0.4868	0.0388	-0.0330	-0.1985	-0.1207	-0.0913	0.0022	0.5554	-0.0520
	0.0273	-0.0822	-0.0273	-0.2639	0.0174	0.0	-0.2614	0.0526	-0.1930	
S	0.8184	0.8431	0.7372	0.7465	0.9144	0.5594	1.0000	0.0	0.0	0.5334
	-0.4296	0.1433	-0.3437	0.5459	0.2996	-0.5031	-0.4817	0.1410	0.4815	-0.1020
	0.1834	-0.3758	-0.4451	0.0628	0.1114	0.0	-0.3966	-0.3394	0.2729	
T1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
T1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 n.a.
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0 n.a.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
T2	0.5903	0.6552	0.5567	0.5624	0.5613	0.5554	0.5334	0.0	0.0	1.0000
	0.3433	-0.0101	-0.3965	0.0251	-0.2200	-0.2783	-0.2367	0.5306	0.7899	0.1255
	0.5333	-0.3943	-0.3253	-0.2829	-0.0118	0.0	0.3824	-0.3935	-0.2284	
T2A	-0.4647	-0.4198	-0.4053	-0.4463	-0.4762	-0.2973	-0.4296	0.0	0.0	0.3433
	1.0000	-0.3948	-0.1757	-0.5019	-0.5465	0.1983	0.2178	0.3407	0.1459	0.3459
	0.4304	-0.1017	0.0459	-0.2622	-0.0695	0.0	0.9728	-0.1698	-0.5248	
T3	0.2095	0.2364	0.3042	0.3456	0.1775	0.4868	0.1433	0.0	0.0	-0.0101
	-0.3948	1.0000	0.7898	0.1898	0.1090	0.6407	0.6353	-0.1692	0.0955	-0.1633
	-0.2929	0.7624	0.7129	-0.4611	0.1779	0.0	-0.3337	0.7922	0.1103	
T3A	-0.3238	-0.3024	-0.2653	-0.2146	-0.3048	0.0388	-0.3437	0.0	0.0	-0.3965
	-0.1757	0.7898	1.0000	-0.1797	-0.1089	0.9242	0.9059	-0.2050	-0.1858	-0.0194
	-0.2882	0.9727	0.9753	-0.4007	0.1816	0.0	-0.1339	0.9985	-0.0841	
T4	0.5696	0.5128	0.6139	0.5717	0.5340	-0.0330	0.5459	0.0	0.0	0.0251
	-0.5019	0.1898	-0.1797	1.0000	0.8279	-0.2985	-0.3145	-0.1410	-0.0101	-0.0298
	-0.1994	-0.0774	-0.2949	0.1559	-0.0974	0.0	-0.4758	-0.1901	0.7582	
T4A	0.2919	0.2498	0.3507	0.3060	0.3326	-0.1985	0.2996	0.0	0.0	-0.2200
	-0.5465	0.1090	-0.1089	0.8279	1.0000	-0.2236	-0.2202	-0.1622	-0.1590	-0.3179
	-0.2740	0.0330	-0.2330	0.0462	0.0689	0.0	-0.5032	-0.1090	0.9898	
TREQ	-0.4998	-0.4633	-0.4057	-0.3785	-0.4802	-0.1207	-0.5031	0.0	0.0	-0.2783
	0.1983	0.6407	0.9242	-0.2985	-0.2236	1.0000	0.9906	-0.0770	-0.1446	0.0935
	-0.1362	0.9486	0.9823	-0.5196	0.1627	0.0	0.2344	0.9254	-0.1901	
TB	-0.4994	-0.4504	-0.4105	-0.3848	-0.4398	-0.0913	-0.4817	0.0	0.0	-0.2367
	0.2178	0.6353	0.9059	-0.3145	-0.2202	0.9906	1.0000	-0.0083	-0.0942	0.1597
	-0.0673	0.9349	0.9681	-0.6136	0.2465	0.0	0.2808	0.9121	-0.1814	
BODREQ	0.0463	0.0823	0.0390	0.0272	0.2453	0.0022	0.1410	0.0	0.0	0.5306
	0.3407	-0.1692	-0.2050	-0.1410	-0.1622	-0.0770	-0.0083	1.0000	0.6273	0.6070
	0.7420	-0.1795	-0.1316	-0.1926	0.4321	0.0	0.4395	-0.1930	-0.1771	
TSSREQ	0.5651	0.6174	0.3203	0.3999	0.5730	0.5554	0.4815	0.0	0.0	0.7899
	0.1459	0.0955	-0.1858	-0.0101	-0.1590	-0.1446	-0.0942	0.6273	1.0000	0.3423
	0.7277	-0.2035	-0.1558	-0.2161	0.1979	0.0	0.2175	-0.1795	-0.1544	
PER 1	-0.2036	-0.1760	-0.4370	-0.3437	0.0219	-0.0520	-0.1020	0.0	0.0	0.1255
	0.3459	-0.1633	-0.0194	-0.2898	-0.3179	0.0935	0.1597	0.6070	0.3423	1.0000
	0.6551	-0.0272	0.0578	-0.2366	0.5107	0.0	0.4148	0.0090	-0.3318	
PER 2	0.0564	0.1187	-0.1499	-0.1680	0.3340	0.0273	0.1834	0.0	0.0	0.5333
	0.4304	-0.2929	-0.2882	-0.1994	-0.2740	-0.1362	-0.0673	0.7420	0.7277	0.6551
	1.0000	-0.2761	-0.1960	-0.2014	0.5187	0.0	0.5174	-0.2806	-0.2532	
TIND	-0.3653	-0.3440	-0.2745	-0.2433	-0.3370	-0.0822	-0.3758	0.0	0.0	-0.3943
	-0.1017	0.7624	0.9727	-0.0774	0.0330	0.9486	0.9349	-0.1795	-0.2035	-0.0272
	-0.2761	1.0000	0.9642	-0.4657	0.1921	0.0	-0.0525	0.9725	0.0611	
TIND 1	-0.4328	-0.4010	-0.3601	-0.3179	-0.4161	-0.0273	-0.4451	0.0	0.0	-0.3253
	0.0459	0.7129	0.9753	-0.2949	-0.2330	0.9823	0.9681	-0.1316	-0.1558	0.0578
	-0.1960	0.9642	1.0000	-0.4654	0.1687	0.0	0.0823	0.9752	-0.2030	
LOADING	0.1122	0.0005	0.0146	0.0256	-0.0573	-0.2639	0.0628	0.0	0.0	-0.2829
	-0.2622	-0.4611	-0.4007	0.1559	0.0462	-0.5196	-0.6136	-0.1926	-0.2161	-0.2366
	-0.2014	-0.4657	-0.4654	1.0000	-0.4275	0.0	-0.4241	-0.4268	-0.0109	
INT	-0.2253	-0.1516	-0.2532	-0.3171	0.2862	0.0174	0.1114	0.0	0.0	-0.0118
	-0.0695	0.1779	0.1816	-0.0974	0.0689	0.1627	0.2465	0.4321	0.1979	0.5107
	0.5187	0.1921	0.1687	-0.4275	1.0000	0.0	0.0600	0.2087	0.1241	
T1B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 n.a.
	0.0 n.a.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
T2B	-0.4436	-0.3821	-0.3800	-0.4287	-0.3942	-0.2614	-0.3966	0.0	0.0	0.3824
	0.9728	-0.3337	-0.1339	-0.4758	-0.5032	0.2344	0.2808	0.4395	0.2175	0.4148
	0.5174	-0.0525	0.0823	-0.4241	0.0600	0.0	1.0000	-0.1238	-0.4787	
T3B	-0.3313	-0.3066	-0.2773	-0.2222	-0.3021	0.0526	-0.3394	0.0	0.0	-0.3935
	-0.1698	0.7922	0.9985	-0.1901	-0.1090	0.9254	0.9121	-0.1930	-0.1795	0.0090
	-0.2806	0.9725	0.9752	-0.4268	0.2087	0.0	-0.1238	1.0000	-0.0821	
T4B	0.2388	0.2102	0.2974	0.2470	0.3099	-0.1930	0.2729	0.0	0.0	-0.2284
	-0.5248	0.1103	-0.0841	0.7582	0.9898	-0.1901	-0.1814	-0.1771	-0.1544	-0.3318
	-0.2532	0.0611	-0.2030	-0.0109	0.1241	0.0	-0.4787	-0.0821	1.0000	

