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COMPUTERIZED MONITORING FOR LEAKAGE DETECTION IN WASTE SUPPLY SYSTEMS

Leslie J. Blythe[1]

INTRODUCTION

Water supply systems are vital arteries in the operation of any city, yet here the age old adage "out-of-sight, out-of-mind" is particularly apropos. The nonhazardous nature of water combined with low retail water prices contributed to an attitude where large system losses were traditionally tolerated. Today, however, problems of deteriorating infrastructure and costly capacity expansion have brought system losses under closer scrutiny. A program which continually monitors system performance in real time would aid in establishing a data base for pipeline repair/replacement decisions as well as conserving water when supply is limited or when the most readily available sources have already been utilized. These problems are not unique to utilities with old systems or in isolated geographical areas. On-line computerized monitoring is thus considered for potential improvements in network operation and maintenance.

To implement computerized monitoring, the program must be both technically and economically viable. First, conventional methods of leakage detection are reviewed to recognize their underlying limitations and identify the possible advantages of the proposed scheme. A brief system description follows including the suitability of existing computer and instrumentation technology. Design hurdles and possible difficulties are also addressed. For economic justification, the benefits of computerized leakage detection must outweigh the associated costs. To determine so, the methodology for a benefit-cost analysis is outlined. Lastly, sensitivity of the ultimate cost justification to several important input variables is taken up. In conclusion suggestions for future work are offered. The objective through these steps is to integrate the relevant engineering and economic concepts and

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evaluate computerized monitoring for leakage detection in municipal water supply systems. For a more in-depth treatment of the subject including causes of pipe failures see Blythe (4).

METHODS OF LEAKAGE DETECTION

Methods of leakage detection have ranged from laissez-faire to active audits and surveys done on an annual basis. Currently practiced detection methods will be discussed in order of increasing sophistication.

The so-called "laissez-faire attitude" may perpetuate when the system performs "well". Despite apparent losses, supply meets demand and there may be little incentive to locate failures. In such a case, no organized detection program exists. The utility responds to customer complaints and by doing so establishes a passive pattern to its detection approach. Standard practice which responds to emergency items only can escalate the costs of later rehabilitation (22) and result in large water losses.

A second approach relies on chance discovery. In municipal locations water mains are normally located in proximity of other utility lines such as electric cable, underground telephone, gas, fire, or sewer. Service workers in these areas may detect leaking or broken mains in conjunction with their work and report any failures. The same applies for highway related excavations. Additionally, visual surface inspection will prove to be unreliable since the number of leaks which surface constitute a small percentage of the total number occurring.

Organized leakage detection programs can be aggregated into four major approaches. The first employs acoustic equipment; the second conducts a water audit; the third utilizes correlators, and the fourth applies tracer gases. The first two are traditional methods, the third incorporates the more recent state-of-the-art equipment, and the fourth is undertaken in special cases when other methods cannot be used.

Acoustic devices work on the principle of sound transmittal. Leaks emit a characteristic noise allowing identification by an experienced operator. The general survey is a two part process where distinction is made between bracketing and pinpointing, pinpointing equipment being of greater precision.

A district is typically covered by crews of one to three who listen at consecutive checkpoints in attempt to "bracket" or locate a leak. Several disadvantages should be noted. Accurate system mapping does not always exist which complicates the bracketing process (18). Detecting characteristic leak noises is a skill sometimes requiring 10 to 15 years experience before full development. Therefore, the use of experienced personnel will ultimately determine the program's effectiveness.

Even when trained personnel are available, limitations exist. Problems of sound propagation may occur depending on pipe material (e.g., cast iron, concrete, PVC) and soil type (i.e., better transmittal in sands than clays). Large leaks with slow velocities may have a less intense sound and go unnoticed, while small leaks under high pressure might emit an intense noise and are detected even though much less water is being lost. Conventional equipment does not reconcile this pressure-velocity difference. Other practical difficulties arise because changes in the piping system and depth of cover will change the characteristic leak noise. In cases of multiple leaks, one may overwhelm the others and a single leak is perceived.

Another serious problem occurs from background interferences. Traffic, subways, pumps, construction, and other ambient urban noises may render leak detection virtually impossible. In an attempt to alleviate these complications, night surveys have been conducted. Overtime charges have increased the real costs of these maintenance programs, and by and large, they have not occurred in depressed or high crime regions.

The second major approach taken in traditional leak detection programs is the water audit. In the audit check point scanning is replaced by flow metering, and failures are later pinpointed using sounding equipment. An area is divided into smaller districts and pitometers and/or master meter recorders are used to determine if a zone's minimum night ratio is above a prespecified expected level. One immediate shortcoming is that the cutoff ratio is selected from empirical observations and is not rigorously tested. The issue of zone decomposition is also an important factor which influences the accuracy of district metering but has received little attention. Additionally, a water audit will not provide accurate enough flow measurements to determine if inaccurate metering is a major contributor to the problem.

Leak noise correlators represent more state-of-the-art equipment and have much higher accuracy in pinpointing leaks than traditional sounding devices. The primary advantage of such systems is that they more effectively screen out background interference noises and are accurate within one to three feet (10), (31). Improved accuracy is valuable not only in locating leaks which were previously undetectable, but also in real cost savings through fewer "dry hole" excavations. For example, dry hole excavations in New York City accounted for 10% of street openings (16).

While leak noise correlations are more advanced than traditional equipment, several disadvantages should be noted. The equipment is expensive and time consuming which has limited its present use to applications where conventional equipment has failed or where conventional apparatus cannot be used. For example, at a rate of 3.7 miles/day, a complete survey is expected to take five years in Denver (39). Trained personnel are necessary and the equipment is bulky requiring van-mounting with an associated follow up crew. For a more detailed treatment of the principles of operation and equipment, further readings by Field (14) and Arnac (2) are suggested.

The last method of leak detection discussed regards tracer gases. In general, use of these has been restricted to special cases and to times when acoustic methods can not be undertaken. Tracer gases are very expensive primarily due to highly sensitive detection equipment or dewatering procedures. Because tracer gas techniques are not practical as part of a regular maintenance program, no further attention is devoted here.

GENERAL SYSTEM DESCRIPTION

At this point we need a better idea of what computerized monitoring for leak detection entails and how the system would operate. The first major departure from conventional methods is that computerized monitoring utilizes on-line detection rather than periodic surveys. By installing pressure and flow gauges at specified locations, a continual record of system operation is provided. Data becomes available on a 24-hour basis and departures from "normal" operating levels can be alarmed or printed out. The contrast becomes evident; the best of the traditional techniques undertook routine surveys on an annual basis while the frequency of other audits ranged from one to five years. As has been well documented (30), (35) the possibility for large leaks going unnoticed over long periods (years) has resulted in huge water losses.

A second major distinction of computerized monitoring is that all measurements can be signaled i.e. telemetered back to a central location. It does not require that work crews be sent out or scheduled during evening, early morning, or weekend hours. It also allows updated knowledge on the entire system rather than updated knowledge on a small segment (~5 miles) surveyed during any particular day.

To implement a computerized failure identification program, the issues of instrument placement and system operation must be addressed. The location of monitoring sites and determination of normal operating pressure and flow ranges are the two design elements considered here.

Specifying appropriate monitoring sites will depend on the system configuration, network characteristics, and equipment limitations. Regarding the first, measurements will be required at all branch points. Otherwise, it would be impossible to preserve the continuity relationship between stations and determine where losses occur. Individual network features will also influence the location of monitoring sites. If it is known that particular zones experience large losses (i.e., geographic "hot spots"), then it will be more worthwhile to place monitoring devices in these troubled areas given a limited budget. Without prior information on areas with above average failure rates, a survey can be undertaken and monitors installed in pipes of greater importance, where priority is established by diameter. The remaining aspect of gauge placement regards placement density. Namely, how closely should monitoring stations be spaced. The separating distance will largely be determined by the equipment accuracy. Instrumentation will function reliably within a specified distance interval, and spacing will be limited by this equipment design range.