EXHIBIT 6
INT:PER CORRELATIONS
No. Operators Employed
Average Flow

	Trickling Filter		Activated Sludge		Other		All	
	PER 1	PER 2	PER 1	PER 2	PER 1	PER 2	PER 1	PER 2
Overloaded (100%+)	.51	.52	No Plants Here		No Plants Here			
Fully Loaded (75% - 100%)	-.15	-.43	-.54	.03	.24	.69		
Moderately Loaded (50% - 75%)	.02	.07	.12	-.59	-.50	.07		
Lightly Loaded (10% - 50%)	.06	-.11	.01	-.35	-.27	-.13		
All	.16	.10	.04	.01	-.23	-.03		

Key

☐ Strong Correlation

◯ Weak to Moderate Correlation

EXHIBIT 7
T_A:PER CORRELATIONS
No. Certified Operators
Permit Flow

	Trickling Filter		Activated Sludge		Other		All	
	PER 1	PER 2	PER 1	PER 2	PER 1	PER 2	PER 1	PER 2
Overloaded (100%+)	D n.a. C .35 B -.02 A -.32 All .09	n.a. .43 -.29 -.27 -.14	No Plants Here		No Plants Here			
Fully Loaded (75% - 100%)	D -.04 C -.13 B .07 A .02 All -.10	-.23 -.36 .29 .05 -.25	.51 .07 .28 -.41 .28	.47 .68 -.19 -.28 .62	n.a. .34 -.31 .26 -.01	n.a. .52 .08 .25 .34		
Moderately Loaded (50% - 75%)	D .08 C -.09 B .13 A .20 All .01	.70 .15 .02 -.03 .27	n.a. -.25 -.04 .92 .08	n.a. -.26 -.11 .61 -.07	-.02 -.33 -.23 -.20 -.40	-.11 .74 13 -.27 .67		
Lightly Loaded (10% - 50%)	D -.23 C -.08 B -.33 A -.25 All -.21	.55 -.15 .07 -.47 -.11	n.a. .50 -.25 -.50 .35	n.a. .18 -.32 -.18 -.00	-.41 -.26 -.22 -.20 -.24	-.31 -.17 -.10 -.09 -.15		
All	D .06 C -.01 B -.04 A -.10 All -.03	.52 .15 -.11 -.20 .09	.09 .06 -.26 .30 -.07	.08 .03 -.42 .08 -.15	-.21 -.18 -.15 -.12 -.17	-.22 -.06 -.06 -.08 -.06		

Key

☐ Strong Correlation

◯ Weak to Moderate Correlation

n.a. Not Available

correlations) or "other" plants (3 positive correlations). The number of certified operators at the D level – a minimum level – does appear, however, to influence the removal of suspended solids in trickling filter plants.

In this run, as in subsequent runs, a number of weak to moderate negative correlations also appeared, suggesting that there appears to be an inverse relationship between T and PER, rather than a direct one. This inverse relationship would say that PER is higher in plants with fewer certified operators per unit of permitted flow. We believe that this is true, in fact, of certain parts of the sample because of individual characteristics of the plants – in specific size, type, loading, or location – and the ability of their managers, but the general conclusion that performance can be positively correlated with the number of certified operators survives because of the preponderance of positive correlations.

In Exhibit 7 it appears also that the presence of D and C level operators (4 positive correlations above 0.4 each) correlates with performance more clearly than the presence of A and B operators (2 and 0 positive correlations, respectively). The use of the ratio of certified operators to permitted flow (T_{1A}, T_{1B}, and so forth) to correlate with performance was a first pass at the analysis and revealed that introducing certification levels in the "T" parameters tended to improve the frequency of correlations over those found (in Exhibit 9) using pure staffing data (INT).

Because the ratio of certified operators to permitted flow might not give the best correlations, however, we looked at two other possible parameters: T_B (1B-4B) T_C (C1-C4), which were ratios of the number of certified operators to average yearly plant flow and to number of operators on the staff (OPL), respectively. In the first case, the number of operators was divided by average flow to adjust for any difference in the extent of plant loading in the sample, largely in the belief that plant hiring practices would probably more closely match the experienced load (or overload) rather than the permitted load. In the second case, we were trying to separate the effect of training certification level from the effect of numbers of staff. In the T_A and T_B measures, the operator that is counted is a trained and certified operator, but he is also an operator who may already show up in the staffing measures of OPL and INT. Thus, T_A and T_B measure the presence of trained and certified operators – in essence, the presence of both training and staff. The T_C measure, however, takes the ratio of trained and certified operators to all operators, thus proportion of a given staff that is trained.

Exhibit 8 shows the results of the T_B correlations with PER. In these data, more significant correlations appear to exist, one negative correlation disappears, several positive correlations are stronger, and two negative correlations are weaker than the previous analysis. Plant performance, therefore, appears to correlate more closely (as judged by the frequency and magnitude of the correlation index) with the ratio of trained and certified operators to average plant flow.

Exhibit 9 shows the correlation values using the T_C ratios which were introduced to try to separate the effect of training from the effect of staffing. This exhibit shows still further improvement over the earlier date. Correlations in the case of overloaded trickling filter plants have disappeared, but new and/or much stronger positive correlations have appeared in the activated sludge and "other" categories. Because of the greater frequency of correlation, we calculated and presented on this exhibit the figures for all plants, of all types and sizes. The relative frequency of correlation of the T_A, T_B, and T_C ratios with performance is shown in Exhibit 10.

The T_C measure – an indicator of the proportion of the staff of a plant that has been exposed to training – is the best determinant of performance that we have found. Where performance is high, the training level of the staff is the most likely reason. Although successful plant operation correlates to some degree with size of staff, it seems to be much more directly related to training achieved.

If training is the major reason for sustaining good performance, the performance of plants that improve should be explainable in terms of training as well. Section A, above, presents a case-by-case view of how training can improve plant performance. To test quantitatively the hypothesis that training relates to performance improvement, we divided our sample of 124 plants into three groups:

(i) Those plants whose performance on BOD or suspended solids removal declined by 10 percent or more in 1971, as measured by a comparison of performance figures for the first three months and the last three months of 1971.

(ii) Those plants whose performance stayed roughly the same (that is, within + 10 percent during 1971, as measured above).

EXHIBIT 8
T_B:PER CORRELATIONS
No. Certified Operators
Average Flow

		Trickling Filter		Activated Sludge		Other		All	
		PER 1	PER 2	PER 1	PER 2	PER 1	PER 2	PER 1	PER 2
Overloaded (100%+)	D	n.a.	n.a.	No Plants Here		No Plants Here			
	C	.41	.52						
	B	.01	-.28						
	A	-.33	-.25						
	All	-.16	-.07						
Fully Loaded (75% - 100%)	D	-.03	-.20	.51	.47	n.a.	n.a.		
	C	-.10	-.33	.17	.74	.17	.59		
	B	.14	.35	.28	-.16	-.33	.08		
	A	.05	.08	-.41	-.28	.26	.25		
	All	-.03	-.19	.40	.74	.34	.36		
Moderately Loaded (50% - 75%)	D	.08	.70	n.a.	n.a.	-.02	-.12		
	C	-.01	.19	-.20	-.26	-.36	0.70		
	B	.19	.06	-.07	-.21	-.24	.09		
	A	.20	-.03	.92	.56	-.20	-.26		
	All	.11	.33	.17	-.10	-.43	.59		
Lightly Loaded (10% - 50%)	D	-.23	.52	n.a.	n.a.	-.30	-.22		
	C	-.06	-.08	.58	.20	-.23	-.17		
	B	-.14	.11	-.21	-.31	-.22	-.14		
	A	-.21	-.46	-.50	-.18	-.22	-.14		
	All	-.11	-.03	.52	.07	-.23	-.16		
All	D	.05	.54	.09	.08	-.17	-.15		
	C	.05	.13	.30	.34	-.14	-.11		
	B	.04	.02	-.14	-.27	-.13	-.10		
	A	-.03	-.17	.37	.13	-.12	-.10		
	All	.06	.14	.36	.31	-.13	-.10		

Key

☐ Strong Correlation

◯ Weak to Moderate Correlation

n.a. Not Available

EXHIBIT 9
T_C:PER CORRELATIONS
No. Certified Operators
No. Operators Employed

		Trickling Filter		Activated Sludge		Other		All	
		PER 1	PER 2	PER 1	PER 2	PER 1	PER 2	PER 1	PER 2
Overloaded (100%+)	D	n.a.	n.a.	No Plants Here		No Plants Here			
	C	-.02	.01						
	B	-.11	-.27						
	A	-.30	-.30						
	All	-.14	-.27						
Fully Loaded (75% - 100%)	D	.11	.12	.51	.47	n.a.	n.a.	.47	.04
	C	.14	.16	.52	.60	.07	.97	.37	.64
	B	.18	.40	.29	-.23	.14	.94	.12	.34
	A	.29	.20	-.41	-.28	.26	.25	-.04	-.08
	All	.26	.35	.64	.53	.10	.97	.38	.57
Moderately Loaded (50% - 75%)	D	.07	.66	n.a.	n.a.	n.a.	n.a.	-.03	.54
	C	-.01	-.04	-.27	-.01	-.28	.77	-.15	.16
	B	.07	-.13	-.01	-.09	-.27	.21	-.13	-.06
	A	.16	-.08	.95	.61	-.35	-.33	.57	.07
	All	.03	-.01	.22	.25	-.34	.71	-.08	.17
Lightly Loaded (10% - 50%)	D	-.23	.52	n.a.	n.a.	-.30	-.21	-.25	.03
	C	.10	.03	.85	.68	.20	.63	.44	.49
	B	-.01	.31	-.49	-.29	.33	.75	.00	.45
	A	-.29	-.45	-.50	-.18	.24	.28	-.09	.02
	All	.01	.21	.36	.52	.26	.69	.26	.55
All	D	.04	.52	.09	.08	-.15	-.15	.05	.24
	C	.03	-.00	.33	.45	-.07	.72	.08	.30
	B	-.02	-.10	-.24	-.27	.08	.61	-.07	.08
	A	-.12	-.22	.34	.16	.06	.15	.25	-.00
	All	.00	-.03	.32	.35	-.01	.73	.06	.28

Key

☐ Strong Correlation

⬭ Weak to Moderate Correlation

n.a. Not Available

EXHIBIT 10
RELATIVE CORRELATION FREQUENCIES BETWEEN T_A, T_B, and T_C FACTORS WITH PERFORMANCE

	T_A:PER Exhibit 7		T_B:PER Exhibit 8		T_CC:*PER Exhibit 9	
Positive Correlations	14		17		27	
Strong		3		5		10
Moderate		11		12		17
Negative Correlations	6		4		4	
Strong		0		0		0
Moderate		6		4		4
Total	20		21		31	

*Without consideration of "all types" column in Exhibit 9.

(iii) Those plants whose performance improved by 10 percent or more in BOD or suspended solids removal in 1971 as measured above.

For each of the three groups, we then computed mean figures for T_B values first and the training index of T_{IND} and produced the results shown in Exhibit 11. Exhibit 11 shows that the plants that made a 10 percent or better improvement in performance in 1971 had, on the average, significantly higher values of T_B and a significantly higher training index than plants which stayed the same or achieved worse performance. (We have been unable to satisfactorily explain why those plants that stayed the same, in many cases, have lower T values than those whose performance degraded.) Exhibit 12 shows the relative values of these correlations using the "worse" cases as the standard. In every training measure, the "better" case has higher training parameters, ranging from 1.3 to 40.0 times as high as the worse case, whereas in no case is the effect of staffing (INT) as important.

C. Conclusions Regarding the Impact of Operator Training on Plant Performance

Examinations of case studies of plants involved in Operation Cleansweep and plants cited by WQB district supervisors as having experienced training benefits provided strong indications that training has had a strong beneficial influence in improving plant performance in a significant proportion of plants whose performance has been historically substandard. In addition, the potential for training benefits in plants encumbered by inadequate facilities is great and may be expected to be realized when physical obstacles are removed.