The second and more difficult design area of computerized monitoring regards the actual detection parameters. Here we must answer the question of what are the appropriate alarm levels to indicate system failures while allowing for normal variations in pressure and flow. To answer this, failures are segregated into the two component parts - breaks and leaks. The distinction is made because the two events differ in nature; breaks are abrupt while leakage is a gradual deterioration process. Identification of the two cases will differ, thus requiring both pressure and flow devices.

Commencing with breakage, we need to alarm conditions outside of the normal operating range. Both pressure and flow in the network will fluctuate due to a roughly diurnal water demand schedule (8), (40). Furthermore, demand can be classified seasonally where summer outdoor uses often attribute to peak periods. Estimates of the mean and standard deviation demand schedules can be used to determine normal operating ranges.

The basic idea of the failure detection mechanism is to examine whether each additional pressure or flow measurement lies outside a specified region around the estimate of the corresponding mean value (m). This region can be defined as a multiple of the associated standard deviation (s). If so, a possible failure event is identified. Subsequent observations will confirm failure and initiate an alarm. Otherwise, the system is considered to be operating normally, and the measurement is used to update the mean and standard deviation estimates. For a discussion and derivation of these statistics see Blythe (4).

Turning now to the more gradual event of leakage, deterioration will occur more slowly over time than by a pronounced impact. Consequently, pressure changes may be too small to detect by short interval comparisons. As an alternative, simultaneous flow measurements at consecutive monitoring stations can be used to conduct a water balance where a difference in inflow minus outflow can be attributed to leakage. Based on pipe class, a threshold level above which leakage is unacceptable can be defined.

Just as pressure levels fluctuate with the diurnal demand, flow and leakage rate will also follow the same characteristic pattern. To avoid repair/replacement decisions based on extreme data, focusing on average leakage should smooth out these fluctuations. Since, the effects will be more noticeable for longer periods, measurements should be averaged to record system decay over time (weekly, monthly, yearly).

As a final note on operation, computer downtime is sometimes mentioned in the literature as a significant handicap. However, the applications reporting problems have much more of a chemical control orientation and are usually in the treatment sector. Downtime in computerized monitoring results in a loss of information not quality degradation. The system performs no more poorly than before program implementation. Problems of downtime are further reduced by the decentralized nature and possibility to telemeter information to a central storage bank. In short, this criticism is not perceived to be a real problem for on-line monitoring.

EQUIPMENT AND AUXILARY SYSTEMS

The equipment requirements and related features of a computerized monitoring scheme are computer hardware, software, instrumentation (pressure indicators, flow recorders) and telemetry devices. The general movement in the computer industry in the recent past has been away from mainframes and towards the use of microcomputers, where the latter have already been successfully employed to alarm exceedance limits (15). Rapid technological hardware advances in this area have had several important consequences, a major one being a reduction in overall system costs. In response, a market for software has arisen leading to a variety of available packages at low costs. The implications of this progress on computerized monitoring in water supply networks favor a decentralized computer scheme which readily lends itself to a complex information network with transfers between many sites.

Smaller capacity computer obsolescence is largely unanticipated for two main reasons. First, they will still be usable in their originally planned function and second, software compatibility developments, as have already occured, are expected to continue as larger memory capacity is achieved. Additional peripheral equipment has also been developed to extend the memory capacity of smaller models.

The software transformation is equally noteworthy. Previously, programs were designed for a particular system or for the specific needs of one application causing large developmental costs and difficult debugging procedures. Now more general, documented software packages are readily available at low costs. The trend is away from in-house reliance on a systems programmer and towards operational ease by water resource engineers and operators. In fact, Marks and Noonan (20) suggest that at least 75% of present computing needs can be done without special programming.

Desirable sensor characteristics are reliability, accuracy, little drift, and infrequent maintenance. Well documented experience with pressure and flow instrumentation has occurred in the wastewater industry where the major problems have been due to "dirty" applications and instrument fouling. However, problems of this nature should not exist on the supply side. As a final note on instrumentation, Edwards (13) extends a basic warning regarding detection of erroneous data. Gradual drift and loss of calibration may go undetected for long periods if data is directly supplied to the CPU unless some validity check is incorporated in the process. Dual sensors are expensive and both may drift and still mutually agree. The suggestion is made to automatically incorporate calibration checks on-line.

Having obtained pressure and flow readings, data transmitted is the next concern. Operationally, a telemetering system connects data sources to a common location over communication channels. These channels could be telephone lines, radio links, microwave signals, or power lines, although phone lines have been most common. Given the number of monitoring stations and remote locations, water supply systems will involve complex telemetry.

The system described thus far has focused on computerized monitoring. However, data acquisition only represents one aspect in the range of computer capabilities. A system might begin with monitoring applications, expand to analysis, and eventually include on-line control. Alternately, utilities who presently computerize some aspects of operation may augment their present functions to incorporate leakage detection. The notion of progressive or phased computerization is summarized by Figure 1 which also illustrates how a decision maker can use the results.

In the initial phase (P-1) the automatically collected information can directly update the inventory of mains in the network on failure record and operating conditions. This updated inventory can then be used for phase two (P-2) analysis (e.g., failure rate vs. diameter, age, pipe material, etc.) as

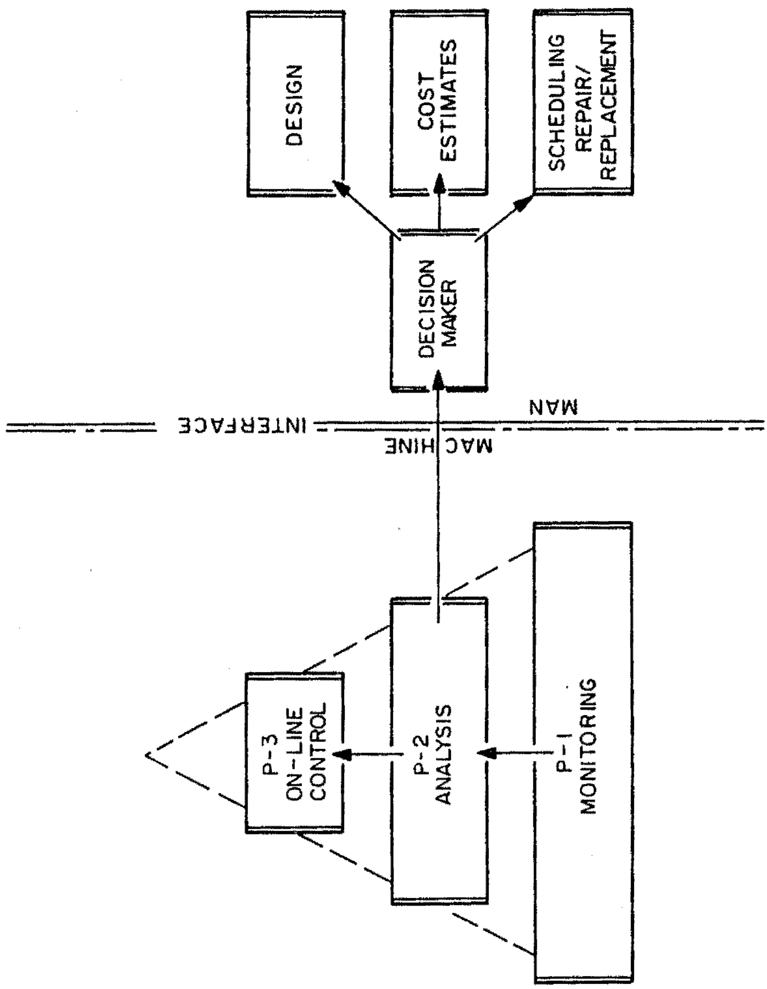

Figure I Phased Development of Computerization well as input to the decision maker in modifying design criteria for pipeline replacements or in estimating and testing predictive models. These models can then be used to project future maintenance costs. Additionally, results from the analysis can be used in scheduling repair vs. replacement decisions. Maintenance can be prioritized according to actual losses on an immediate and as needed basis when system failures are identified. In phase three (P-3) the computer and instrumentation can automatically perform control functions. (e.g., valve or pump shut-off; pump motor speed adjustments). The same conductors carrying telemetering signals in one direcion can carry control information in the other, although the number of monitored and controlled points need not be the same. Some applications in the water industry are now examined to illustrate these points.