A computer correlation study of a sample of Texas wastewater treatment plants, conducted independently of the earlier two studies, showed that the proportion of the staff of a plant that has been exposed to training is the best determinant of performance, both for plants with sustained records of good performance and for plants that made a 10 percent or better improvement in performance in 1971.

As a result of these separate studies, we may conclude that training bears a direct and measurable relationship to plant performance improvement as well as to plant performance levels. Both of these relationships could have been explored further with greater data availability (on all plants in Texas) and additional study resources. It

EXHIBIT 11
CHANGES IN PLANT PERFORMANCE WITH TRAINING AND STAFFING PARAMETERS

Parameter	BOD			TSS		
	Worse	Same	Better	Worse	Same	Better
T_{1B}(D)	.0006	.0003	.0011	.0009	.0001	.0012
T_{2B}(C)	.0150	.0140	.0400	.0200	.0085	.0520
T_{3B}(B)	.0120	.0062	.0200	.0100	.0072	.0270
T_{4B}(A)	.00008	.0005	.0032	.0010	.0005	.0038
T_B(All)	.02768	.0210	.0643	.0319	.0163	.0830
INT	.0081	.0101	.0109	.0134	.0081	.0076
T_{IND}	6.186	5.160	10.043	6.858	6.606	10.950

EXHIBIT 12
RELATIVE VALUES OF CORRELATIONS OF CHANGES IN PLANT PERFORMANCE WITH TRAINING AND STAFFING PARAMETERS

Parameter	BOD			TSS		
	Worse	Same	Better	Worse	Same	Better
T_{1B}(D)	1.0	0.5	1.8	1.0	0.1	1.3
T_{2B}(C)	1.0	0.9	2.7	1.0	0.4	2.6
T_{3B}(B)	1.0	0.5	1.7	1.0	0.7	2.7
T_{4B}(A)	1.0	6.2	40.0	1.0	0.5	3.8
T_B(All)	1.0	0.7	2.3	1.0	0.5	2.6
INT	1.0	1.3	1.3	1.0	0.6	0.6
T_{IND}	1.0	0.8	1.6	1.0	1.0	1.6

the plant was brought before the WQB, the operator was an uncertified part-time employee. Operator training recommended by the Board was under way at the close of 1971, but the results of training had not yet materialized at the time this report was written. The WQB expects good performance from this plant in 1972.

- *Case 11*

At the beginning of 1971, this plant was seriously noncompliant on BOD and TSS and was not self reporting. During 1971, the hiring of a trained and certified operator has caused dramatic improvement in both performance areas, although the plant is not yet compliant on TSS.

- *Case 12*

The Case 12 facility was an older plant, in deteriorated condition, that was noncompliant on BOD and TSS. During 1971, some repairs were made, and the town initiated action to acquire a new plant. The potential for training impact after addition of new facilities is strong.

- *Case 13*

This town has three small plants, all of which are seriously overloaded and seriously noncompliant on BOD and TSS. Subsequent to the WQB hearing, the town decided to join a regional plant now in the planning stage. Training does not appear to have a bearing on the problem or its resolution in this case.

- *Case 14*

The plant in Case 14 was seriously overloaded and noncompliant on BOD and TSS – in large part because of a sewer collection system that was permitting excessive infiltration. During the year since the Board hearing, the country has hired a consulting engineer to survey the situation. On the basis of this work, improvement has been noticed on both BOD and TSS. Training does not have a bearing on this problem; however, a properly trained and experienced operator might have been able to bring about significant improvement in lieu of calling in a consulting engineer.

- *Case 15*

This plant needed additional treatment facilities, including chlorination capability, and it was not reporting complete information on its self-monitoring reports. Because of its failure to respond to the WQB's inquiries, this plant has been referred to the State Attorney General's office for action. It should be noted that the WQB, through corrective proposals, makes an extended effort to avoid such fines. Further, only in instances of complete uncooperativeness are these matters referred to the State Attorney General's office. The potential for training impact after the addition of new facilities is strong.

- *Case 16*

This overloaded plant was noncompliant on BOD and TSS and was not sufficiently chlorinating its effluent. Improvement has been effected in chlorine content of effluent and on TSS, but not in BOD performance. Training does not appear to have an influence here.

c. **Findings from the Operation Cleansweep Investigation.** The types of problems, solutions selected, and apparent influence of training in resolving the 16 cases of noncompliance with WQB standards, as described above, are summarized in Exhibit 1. As shown, the performance of four of the plants that were in serious violation of their state wastewater permits in early 1971—or 25 percent of the plants brought before the WQB in the first quarter of 1971—was improved significantly at least in part through operator training. Two of these plants became compliant on both BOD and TSS measures. The plants that appeared most responsive to the influence of training were those characterized by poor operation as a result of lack of operator knowledge, rather than those that were seriously overloaded.

In addition to the cases identified as responding positively to training, there was one case—case 10—in which surveillance authorities observed that the operator was just undergoing training at the time of this report and anticipated the training to yield strong positive results. At least two other problem situations—cases 5 and 14, in which consulting engineers were retained—might have been resolved through the hiring of a properly trained operator.

Thus, from this sample of "problem plants" in serious violation of pollution control standards, possibly as many as 45 percent (seven out of 16) exhibited problems potentially susceptible to resolution through operator training, and 25 percent (four out of 16) effectively used training in resolving those problems.

2. WQB District Supervisors' Survey

a. **Overview.** The survey of the WQB district supervisors to determine which plants had noticeably benefited from training began as a telephone interview with each of the 12 district would have been useful, for instance, to vary the rate of performance improvement to determine the precise relationship between training and performance.

PART V
THE RETURN ON THE PUBLIC INVESTMENT IN WASTEWATER TREATMENT PLANT OPERATOR TRAINING

Part IV of this report concluded that training of wastewater treatment plant operators does have several beneficial effects upon the quality of plant effluent and efficiency of plant maintenance and operations. The formulation of a statement of the precise dollar value of these benefits would be very difficult, if not impossible, and it is not within the scope of this study to attempt to produce such a statement. However, it is possible from the study to develop some quantitative insights into the value of training benefits that should be useful to decision-makers considering the desirability of sponsoring and/or conducting additional operator training.

The public investment required to initiate and support the effective operation of a municipal wastewater treatment plant is substantial – estimated in excess of $160 million in Texas. This investment is made with the expectations that capital plant will be utilized in such a way as to maximize the useful life and that specified levels of effluent quality will be achieved. Therefore, this part of the report considers the value to the public of training benefits in terms of:

(i) The value of the capital assets entrusted to the care of individual operators.

(ii) The investment that is wasted when a treatment plant does not fulfill its BOD and TSS removal requirements.