COMPUTER AND INSTRUMENTATION APPLICATIONS IN THE WATER INDUSTRY

Computers, pressure sensors, flow meters and telemetry have all been used in wastewater treatment, water quality monitoring, and distribution. Some uses in the past were motivated by high energy costs. Now as municipalities face the prospect of capacity expansion and unaccounted-for-water figures on the order of 30%, the economic climate may be ripe for computerized leak detection. Several domestic and foreign programs are examined to cite examples of the above and to identify future industry trends.

A recent example of a flow monitoring program applied to a wastewater collection system can be seen by the St. Louis Metropolitan Sewer District (SLMSD). As part of the public works maintenance program, SLMSD implemented a low cost, long-term flow monitoring system (28) in response to sewer maintenance problems - 370 collapses occurred in 1981 alone. Flow sensors were selected to measure flow, and data were telemetered to a microcomputer (monitor) over phone lines. The system has been used in design, planning, infiltration/inflow studies, rehabilitation, and maintenance scheduling.

Computerization has also been useful in water quality monitoring. The New York State Department of Environmental Conservation has applied a computer system to data collection, command transmittal, and alarming limits (7). The system operates under the management by exception principle where deviations from prespecified norms are displayed for later correction.

The business extensions of computerized systems have saved time, increased efficiency, and performed tedious calculations. Billing and accounting procedures have been greatly facilitated where reports previously requiring days or weeks of preparation can be completed in minutes. An important use has been in conjunction with preventative maintenance. The Army Corps of Engineers undertook a study of the network in Buffalo, New York where a primary objective was to develop a computerized inventory file (11). Once the inventory is computerized, the network can be analyzed for failure rates and likely causes. The study also suggested which parameters to encode for each pipe (19).

Domestically the following three case studies are considered in greater detail: Philadelphia, Atlanta, and Denver. In addition, selected applications in England, Japan, and Germany are also examined. Each of these has implemented forms of computer control in their distribution system. Development has proceeded in stages, for the most part, in much the same way as the phased process described in the general system description. Although specific classification may not follow the phase-one, -two, and -three breakdown shown in Figure 1, developmental sophistication increases in much the same way.

The Philadelphia system is undertaking automation and computerization of its water and wastewater treatment plants. A central facility, called the Load Control Center (LCC), monitors and controls pump stations throughout the distribution system. Pressure, flow, water elevation, and chlorine residual data are telemetered to the LCC by microwave frequency multiplexing via remote satellite stations (17). Control commands are similarly sent by microwave radio signals to operate booster pumps, service pumps, and distribution system valves (9). The following are among the functions performed by the LCC: data logging, inventory of mains, computerized network mapping, trend analysis, leakage data analysis, an updating of predictive and a repair/replace model, stray current locating, and frost monitoring (41). The overall program is a phased development (5 stages) and proceeds from monitoring through complete automation. Control has focused on chemical feed (water quality) and pumpage (energy savings) (27). Conservative estimates of chemical, power, and labor savings break even with the costs of automation at three to five years (1), (27). The management information system (MIS) approach to distribution planning is recommended as well as an infiltration/inflow (I/I) survey (29).

Atlanta's water distribution system is remotely monitored and controlled, the primary objective being energy conservation and reduced power costs. The first computer system was installed in 1975 to monitor average and hourly flow rates and pressures (36). After two years of successful operation, the decision was made to fully computerize the distribution system which can be incremented as the network expands. In 1979 a dual computer system was installed to (i) monitor the system for pressure and flow rate and (ii) to control remote pumping. Data have been helpful in detecting main breaks, although this was mentioned as secondary. The central computer generates reports automatically and alarms high and low exceeded limits. No major maintenance or programming problems were reported.

The last domestic application addressed pertains to automation in the Denver system. Denver has undergone a phased development since the 1950's when pump stations were automated. The first efforts focused on power conservation as in some cases above. Later phases were aimed at computer operation of the distribution system and automation of the treatment plant facility (7). The centralized system is broken down into two parts, data acquisition and process control. Dual computers divide the two functions and provide redundancy in the event of a power failure (25). Remote multiplexing has lead to faster response times. Economic justification was based primarily on power savings, process efficiency, and valid data collection.

In the late 1950's a 15 year program was designed in Sugarbrook, England to minimize costs for the East Worcestershire Waterworks Company (EWWC) supply network. Today the system is fully automated where minicomputers are used in monitoring and remote control (21). Telemetering successfully utilized radio links (where only one 12 minute interruption occurred in 10 years). The aim of the control scheme was to minimize pump costs, and 5% order of magnitude savings were noted. Operators supervise and check for abnormalities such as main bursts. However, before automation progresses to this area, it was felt that further study was required.

The Wessex Water Authority (England) extends the aim of minimizing pump costs to include locating and reducing water loss by pressure and flow control (21). Although the pump control scheme is not as sophisticated as that of the EWWC, prediction is also applied to pressure and flow control with "striking results in savings on distribution losses".

Other on-line computer systems have been implemented in England. One fairly sophisticated system in Hamburg utilizes multi-processors (12). Routine tests performed include data scanning and limit checks of all monitored inputs. Exceeded limits are alarmed and logged. The system can recognize pipe ruptures, initiate corrective action through pump and valve control, and compute fault frequency statistics.

Ongoing British research in automation is being conducted by the Water Research Centre for the utility industry. A five year program was established by the National Water Council, a large part of which addresses leakage and detection in distribution systems. Particular focus is being given to accurate measurement of pressure and flow distributions and to automatic analysis of leak data. Full-scale facilities in water distribution, treatment, and sewage treatment to test instrument control and automation specifications are planned. The potential for on-line leakage detection has also been recognized in Japan where the need to incorporate preventive maintenance control into a computer hierarchy has been emphasized (26).

Work in Germany has applied leak detection and localization to both compressible and incompressible fluids. Small leaks in gasoline pipelines have been isolated using pressure drop and flow rate measurements, and the technique can also be applied to water mains (33). Utilizing cross correlation, this technique has been implemented on a microcomputer and tested on a gas line under actual operating conditions (34). Setting up an artificial leak to obtain system specific data is suggested. This application represents the closest parallel to computerized monitoring for leak detection and a strong evidence of operational feasibility.

To conclude this section on applications, what we can extract from experience in the water industry is that the technology exists, that it has been successfully implemented in varying degrees of sophistication, and that expected future trends will proceed along the lines of expanded automation. In the next section the benefits and costs of computerized monitoring are identified to determine if financial incentive is provided.

BENEFIT-COST ANALYSIS

In evaluating the program's economic viability, two perspectives can be taken depending on the utility's ownership, namely municipal (government) or investor (private) with the breakdown in the U.S. being roughly 70-30 respectively (32). In the government owned case, maximizing social welfare is the appropriate criterion while under an investor owned scenario net gains to shareholders determine worthwhile investments. The real difference between these perspectives is not so much a generic identification of benefits and costs but rather a question of where the boundaries are drawn. In either case maximizing net present value will measure the economic gain.

The net present value criteria measures economic viability through monetary benefits exceeding the costs. Future dollars are discounted to account for current investment opportunities. The discount rate can also account for risk in that a safe dollar is worth more than a risky one. Additionally, risk can be incorporated by taking a range of benefits and costs with an associated probability density function to arrive at an expected value.

Benefit-cost analysis forces one to define and quantify the benefits and costs associated with the project. Transfers should not be included while any externalities should. Benefits and costs are classified as direct or indirect, direct being a primary result of the project while indirect measuring secondary impacts. Benefits and costs are assessed using market data where available. Where market inefficiencies occur or when no market exists, shadow prices can be employed to reflect "true costs". This can be particularly important in valuing water which has traditionally been underpriced. In the absence of a market, impacts such as water quality, human health, or inconvenience may be exceedingly difficult to quantify. These indirect effects, however, may be important, and an analysis which avoids mentioning them at least qualitatively will under or over state the actual net benefits. Using creative measurement techniques, some of the problems can be avoided.

Traditionally, a variety and a combination of investment criteria have been used in deciding if a project should be undertaken and how to prioritize or establish rank among competing alternatives. These criteria include payback, average book return, internal rate of return, the benefit-cost ratio, and net present value (NPV). Limitations of the first four are well documented (6), and we conclude in support of NPV.

To measure NPV, the benefits (B_t) and costs (C_t) in each period t are projected. Since we are interested in improvements generated by the project, aggregate benefits must be greater than total costs. To compare this net effect today, future forecasts are weighted by an appropriate discount rate (r). Net present value is thus given by

$$NPV = B_o - C_o + \frac{B_1 - C_1}{1+r} + \frac{B_2 - C_2}{(1+r)^2} + \ldots + \frac{B_n - C_n}{(1+r)^n} = \sum_{t=o}^{n} \frac{B_t - C_t}{(1+r)^t},$$

where $t = 0$ initial period,

$t = n$ project life (typically years).

$NPV > 0 \rightarrow$ Project adds value to the utility or increases welfare.

$NPV = 0 \rightarrow$ Project does not change the existing status quo.

$NPV < 0 \rightarrow$ Project contributes no net gains.

It is not the intention here to create NPV as the panacea of investment decision making. Cash flow estimates may be difficult to reliably forecast, and there is the never ending debate on selecting an appropriate discount rate. However, NPV is based on a sound theoretical framework and does not suffer from the shortcomings of other criteria. In the final evaluation sensitivity analysis is suggested to see how responsive the results are to changes in uncertain inputs.

A specific evaluation can only be done for a particular municipality. The results and ultimate decision are subject to system dependent inputs where the economic justification is determined by the level of leakage, water pricing, water treatment and pumpage (energy) costs. The results from one city (utility) can not be applied to another unless the basic inputs are analogous. Additionally, depending on whether a public or private perspective is appropriate, values for discount rate, benefits, and costs will differ. Consequently, an overall methodology to carry out a detailed analysis is undertaken here.

To present this overall methodology, a general slate of benefits and costs generated from computerized monitoring is defined, and steps for their measurement are itemized. Benefits are taken up first, for certainly if these are found to be insignificant, there is no need to conduct detailed cost estimates. The discussion of costs follows with the same progression from direct to indirect.

Direct Benefits

The direct benefits of computerized monitoring are considered as the potential cost savings over existing practice. When compared to conventional methods, these primary benefits result from prompt failure identification. Leaks and breaks which could previously go undetected for years and lose vast quantities of water (on the order of 10^6 gallons per day; (30), (35)). This brings us to the first direct benefit considered - the value of water saved.

The value of water saved is based on two dominant variables: (i) the quantity of water lost and (ii) the price of water. Estimating the quantity of water lost is addressed first, and water pricing is discussed in the sensitivity analysis section. The quantity of water lost depends on the number of system failures, the leakage rate, and the time until detection and repair. Two levels of maintenance programs are considered, active and passive, to show how the amount of water lost can be estimated for each.

We begin with the simpler case of an active leak detection program where good maintenance records have been kept. Given this data, the number of system failures can be estimated. If a sufficiently long historical record exists, it can be used for parameter estimation of a model predicting the expected number of failures in future years. The records should also contain the approximate leakage rates which can then be used to come up with an average leakage rate (gpm) for the system. Knowing the approximate number of failures and average leakage rate, the last required estimate is duration.

In general, the time to detection will depend on the failure intensity and the method of detection. For major breaks or serious outages customer complaints will be reported even without a monitoring program; the event is assumed to be so severe as to be noticed within hours. However, the smaller magnitude leaks may go undetected for long periods and it is primarily these where monitoring will make a real difference. Once identified, the repair time is taken to be the same with or without on-line monitoring and therefore it is not pertinent in the comparative analysis.

With respect to maintenance programs, detection time is a direct function of survey frequency. For example, if a sounding program is undertaken every two years, then an upper bound on the maximum time before detection is provided (ignoring deficiencies of surveys and sounding devices). A more realistic approach might use the average time between surveys and is suggested here. In the next section, we examine the economic feasibility vs. the quantity of water lost which will be a very useful measure in light of the duration argument above.

Greater difficulties are encountered in passive maintenance programs due to the lack of data and routine surveillance. A rough way to quantify the amount of water lost is through the unaccounted-for-water (UFW) estimates. By examining the fraction of total UFW attributable to leaks and breaks and having defined the degree of "allowable" leakage (i.e. that level below which it is uneconomical to detect and repair), an estimate of economically recoverable water loss can be obtained by the difference. The main problem with this method is that total UFW estimates may be very inaccurate and the fraction assigned to failures even more so.

As an alternative to deriving a water loss estimate from UFW, some engineering studies have derived results based on different assumptions. In the Boyle study (5), the number of leaks and average leakage rate were based on agency interviews and a demonstration project. A two-year duration was assumed in calculating benefits. Using utilities with detection programs as a reference, the rationale given was that small leaks could go longer without a detection program while large leaks would be detected sooner. In the absence of better data, this duration assumption does not appear to be unreasonable. In Boston's MDC Demand Management Report (37) only losses from main breaks were directly estimated. The number of breaks used was obtained from city records. While these numbers may be justified for main breaks, lower level leakage is not included in this category. No attempt was made to estimate each of the quantity components (number, rate, duration). Instead a variation on the UFW approach was taken (called a flow profile in that context). An aggregate estimate for savings from 10 communities was derived rather than individual assessments, despite the wide variety in maintenance programs.

Given a lack of data, what can be said about intercity comparisons and extracting information from one city for use in another? If statistical information is based on pipes of the same characteristics (e.g., material, diameter, age, or age span) and if operating environments are similar, then data on the number of breaks per length should be useful in the network lacking data. Likewise, average leakage rates should be transferable. On the other hand, the time until detection should reflect the particular maintenance program. This approach offers advantages over the UFW estimates since the potential for errors in the latter is large. It also provides more reliable and justifiable estimates than by straight assumptions.

Lacking reliable data, information from actively maintained systems can be transferred to systems of passive maintenance. Instead of reducing water loss estimates to a single number, one can obtain (by regression analysis of break frequency on significant variables) the most likely range of variation for a given class of pipe and evaluate the effects on a probabilistic basis. Uncertainty in the estimate is therefore directly encoded.

Once the quantity of water saved has been established, two other direct benefits can be computed as a result of these savings. These are reduced energy and chemical costs which will vary for different utilities. Typical cost estimates are sometimes quoted but should be verified for a particular system. The estimates, however, are straightforward to obtain.

In addition to the above, the last direct benefit discussed is delayed capacity expansion. Construction of new facilities can be deferred because the water savings are like an effective decrease in total demand. Alternatively, this can be viewed as an effective increase in capacity allowing the postponement of capital expenditures. Given investment opportunities, the value of deferred system expansion can be approximated for a community of projected growth rate and future demand. Potentially preventing lost water, saves on power, chemical, and capacity expansion costs. We now turn to the indirect benefits which indeed are numerous.