A. Value of Capital Assets per Operator

The value of the capital assets entrusted to individual Texas municipal wastewater treatment plant operators was estimated by calculating the operator population and capital investment for a random sample of plants in the state of Texas. In most aspects of the calculations, supplementary data were acquired with the cooperation of the Texas WQB.

1. Explanation of Calculations

To determine the average value of capital assets per operator represented by Texas municipal wastewater treatment plants, using a Kendall and Smith Table of Random Numbers, a random sample of

50 plants was selected from the EPA STORET information system, which lists 993 separate municipal treatment plants in Texas. These 50 selected plants are identified in Column 1 of Exhibit 13.

Each of these 50 plants was then categorized by physical characteristics according to nine basic types of conventional wastewater treatment plants listed in the study, "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities," prepared by Black and Veatch, Consulting Engineers, for EPA in October 1971. When a random STORET sample plant indicated a nonconventional plant type – that is, one that did not correspond to the Black and Veatch categories – the plant was discarded from consideration and another random sample substituted. The nine plant types, coded as numbers 1 through 9 in Column 2 of Exhibit 13, are as indicated in Exhibit 14. Plants below .5 MGD design flow are indicated by an asterisk in this column.

Next the design size for each sample plant was extracted from the STORET data and rounded to the nearest of 1, 3, 5, 10, 20, 35, 65, 80, or 100 million gallons per day in order to gain compatibility with the plant-size categories established in the Black and Veatch study. Plant design capacities as rounded for the 50 randomly selected plants are shown in Column 3 of Exhibit 13.

The operator complement for each sample plant – Exhibit 13, Column 4 – was determined on the basis of the Black and Veatch study, which sets forth standard plant manning tables for estimated staffing needs developed in that study for operators (and other plant personnel) according to plant type (nine categories) and design capacity. While actual staffing in a given plant may not meet these estimated needs, this study presents the best available basis for determining complement. Because many operating plants are widely reported to be staffed below recommended levels, it is likely that our staffing estimates understate capital investment.

Further, we suspect that the Black and Veatch data overstate operators because they lack discretion for plants below the design flow of 1.0 MGD. Over 60 percent of the random samples were plants with design flow of less than .5 MGD. Such plants are likely to have one or two operators, often part-time. While the Black and Veatch minimum for its 1 MGD category is four operators for primary plants and five for secondary, field research indicates that the new smaller plants are often self contained and automatically controlled – requiring little attention – and that the older plants, though needing additional workers to become effective, do not have

EXHIBIT 13
CALCULATED CAPITAL INVESTMENT PER OPERATOR FOR 50 RANDOMLY SELECTED PLANTS

(1) Plant Name	(2) Type	(3) Size	(4) Number of Operators	(5) Population Served	(6) Estimated Capital Investment (ECI)	(7) ECI per Operator
1. Seabrook	4	1	5	5,000	$ 150,000	$ 30,000
2. Itasca	1	*	1	1,200	54,000	54,000
3. Stamford	4	*	1	5,400	163,200	163,000
4. Clute	7	*	1	8,000	200,000	200,000
5. Lewisville	4	1	5	3,300	115,500	23,100
6. Monahans	4	1	5	11,000	220,000	44,000
7. Alpine	1	*	1	5,400	162,000	162,000
8. Mineral Wells	4	1	5	33,000	528,000	10,560
9. Universal City	7	1	5	15,000	300,000	60,000
10. Bellville	4	*	1	2,000	90,000	90,000
11. Lackland City	4	*	1	6,300	189,000	189,000
12. Galveston County No. 1	4	1	5	5,300	159,000	31,800
13. El Paso (Ascarate)	4	*	1	2,500	112,500	112,500
14. Houston WCID No. 44 - Plant No. 2	4	*	1	4,700	164,500	164,500
15. Bexar County (Kirby)	7	*	1	2,300	103,500	103,500
16. Columbus	4	1	5	3,500	122,500	122,500
17. Sour Lake	7	*	1	1,600	72,000	72,000
18. Houston Chadwick Manor	4	*	1	500	57,500	57,500
19. Granger	4	1	5	1,300	58,500	11,700
20. Waxahachie	4	1	5	11,800	236,000	47,200
21. Byers	7	*	1	500	57,500	57,500
22. Midland	4	5	7	61,700	678,700	96,957
23. Bexar County (Oak Hills)	7	*	1	6,300	189,000	189,000
24. Houston WCID No. 78 (Alief)	4	*	1	2,000	90,000	90,000
25. Sinton	4	1	5	4,800	168,000	33,600

*Under .5 MGD.

EXHIBIT 13 (Cont'd)

(1) Plant Name	(2) Type	(3) Size	(4) Number of Operators	(5) Population Served	(6) Estimated Capital Investment (ECI)	(7) ECI PER Operator
26. Silverton (Plaza Lake)	1	*	1	1,050	47,250	47,250
27. Eastland	4	*	1	3,000	105,000	105,000
28. Graham	4	1	5	9,400	235,000	47,000
29. Post	1	*	1	4,430	155,050	155,050
30. Van	4	*	1	1,700	76,500	76,500
31. Beeville (New Plant)	4	1	5	6,000	180,000	36,000
32. Port Arthur (El Vista WCID No. 111)	4	*	1	1,200	54,000	54,000
33. Colorado City	4	1	5	6,700	201,000	40,200
34. Fort Bend County (Stafford)	7	*	1	3,000	105,000	105,000
35. Humble	4	*	1	1,700	76,500	76,500
36. Kemp	4	1	5	950	80,750	16,150
37. Kemah	4	*	1	3,000	105,000	105,000
38. Pasadena (North Side)	4	5	7	225,000	1,125,000	160,714
39. Alta Loma (WCID No. 8)	4	*	1	1,400	63,000	63,000
40. Arp	4	*	1	700	59,500	59,500
41. Lorenzo	1	*	1	1,300	58,500	58,500
42. Sugarland (Quarters Plan)	4	*	1	700	59,500	59,500
43. Lancaster	4	*	1	5,500	165,000	165,000
44. Gruver (Farwell Draw)	1	*	1	1,000	85,000	85,000
45. San Diego (Stp Outfall 1)	4	*	1	3,000	105,000	105,000
46. Pinehurst	7	1	5	1,800	81,000	16,200
47. Wortham (Northeast)	1	*	1	1,100	49,500	49,500
48. Elkhart	4	*	1	1,000	85,000	85,000
49. El Campo (Plant No. 1)	4	1	5	8,760	219,000	43,800
50. Mabank	1	*	1	1,150	51,750	51,700
TOTAL			126		$8,068,200	$ 64,033

*Under .5 MGD.