INDIRECT BENEFITS

One area for benefit realization is reduced infiltration/inflow (I/I). Leaks from the water supply network find their way into the storm and sewer system thereby increasing the required waste handling and treatment capacity. On a nationwide basis it has been estimated that one-half of all wastewater treated is attributed to I/I (28), a fraction of which is due to leakage. While the previous focus has been on the supply side utility, the treatment industry will also benefit from the program. Sometimes these two utilities fall under the same jurisdiction in which case reduced I/I would be a direct benefit. The cost savings will depend on the amount of reduced I/I and the associated treatment costs.

A second area for utility cost savings can result from fewer lawsuits. Liability for property damage has varied with the case, but the established precedent has been to prove a utility's negligence. With a monitoring program in place, not only should there by less ensuing damage but the utility will also have stronger grounds to win its cases. The costs of litigation are high and difficult to predict. To estimate cost savings, previous legal fees (attorneys, courts, and awarded claims) should be examined. Depending on the degree of on-line implementation, an average of previous expenses could be reduced by roughly the same proportion as program development. This procedure assumes that damages are virtually eliminated which is not unreasonable if data are frequently reported and repairs are prompt.

Another benefit to the utility includes increased revenues. Increased revenues represent income from water which would otherwise be lost, provided that demand exceeds supply (as in the western U.S.). An estimate can be derived from the retail price of water times the potential water savings. If demand is satisfied at the existing price level, then recovered losses will not increase revenues. The water savings allow the total number of consumers to increase without making current clientele any worse off.

Other benefits to the utility include increased reliability and fewer service interruptions. Overall system operation will improve as a consequence of 24-hour monitoring. Specific measures of reliability are not considered at this time. However, one possibility would be the expected decrease in emergency maintenance costs. The remaining benefits discussed qualify as intangible for our purposes. The effects are either deemed too difficult to measure, or they are mentioned as peripheral benefits but are unlikely to make a significant difference in the analysis.

Improved water quality would result from less infiltration/inflow and better repair scheduling both of which reduce the likelihood of contamination before and during repair. Valuing water quality is a near impossible task if one were to ask individuals for their personal assessments. Since water is a public good, individuals have an incentive to over-value quality in hopes of enjoying better grade water but avoiding the associated costs. Alternatively, a reduction in chemical treatment costs on the utility's behalf would measure the quality change, but it is unlikely that this effect would be large enough to notice or could ever be separated out from general reduced chemical usage.

Repair costs should also be lower as a result of timely failure identification. Leaks and breaks detected and repaired at an early stage will not have the chance to magnify and bring about future deterioration, but these effects are very difficult to measure before program implementation. After the fact, actual repair records can be compared (normalized to account for a greater number of identified failures). However the valid comparison is with vs. without computerized monitoring not before vs. after.

An additional public benefit from the business sector is discussed but not quantified. Businesses have suffered economic hardship from water main bursts, and a reduction in failures of this magnitude can represent significant savings. It has been reported that on average two water main breaks per day occur in New York City which have sizeable impact on businesses

(23). In many instances commercial/retail shutdown is temporarily required. The devastating effect of a main break during a seasonal peak period in New York City's garment district exemplifies this point (26). Numerous other instances could be sited, but the locations and durations all lead to different displacement and damage costs. Having convinced ourselves that the potential benefits are indeed significant, we now consider the corresponding costs.

DIRECT COSTS

The direct costs of computerized monitoring are fairly straight-forward to identify generically and are attributed to equipment purchases, installation, operation and maintenance, and staff training. All of these primarily focus on detection. Leakage control requires that identified failures are corrected, and the corresponding repair cost should also be considered. In general, the direct costs like the direct benefits will be system specific depending on the project design, system size, and degree of implementation.

Computer hardware costs will primarily be a function of the number of decentralized and central read out units where estimates can be obtained from equipment manufacturers. An examination of existing software packages will determine suitability of different equipment brands. Many of the computerized applications include cost summaries, but these either differ too widely or are too outdated to be useful.

Pressure sensors and flow recorders are the next major items on the cost schedule where cost depends on the number for optimal placement throughout the system. Once it has been regionally decided where to implement monitoring, costs can be solicited from manufacturers. Since excavation for placement will be a large component, the comparison should be made on installed basis.

The third major area of cost appraisal involves telemetering. Once the number and location of monitoring sites are known, the telemetering equipment options can be examined. Many of the most economical applications cited in the literature have multiplexed over rented phone lines. In the absence of nearby lines, other communication channels must be examined and priced out.

Additional costs include related equipment such as multiplexers and transmitters. Again costs and options can be obtained from manufacturers.

In conjunction with installed equipment costs, operating and maintenance (O+M) cost estimates should be estimated. These estimates can then be compared to manufacturer's actual service records for similar applications where available. While an analogous system is unlikely to exist, installation listings should reveal parallel components in other systems where service histories and repair records can improve cost estimates. Any additional wages of operators should also be included.

Failure correction is the last direct cost considered as part of the network maintenance program. Having identified leak/break locations, they must be fixed either by repair or replacement for the overall plan to be effective. There is no reason to believe that the repair or replacement costs for computerized monitoring should differ from other leak detection methods. Departures occur in the method of detection not the corrective action taken. Walski (38) has approximated these cost functions for water supply systems.

INDIRECT COSTS

The indirect costs identified are not numerous but capture important consequences such as possible displacement or disruption to the public and difficulties the utility might experience in implementation. The first two may be quite significant and the last items are included for completeness.

Perhaps the most important externality to the public regards the method of financing. If the government (state or federal) provides any grants or low interest loans, this is a subsidy which occurs at the taxpayers' expense. The utility receives a direct benefit, but taxpayers pay the bill. Because this situation represents a transfer, it is not quantified. However, the distributional effect should be overlooked.

A second major indirect cost regards public inconvenience during instrument installation. Monitoring devices are placed on-line in the distribution network which will require considerable disruption in heavy traffic areas. Customer service will be interrupted and it may take years to complete a full project implementation. No attempt is made to quantify inconvenience or disruption here. However, these effects will be sizeable. (For a discussion of travel time inconvenience valuation see Mishan (24).)

The next displacement considered is drawn from the investment side of the evaluation. Economic arguments have been made that a proposed project should consider the opportunity cost of public funds, and theoretically this is true. However, an opportunity cost rationale can be incorporated through the discount rate, where the opportunity cost is measured by the amount of displaced consumption and investment. Consequently, the opportunity cost is not tabulated as a cost in its own right but can be implicitly considered in discounting.

As impedences to carrying out a computerized program, a shortage of technical personnel and operator resistence are sometimes mentioned. With respect to the former, concern is justified in the short run, but training should eliminate some of the new demand for skilled labor. Regarding operator resistence, reorientation of present staff would hopefuly eliminate any employee fears and attempted barriers.

This completes the discussion of costs and benefits. Sensitivity of the analysis to uncertain or variable inputs is considered in the next section.

SENSITIVITY OF THE DECISION TO INPUT VARIABLES

Having identified the inputs for the benefit-cost analysis, we now examine how these values will determine project feasibility. Namely, how changes in the inputs can alter the decision to go ahead with project implementation. If significant price changes occur, the net gains at some future time may be sizeable even if the project is not justified by current standards. First, changes in the value of water are considered by examining the amount of water lost and the price of water. Then, changes in computer equipment, energy, and chemical costs are discussed. Lastly, different levels of discount rate and project design life are incorporated by looking at the parameters over actual values for selected U.S. cities.

For municipalities with low levels of leakage, present implementation is not likely to be justified, at least on a city-wide basis. If particular geographic "hot spots" exist, then the program may be feasible for small scale development. On the other hand, areas experiencing large water losses are likely to incur sufficient savings to offset the costs of capital investment. Insufficient current cost savings do not rule out future viability. Small leaks may undermine bedding, precipitate freezing, or bring about greater system failures if uncorrected. In short, condition of the physical system is not static, and the decision may change in time or over geographic boundaries.