EXHIBIT 14
SUMMARY OF BLACK AND VEATCH PLANT TYPE CATEGORIES

Type	Liquid Treatment			Sludge Handling Facilities		
	Primary	Trickling Filter	Activated Sludge	Digestion and Beds or Lagoons	Digestion and Sludge Dewatering	Dewatering and Incineration
1	X			X		
2	X				X	
3	X					X
4	X	X		X		
5	X	X			X	
6	X	X				X
7	X		X	X		
8	X		X		X	
9	X		X			X

sufficient staff. Accordingly, for all sample plants of a design capacity under .5 MGD, we have imputed a complement of one operator.

Estimated capital investment per plant (Column 6 of Exhibit 13) was calculated on the basis of population served by each plant and Texas cost data developed under the Construction Grants Program (Public Law 660) for fiscal year 1969. Population served by each sample plant (Column 5) was derived from STORET system information in most cases. Investment costs were derived from the graph shown in Exhibit 15, which charts population served against per capita investment costs experienced under the Construction Grants Program for secondary treatment plants, excluding land costs. Estimated capital investment per plant (Column 6) was calculated by multiplying the Column 5 population data by the per capita cost of investment derived from Exhibit 15. Because our random sample includes a few primary plants, capital investment estimates for those plants may be slightly overstated.

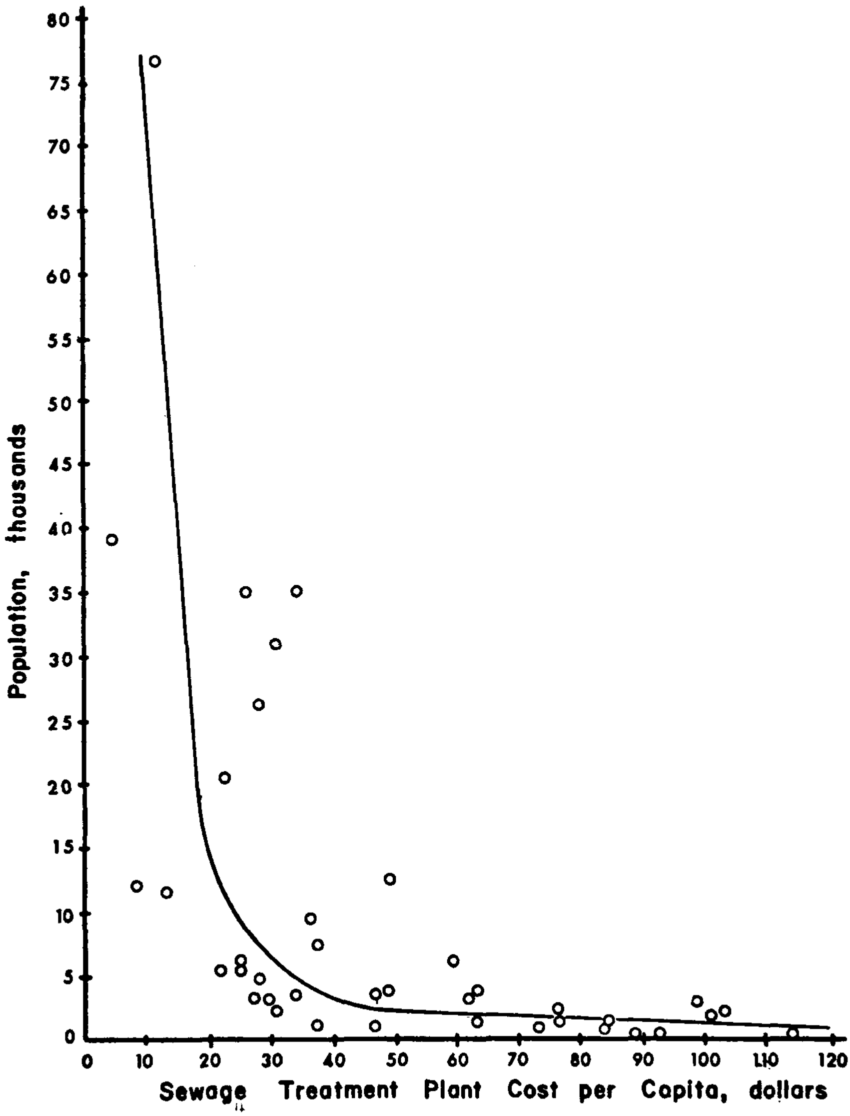
The estimated capital investment (ECI) for each plant (Column 6 of Exhibit 13) was divided by the calculated number of operators (Column 4) to derive the estimated capital investment per operator (Column 7) for each of the 50 randomly selected plants.

Overall, in the 50-plant sample, there was a total estimated capital investment of $8,068,200 under the responsibility of an estimated 126 operators, for an ECI per operator of $64,033. This investment per operator is substantially higher than the $10,200 invested by American industry for each of its production workers.

2. Interpretation of Calculations

These conservative figures reveal the minimum extent to which public investment in wastewater treatment facilities is exposed to risk when plant operation and maintenance is entrusted to an untrained or inadequately trained operator. The real extent of the risk accepted may be better appreciated when it is understood that the ECI per operator offered above is calculated on the theory that all operators are working at the same time (that is, that all of the plants in the sample conduct single-shift operations). Although no data are available to indicate the dispersion of operators among shifts, common sense and casual observation are sufficient to conclude that some plants have operators on two or even three shifts. If the calculation were made on the basis that to run two shifts necessitated an even split of operators between shifts, the average value of plant entrusted to each operator at any one time would be

EXHIBIT 15
PER CAPITA WASTEWATER TREATMENT PLANT
INVESTMENT COST DATA



Source: "Regional Sewerage Systems and Treatment Costs in Texas," Nicholas W. Classen, Bobby G. Scalf, and Joseph B. Copeland, Jr., Texas Water Quality Board, Austin, Texas, Agency Publication No. 70-03.

closer to $128,000. Further, as explained above, the use of Black and Veatch recommended staffing levels for this calculation renders the number of operators somewhat high, thus resulting in a substantial understatement of the average investment per operator.

Perhaps more important than the average is that many operators in Texas – and presumably elsewhere – are daily entrusted with as much as $200,000 worth of plant and some with even more. In analogy, few drivers would entrust a $3,000 automobile to an untrained, inadequately trained, or unlicensed driver, and a wastewater treatment plant operator is daily responsible for over 20 times this investment.

In contrast to the ECI per operator, which may well range in excess of the $64,033 presented in Exhibit 13, EPA experience in the Public Services Careers Program and other similar operator training programs suggests that the cost of training a single operator, exclusive of support costs associated with training of the disadvantaged, average in the vicinity of $565.

B. Wasted Investment Through Substandard Effluent

Another perspective on the value of training benefits was developed through further consideration of some of the plants which were subjects of the Part IV case studies to determine the extent to which training prevented waste of capital investment that would have been caused by delivery of a substandard product. In a number of the case studies, plants were identified in which recent training could be isolated as the substantial cause of improved performance. For certain of these improvement cases, quantitative data showing the quality of the effluent in terms of BOD and TSS before and after training were available through the Texas Water Quality Board. These data were manipulated as described below to calculate the "stop-loss" on capital investment. A further calculation offset the cost of training against the stop-loss on capital to estimate the net return on the training investment for these plants.

1. Explanation of Calculations

The plants selected for inclusion in this portion of the study include the four plants cited in Operation Cleansweep in the first quarter of 1971 for noncompliance with WQB standards that could be identified as achieving performance improvement largely as a result of training. In addition, 15 plants identified by the Texas WQB district supervisors as having improved their performance as a result of training since 1970 were included because data were available. For all 19 of these case study plants, data to substantiate the performance improvement were derived from the Texas Water Quality Board self-reporting information system. Data on the 19 plants are presented in Exhibit 16.

Effective improvement in performance (Column 2) was calculated on an average basis, giving equal weight to BOD and TSS levels. The figures presented in Column 2 of Exhibit 16 were derived by calculating the difference between first-quarter and last-quarter 1971 levels of BOD and TSS and averaging them.

Column 3 sets forth an average of the BOD and TSS performance standards established for each plant by the Texas Water Quality Board.

The capital investment figures presented for each plant in Column 4 were calculated on the basis of population served by each plant and Texas cost data developed under the Construction Grants Program for fiscal year 1969, as described in the calculation of ECI per operator in Section A-1 above. Supporting data are provided in Appendix A.

The effectiveness with which the capital investment for each of these plants was being utilized before and after training was expressed in terms of the imputed proportion of the investment that was actively producing to design capacity. Pre-training effective capital was calculated by dividing the standard for each plant by the average combined BOD/TSS performance before training (in the first quarter of 1971); the quotient, representing the fraction of intended BOD/TSS removal being realized before training, was multiplied by the plant's total capital investment to determine the equivalent fully effective capital investment that would produce the same quality effluent. In some instances, plants that were performing well within their compliance specifications have pre-training effective capital estimates well in excess of their actual capital investment costs. This implies that the plants were already performing more effectively than was hoped.

Post-training effective capital was calculated by dividing the standard for each plant by its average combined BOD/TSS performance after training (in the last quarter of 1971); the quotient representing the fraction of plant effectiveness after training was again multiplied by the total capital investment in the plant to determine the equivalent effective capital represented by its performance. Pre-training and

EXHIBIT 16
CALCULATION OF "STOP-LOSS" ON CAPITAL INVESTMENT AND RETURN ON TRAINING INVESTMENT IN 19 CASE STUDIES

(1) Plant	(2) Average Effective Change	(3) Average BOD/TSS Standard	(4) Capital Investment	(5) Pre-Training Effective Capital	(6) Post-Training Effective Capital	(7) Stop-Loss on Capital	(8) Cost of Training	(9) Net Return	(10) Ratio of Training Investment: Net Return	(11) % Improvement After Training	(12) % Reduction of BOD/TSS in Effluent
Kaufman	38.5	34.5	164,500	85,540	205,625	120,085	2,825	117,260	1:42	240	58
Corpus Christi (W'Side)	14.0	20.0	175,000	98,000	164,500	55,500	3,955	62,545	1:15	166	40
Corpus Christi (B'Way)	3,8	20.0	400,000	240,000	272,000	32,000	4,520	27,480	1:6	112	11
Mathis	23.2	57.0	174,000	140,940	210,540	69,600	2,825	66,775	1:24	149	65
Lockhart	9.5	20.0	207,000	298,080	910,800	612,720	2,825	609,895	1:216	316	68
Jasper	4.6	103.0	150,000	364,500	408,000	43,500	3,390	40,110	1:12	112	11
Beaumont	5.9	20.0	544,000	451,520	598,400	146,880	3,390	143,490	1:42	132	24
Brownwood	30.5	23.0	342,000	430,920	639,540	208,620	2,825	205,795	1:73	148	32
Midland	5.9	20.0	678,700	1,174,151	2,395,811	1,221,660	3,955	1,217,705	1:307	204	51
Odessa (BOD only)	178.8	35.0	795,300	508,992	1,725,801	1,216,809	5,085	1,211,724	1:238	334	65
Grandview	6.5	20.0	85,000	115,600	207,400	91,800	565	91.235	1:161	178	44
Forney	10.2	20.0	78,750	96,075	255,938	159,863	565	159,298	1:282	266	62
Plano	4.0	20.0	260,000	239,200	293,800	54,600	3,955	50,645	1:13	122	18
Nocona	32.0	77.0	153,125	208,250	482,343	174,093	565	173,528	1:307	231	57
Bridgeport	16.0	30.0	140,000	128,200	257,600	129,400	565	128,835	1:228	198	49
Gainesville	6.7	20.0	300,000	232,500	312,000	79,500	2,825	76,675	1:27	135	26
Brownsville	12.7	20.0	643,000	482,400	926,208	443,808	3,955	439,853	1:111	191	48
Donna	25.2	20.0	198,000	39,600	87,120	47,520	2,825	44,695	1:16	155	36
Edinburg	4.4	20.0	360,000	288,000	348,480	60,480	2,825	57,655	1:20	121	17
TOTAL			5,848,375	5,622,468	10,701,906	4,968,438	53,675	4,926,763			
AVERAGE			307,809	295,919	563,258	261,497	2,825	259,303	1:91		

post-training effective capital estimates appear in Columns 5 and 6, respectively, of Exhibit 16. "Stop-loss" on capital (Column 7) was derived by subtracting Column 5 from Column 6.

The number of operators in each plant was estimated according to Black and Veatch staffing guides and EPA STORET data regarding type and size of plants, as described in section A-1, above. Since the actual proportion of the operator staff trained in each case was unknown, it was assumed that all operators in each plant were trained; clearly this method overstates the number of trained operators. The number of operators for each plant was then multiplied by $565, the cumulative historic cost experience of EPA in administering the Public Service Careers Program for operator training (exclusive of the expense of supportive services offered to disadvantaged trainees). Resulting training cost calculations are shown in Column 8.

Net gain in effective capital, shown in Column 9, was derived by subtracting Column 7 from Column 8. The Column 10 ratio of training investment to net capital return was calculated by dividing Column 9 by Column 8.

Percentage improvement in plant performance in terms of increase in BOD and TSS removal was determined by dividing BOD/TSS combined average performance in the first quarter of 1971 by the level of performance achieved after training, in the last quarter of 1971. The results of this procedure are presented in Column 11 of Exhibit 16.

Finally, the percentage of the reduction of BOD/TSS in the effluent of each of these plants was determined by dividing the effective change (Column 2) by the BOD/TSS performance achieved before training (in the first quarter of 1971).