One of the problems facing both public and private utilities is ineffective water pricing. The price of water in the majority of cases is set artificially low and does not reflect the true cost of providing service. By and large, water has not been viewed as an economic good, and the conventional approach has been to treat it as a requirement rather than a quantity demanded. Costs should be assessed on an incremental basis to insure price reflects the cost of the last unit consumed, otherwise known as marginal cost pricing. When water is underpriced, there will be little economic incentive to prevent system losses, and this in turn will influence the maintenance program.

Additionally, computer costs enter the analysis as determinants of the direct benefits and costs. As technology expands and more software is developed, costs in the computer industry will decrease. Indeed, this trend has been observed in the past, and if prices drop, a program currently unjustified by the NPV criterion may be worth implementing at a future date.

Changes in energy pumpage and chemical treatment cost levels should also be considered. Increases in these, which are likely to occur given inflationary pressure, will bring about greater cost savings as more water is conserved.

Choices of project life and discount rate determine how benefits and costs are accrued. Project life specifies the period over which benefits and costs are forecasted, and discount rate establishes how heavily those benefits and costs are weighted. For long term projects differences in project life are expected to be small since the distant effects are most heavily discounted and thus contribute relatively little to the overall net effect. In the next section a range of typical values for several of the above inputs is used to show how the decision to implement computerized monitoring might change.

EXAMPLE OF SENSITIVITY ON THE VARIABLES USING SELECTED U.S. CITIES

We would like to define the threshold above which the best decision is to implement the project. The threshold marks the point of indifference where computerized monitoring just covers its costs but generates no additional savings (i.e., NPV = 0). Once project costs are known, they can be compared to the present value of benefits at particular levels of the variables to assess feasibility.

In computing the value of water saved, the degree of unaccounted-for-water (UFW), price of water (P_W), discount rate (r), and expected project life (T) were all varied. UFW figures were obtained from the AWWA 1981 Water Utility Operating Data (3). A cross section of U.S. cities experiencing different levels of losses were selected. These cities represent a fairly diverse geographical area and are listed in Table 1 along with total UFW estimates.

Table 1 Unaccounted-for-Water Estimates in Selected U.S. Cities

City	Range (10^3 gallons/year)	UFW (10^3 gallons/year)
Anchorage, AK	0 - 500,000	295,600
Ann Arbor, MI	"	298,318
Jacksonville, FL	"	308,967
Wilmington, NC	500,001 - 1,000,000	698,921
Richland, WA	"	731,722
Clear Rapids, IA	"	900,754
Albany, NY	1,000,001 - 2,000,000	1,000,000
Topeka, KS	"	1,230,800
Orlando, FL	"	1,785,417
St. Paul, MN	2,000,001 - 4,000,000	2,400,000
Omaha, NB	"	3,254,000
Toledo, OH	"	3,480,470
Rochester, NY	4,000,001 - 6,000,000	4,471,678
Denver, CO	"	4,589,551
Indianapolis, IN	"	5,069,820
Birmingham, AL	6,000,001 - 8,000,000	6,733,000
Louisville, KY	"	7,035,000
Kansas City, KA	"	7,860,000
Dallas, TX	8,000,001 - 10,000,000	9,226,775
Seattle, WA	10,000,001 - 12,000,000	10,031,673
Long Beach, CA	"	11,307,536
San Antonio, TX	"	11,815,000
Los Angeles, CA	12,000,001 - 14,000,000	12,700,000
San Jose, CA	14,000,001 +	24,362,263
El Paso, TX	"	31,330,143
Detroit, MI	"	38,005,600

As previously mentioned, system failures are only a fraction of total UFW. Furthermore, not all losses can be recaptured. In line with these considerations, it was assumed that 20% of total UFW represents recoverable losses. This assumption was only made for illustrative purposes; recoverable losses must be assessed for a particular system.

The retail price of water was likewise obtained by referencing the 1981 Water Utility Operating Data (3) and different literature citations. A range of \$0.50/1000 gal to \$2.00/1000 gal (in \$0.50 increments) includes the average rate of most cities. Since retail values alone can be misleading, marginal costs of 5.00, 10.00, and 15.00 \$/1000 gal were assumed to include the costs of capacity expansion for illustrative purposes of the calculations. Similarly, these must be verified in an application. Since present value was found to be a linear function of the price of water (Figure 2), a marginal cost comparison can be done by extrapolation.

A discount rate of 5 - 17.5% was selected to include reasonable estimates of both public and private sector evaluations. The lower range of 5 - 10% was chosen for public evaluations while the upper range of 10 - 17.5% should be reasonable for the investor owned case. Present value was estimated at every 2.5% interval.

Lastly, given uncertainty on how long equipment will satisfactorily operate, sensitivity is carried out for the expected project life. A range of 15 to 50 years was selected in 5 year increments.

Results of the various present value calculations are summarized by Figure 2. To assess the sensitivity, one variable was changed while holding the others constant at a representative value. These values, considered to be the nominal case in the present value calculation, are as follows: 3 billion gallons UAW, 10% discount rate, \$1/1000 gallons retail water price, and 25 year expected project life. Other nominal values would result in a parallel shift of the curves.

Looking at Figure 2, it can be seen that the decision strongly depends on discount rate and water price but is not very sensitive to project life. UFW estimates will also influence the outcome, but the magnitude of these is so large that errors of this scale are unlikely. To illustrate these sensitivities, we examine how much each variable must change to produce an equivalent impact on present value.

A 5% error in discount rate (say from 5-10%) would result in a \$3 million

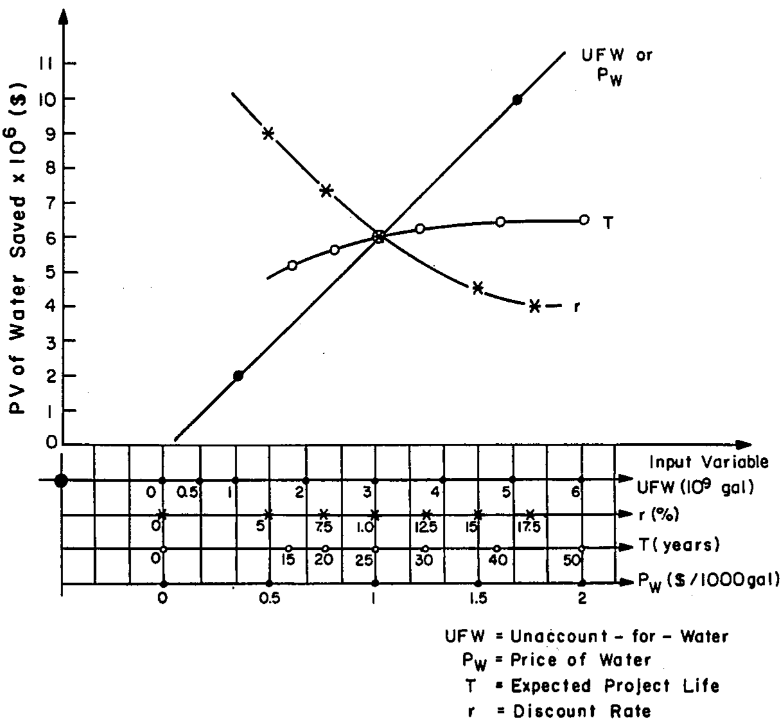

Figure 2 Sensitivity of the Present Value of Water Saved to Input Variables

underestimate of benefits in the present value calculations. The decision is thus highly sensitive to r at the low range encountered in public evaluations. Within the private realm discount rate is not quite so sensitive. The same 5% error (only this time in the 10-15% interval) results in a $1.5 million underestimate which is still significant but not as critical.

A $3 million present value misestimate can also occur from $0.50/1000 gal underpricing in retail water values. Given existing practice of artificially low water rates, this represents a serious problem if the evaluation is based on current price structure. As mentioned, an efficient evaluation would use a price equal to marginal cost strategy. Capacity expansion is thereby incorporated. (This is consistent with the concept of shadow pricing.)