2. Interpretation of Calculations

As shown in Exhibit 16, the net improvement in effective capital in the 19 case-study plants was equivalent to a combined investment of $4,926,763. For every dollar invested in training in these plants, the equivalent of an additional $91 investment was activated in terms of improved performance. As a result of training, the quality of effluent produced by all of these plants improved substantially, in a range from 11 to 68 percent reduction of average combined BOD/TSS. Further, overall improvement ranged between 112 and 334 percent over pre-training levels.

These results are sufficiently startling to warrant further comment, in terms of both the reliability of the calculations and their implications.

It is recognized that the data utilized to produce the calculations displayed in Exhibit 16 are less than perfect and could have been improved substantially upon additional research conducted over a longer period and with more resources than were available for this study. In addition, the availability of additional data would have permitted refinement of the calculation methodology and might have permitted consideration of operation and maintenance costs. The limited qualitative data we have indicates that both operation and maintenance costs are likely to rise after training because trained operators command higher wages and are likely to perform vital routine maintenance tasks that were previously ignored. Further, consideration might well have been given to the value of the possible extended plant life that could result from improved operator maintenance procedures as a result of training.

A further qualification is found in the methodology. The final calculations represent a measure of stop-loss on capital and return on training investment over the life of plants only if it is assumed that the plants had always, before training, been operating at the level of effectiveness measured just prior to training (during the first quarter of 1971) and that they will continue, after training, to perform at least as well as the level achieved just before training (in the last quarter of 1971). Obviously performance in the past and future may vary with a variety of independent phenomena, such as quantity and quality of influent, plant age, and so forth.

Nevertheless, we believe that the calculations presented in Exhibit 16 do offer a reasonable benchmark of the value that can be attributed to investment in wastewater treatment plant operator training. If these figures overstate the value of training investment by as much as 50 percent, the conclusion that the payoff an operator training investment is enormous remains valid.

On the basis of this study, it is not possible to state with certainty that the training investment results that are presented in this report may be imputed to operator training in general throughout the state of Texas and throughout the country. The fact that in 12 of the 16 plants called before Operation Cleansweep in the first quarter of 1971, training had no apparent influence on subsequent performance improvement does not say that trained operators were not essential to effective operation in those plants. It does say that without regard to the status of operator training in those plants, other adjustments in plant, equipment, staffing, or funding were necessary before improved operating efficiency would be possible. We can accept as fact that in many plants—and probably most plants—training acts in combination with other factors to cause effective performance. Yet the fact that a number of cases were found in Texas in which training could be identified as the only significant variable leading to effective performance signifies that training is by itself, as well as in combination with other factors, critical to realization of anticipated return on capital investment.

Thus far, we have been examining overall return on training investment without reference to the different views of investment and return as they might appear at different levels of the government. Typically the largest share of the capital for investment in a treatment plant comes from the federal and state governments. On the other hand, local governments bear almost the entire operation and maintenance costs. If, as we suspect, the cost of operation and routine maintenance goes up with training, local decision-makers might see a negative incentive to invest in training. This might be true particularly if the local government must pay for all or part of the training.

However, in Texas, as in some other states, there is a very real potential out-of-pocket cost to the local government if its plant effluent is not meeting the state standard. This is a daily fine to be paid to the state for noncompliance; in Texas, it is $1,000 a day for each day of noncompliance. These fines are imposed only after exhaustive efforts have been made by the WQB, and where there is utter disregard for the Board's recommendations. While plant effectiveness varies and generally noncompliant plants may be in compliance on some days, the fine can obviously add up rapidly and become a very substantial sum. Particularly for smaller communities, such a fine would seem to provide an incentive for communities to train operators if this is the action required to reach compliance.

In 17 of our sample cases in Part IV, plants moved from a generally noncompliant to a compliant status substantially as a result of operator training. Bringing a plant into compliance represents a very real return on training investment in the fear of fines avoided for these localities. However, because the fine is a payment from one government body to another—a transfer of money from one jurisdiction to another encompassing jurisdiction—it is not a real saving to the national or even statewide public. Therefore, we have not calculated this as a part of the national return on training.

C. Conclusions Regarding the Return on the Public Investment in Wastewater Treatment Plant Operator Training

The average estimated capital investment per operator is at least $63,700 and could well be closer to $127,400. Further, many individual operators in Texas – and presumably elsewhere – daily hold responsibility for capital plant valued at $200,000 or more. All of these figures are considerably higher than the $10,200 invested on the average by American industry for each of its production workers and support the need for training as insurance that capital will be used optimally.

An analysis of 19 of the case-study plants discussed in Part IV of this report revealed that for every dollar invested in training, the equivalent of an additional $91 investment in capital plant was activated in terms of improved performance. Further, the degrees of reduction of BOD/TSS in plant effluent and levels of overall improvement following training indicate conclusively that for these plants, the value of the return on training was high in terms of both dollar investment and cleanliness of water treated.

APPENDIX A
ECI PER OPERATOR CALCULATIONS FOR 19 CASE STUDIES

	(1) Plant Name	(2) Type	(3) Size	(4) Number of Operators	(5) Population Served	(6) Estimated Capital Investment (ECI)	(7) ECI Per Operator
1.	Kaufman	4	1	5	4,700	164,500	32,900
2.	Corpus Christi (W'Side)	4	3	7	5,000	175,000	25,000
3.	Corpus Christi (B'Way)	5	10	8	82,000	400,000	50,000
4.	Mathis	4	1	5	5,800	174,000	34,800
5.	Lockhart	4	1	5	6,900	207,000	41,400
6.	Jasper	1	3	6	5,000	150,000	25,000
7.	Beaumont	4	3	6	34,000	544,000	90,666
8.	Brownwood	4	1	5	18,000	342,000	68,400
9.	Midland	4	5	7	61,700	678,700	96,957
10.	Odessa	7	5	9	72,300	795,300	88,367
11.	Grandview	7	*	1	1,000	85,000	85,000
12.	Forney	4	*	1	1,750	78,750	78,750
13.	Plano	4	5	7	13,000	260,000	37,142
14.	Nocona (South)	7	*	1	4,375	153,125	153,125
15.	Bridgeport	1	*	1	3,000	140,000	140,000
16.	Gainesville	4	1	5	15,000	300,000	60,000
17.	Brownsville	4	5	7	53,600	643,200	91,886
18.	Donna	4	1	5	6,600	198,000	39,600
19.	Edinburg	4	1	5	20,000	360,000	72,000

*Under .5 MGD

ACKNOWLEDGMENTS

Harbridge House wishes to acknowledge the assistance of the Texas Water Quality Board (WQB) in permitting this investigation to be made and materially assisting in its execution. The WQB generously provided most of the data on the case examples and the statistical studies from their extensive and well-organized files and reports. Also to be thanked is the Water Resources section of the North Central Texas Council of Governments (NCTCOG) whose personnel materially helped in data collection and served as a sounding board for some of our findings.

Despite the generous assistance of these two organizations, the findings, conclusions, and recommendations presented in this report remain the responsibility of Harbridge House.