UFW follows the same linear pattern as water price; however, the horizontal axis differs in magnitude. The reference $3 million PV error would result from 1.5 billion gallon UFW inaccuracy. While the decision to implement is sensitive, it is unlikely that an error of this magnitude would occur. From Table 1, 1.5 billion gallons is larger than some of the total UFW estimates. For cities at the upper end of the loss scale, a 1.5×10^9 loss might be possible. (For example, this is approximately 4% of the amount reported for Detroit.) Care should be taken in reviewing total system losses before this sensitivity is applied or dismissed.

Finally, expected project life is varied over a 15 to 50 year design period. The entire range roughly accounts for a $1.3 million PV difference. The change in benefits between 5 year intervals is not large or very significant provided equipment need not be replaced. These results make intuitive sense from the PV equation. Distant future events are more heavily discounted and therefore benefits (or costs) at this horizon make little contribution.

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

Given sizeable water losses in urban distribution systems, attention for corrective action focused on leaks and breaks since they are large contributors to the problem of unaccounted-for-water. Because UFW estimates can be very unreliable, future attention should also be directed towards meter maintenance programs and towards more extensive metering especially in the public use category.

Conventional leakage detection techniques have some underlying limitations such as background noise level interference, reliance on operator skill, and infrequent survey frequency. With these limitations in mind, computerized monitoring was proposed. On-line detection offers the advantage of prompt failure identification and large corresponding water savings. Drawing on instrumentation experience and computer applications in other areas of the water industry, parallels to demonstrate technical feasibility can be drawn.

Before detailed costs can be worked out, additional study is needed to make specific instrumentation and equipment choices. Basic pressure and flow sensors are well established, but detailed comparisons of individual types and models will be required for an application of the magnitude involved. Likewise, careful examination of telemetry options should be undertaken.

Structuring the computer system will be a major effort needing future research. On-line monitoring is essentially an information network. How the network will be put together, the level of interaction between decentralized computers and a central data bank, and the number of pipes each computer can handle are all crucial but still undetermined design issues.

Once the technical evaluation has been completed, the benefits and costs can be quantified to determine economic feasibility. Using the net present value criterion, benefits greater than costs justify program implementation. These benefits and costs were defined along with procedures for estimating the tangible effects.

The largest expected benefit is the value of water saved, a quantity determined to be highly sensitive to discount rate (especially in the lower range of public evaluations), and to the price of water. Sensitivity to UFW can be considered as moderate and depends on the magnitude of losses. The expected project life beyond a 25 year design period has little effect on the decision to implement. The largest expected costs are associated with computer equipment and instrumentation. The final results and ultimate decision are system specific. Results for the same system may even change over time as greater losses evolve or if price structure changes.

To arrive at a definitive conclusion, the evaluation must be undertaken for a particular city. Computerized monitoring represents a potentially viable technique for failure identification and addresses the issues of technical and economic feasibility on a preliminary basis. What is now called for are more in-depth analyses on the specific design issues and cost assessments. As more information develops, we can look to developing standards for leakage measurement and better estimating techniques for "allowable" leakage. Here one step is taken in the direction of an effective maintenance program and towards improved distribution control.

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SLURRY PIPELINES — AN OVERVIEW[1]

Robert R. Faddick[2]

INTRODUCTION

Slurry pipelining involves the transportation of particulate solids in a liquid carrier through a pipe under pressure. The liquid most commonly used is water, although liquors, brines and hydrocarbons (fuel oil, methanol, crude oil) have been used. The solids are usually products of the mineral industry, although agricultural and food products are also pipelined in slurry form. The mineral solids may be raw ores, beneficiated ores, or wastes such as tailings. Some examples are coal in oil, salt in brine, iron concentrates in water, and fly ash in water.

Generally, most slurries are inert, that is, non-reactive. Occasionally, reactive slurries are encountered where some or all of the solids can be partially dissolved in the liquid carrier, e.g., trona in water, or salt in water. The saturation level of such slurries is temperature-dependent. For purposes of throughput determination, the ratio of undissolved solids to dissolved solids is of concern when the brine carrier is separated from the solids and is recirculated. Otherwise, the total delivered solids, both undissolved and dissolved, contribute to the pay load.

There are mineral slurries which are inherently inert until made reactive by chemical treatment. For example, power plant scrubber sludge (calcium sulfate or sulfite) can be treated with a hardening agent which increases the slurry viscosity with time until it eventually sets up like concrete. Obviously, the slurry residence time of transportation in a pipe is minimal compared to the time for stabilization in a waste area.

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While the emphasis here is on mineral slurries, many unusual slurries have been pipelined. These include many kinds of waste products - sewerage sludges, bagasse (waste sugar products), and household garbage. Other interesting mixtures that have been pumped are peas in water for food processing (without being damaged by pumps), one-meter long pulpwood logs, live fish pumped past hydro-electric turbines, and grass seeds mixed with wood-fiber mulch for hydraulic revegetation of mountains. Appendix A lists numerous slurries which have been pumped.

Long distance pipelines have several advantages:

1) They have low operating costs which are relatively immune to cost escalation. However, their capital costs can be high. The major cost of a long distance pipeline is the steel pipe.

2) Pipelines have high reliability. Some water pipelines are over 100 years old and are still operating. Many of the long distance slurry pipelines are available well over 95% of the time. Some use factors are nearly 100%.

3) By their nature of being pressurized containers, pipelines require little manpower and are conducive to automation. The economics of long-distance pipelines are enhanced by high volumes of steady throughput which are also conducive to automation.

4) Overland pipelines are normally buried in trenches below the frost level. Consequently, they are out of sight, allowing for an aesthetic right of way which can be restored quickly to its original appearance. Of all the transportation modes, buried pipelines are probably the

least harmful to the environment.

5) The health and safety aspects of slurry pipelines, particularly buried pipelines, are noteworthy because the slurry is totally contained. This type of transportation mode is relatively quiet; few slurries emit toxic fumes, and the slurries do not come into contact with the general public where accidents can occur. Furthermore, many pipelines have an enviable record of longevity.

6) For the most part, slurry pipelines use water as the carrier liquid. It is generally the most abundant and inexpensive liquid although there can be exceptions depending on the source of solids being transported, their market destination, and the end use or process.

THE PAST

The earliest known slurry pipeline transported a gold bearing gravel-water slurry in a California placer mining operation in the late 1850's. In 1889, a patent claim was filed by W.C. Andrews for a slurry system although no record exists of its application. In 1904, coal pipelines were mentioned in a patent application by W.T. Donnelly of Brooklyn, N.Y.

The earliest working coal slurry pipeline was operated in England in 1914 by G.G. Bell. It transported 50 tph of 50% coal by weight at 1.2m/s in a 200-mm diameter pipe a distance of 600 m from barges in the Thames River to a power house. In the U.S., an anthracite sludge line was built in the late 1920's near Mt. Carmel, Pennsylvania. The pipeline was 1.6 km long and carried solids at 40 to 65% by weight.

Today's list of slurry pipelines is extensive, whether one considers long distance pipelines only, or whether one includes every slurry pipeline over one kilometer in length. Appendix A gives an idea of the range of commodities, solids throughput and pipeline diameters and length. The list is by no means complete but does show a preponderance of mineral commodities. Although this section will emphasize mineral solids, it does recognize the application of slurry pipeline technology to the transportation of food products, agricultural products, encapsulated solids, and three-phase (solids-liquid-gas) mixtures.

The mineral slurries, the transported product,may be a raw ore, a beneficiated ore, or a waste, called tailings. The tailings may be discharged into a settling pond, returned to a mine as backfill for ground support, or developed into a useful product such as landfill by the addition of a stabilizer. Several companies have found certain stabilizers which produce a landfill with fairly high load bearing capacities. For example, the Synearth process developed by the Dravo Corporation (Ref. 1) in the United States adds a cement-like stabilizer to a power plant wet scrubber sludge containing fly ash and sulfur dioxide compounds.

THE PRESENT

It is obvious from Appendix A that slurry pipeline technology is well established. This means that the technology is sufficently well understood so that a systems approach to slurry pipelining can be applied. Adequate information can be obtained for each element of the system. For example, most slurry pipeline systems involve preparation of the slurry at the commodity source, pipeline transportation from source to market, and, possibly, solids separation (dewatering) at the user point. Dewatering is not always necessary ; some examples being the calcining of a limestone-water slurry, or direct combustion of a coal-oil slurry or a highly-concentrated coal-water slurry.

Preparation of a slurry usually involves crushing and grinding of the solids, perhaps some cleaning and sorting, all followed by a mixing of the solids with water. Crushing and grinding are expensive. Therefore, reduction in particle size should be minimized wherever possible. Figure 1 shows a typical relationship between the cost of slurry preparation and the degree of reduction of particle size for coal. The particle size is represented by a weighted mean particle size (Ref. 2) for convenience.

There are two possible constraints in minimizing solids reduction: market requirements, and a solid size amenable to pipeline transportation. The first constraint tends to be nebulous at times. Rigid market specifications for particle size are not always dictated by product end use (e.g., combustion of coal) but by past experience and preference in materials handling. Lump solids are preferred because they are less dusty and handle more easily than powders, even though the end use may require a powder.

On the other hand, the pipeline transportation constraint is more explicit. It is a well known fact that fine solids are easier to pipeline in slurry form than coarse solids. Energy requirements to pump a slurry are high for coarse solids but decrease rapidly to some minimum value as solids size is reduced. Furthermore, pipe wear by erosion can be severe with large particles. If the solids are made too small however, (approaching near-micron sizes) the energy requirements for pipeline transport climb rapidly because a thick paste-like slurry develops. Fig. 2 shows such a cost-particle size relationship for the pipeline transportation of coal (Ref. 2). Slurries of fine particles are said to be homogeneous or slow-settling whereas slurries of coarse, heavy particles are said to be heterogeneous or rapid settling. Most mineral slurries are composite in size distribution which is why their evaluation for pumpability is often complex.

At the terminal, the system contains dewatering equipment such as screens, centrifuges, filters, and dryers. Homogeneous slurries are much more difficult and costly to dewater than heterogeneous slurries. Figure 3 shows a typical cost-particle size relationship for the dewatering of coal (Ref. 2).

Regardless of the commodity, if such cost curves can be prepared, as shown above, for preparation, pipeline transportation, and separation, a slurry pipeline system can be optimized with respect to particle size, to give the lowest total cost. See Figure 4.

As with any technology, there are certain problem areas that require special attention. There are three major ones with slurries: flow and pressure requirements, particle size degradation, and wear of pumps and pipes. Depending on the commodity to be transported and the topography to be traversed by the pipeline, the ranking of the problem areas may be interchanged. For example, a gravity line is not concerned with pump wear but with pipe wear. Hoisting coarse solids upward in a pipe must overcome the static lift but pipewall friction itself is small (Ref. 3).

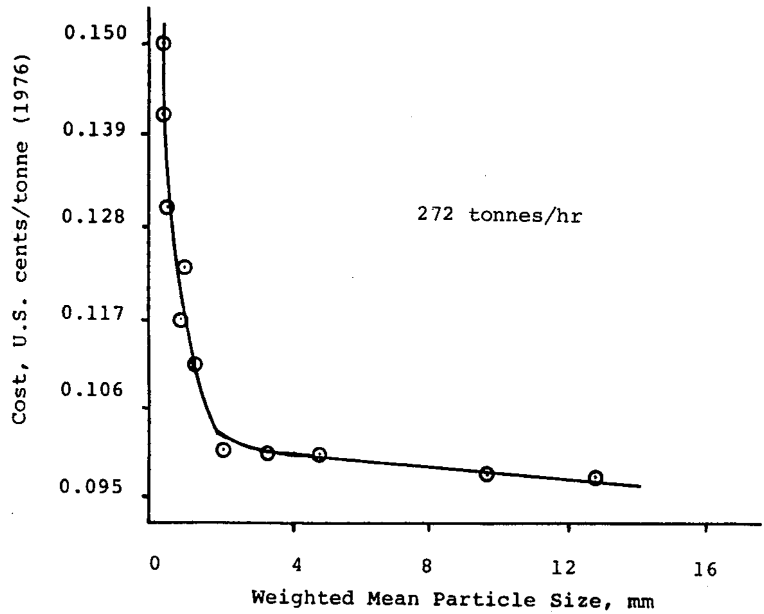

Fig. 1 - Cost Curve for Coal Slurry Preparation

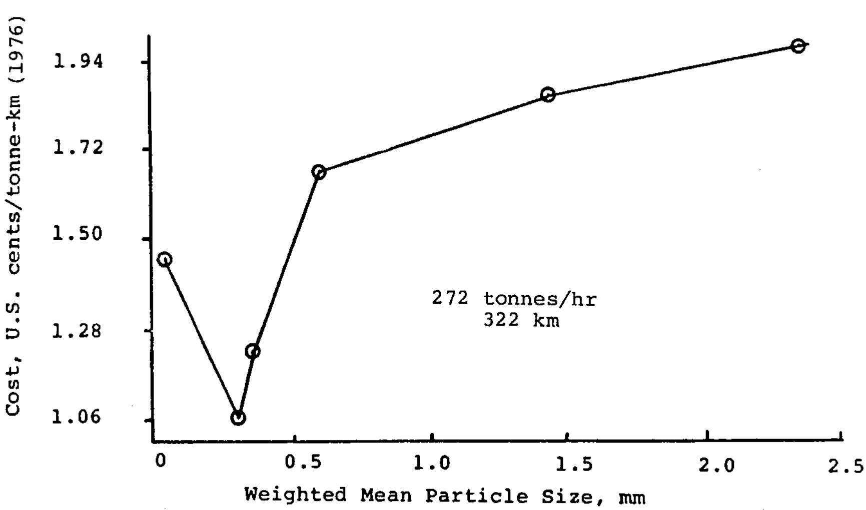

Fig. 2 - Cost Curve for Coal Slurry Pipeline Transportation.

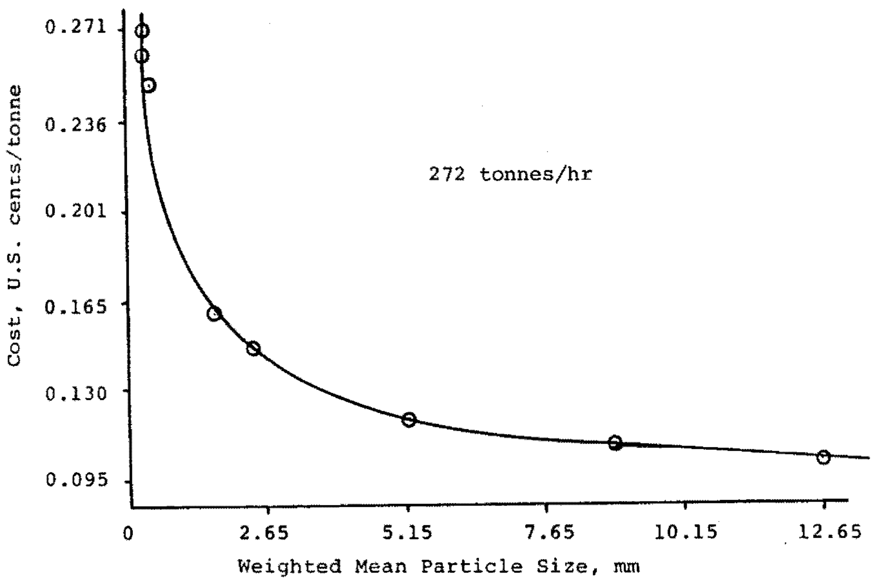

Fig. 3 - Cost Curve for Coal Slurry Separation.

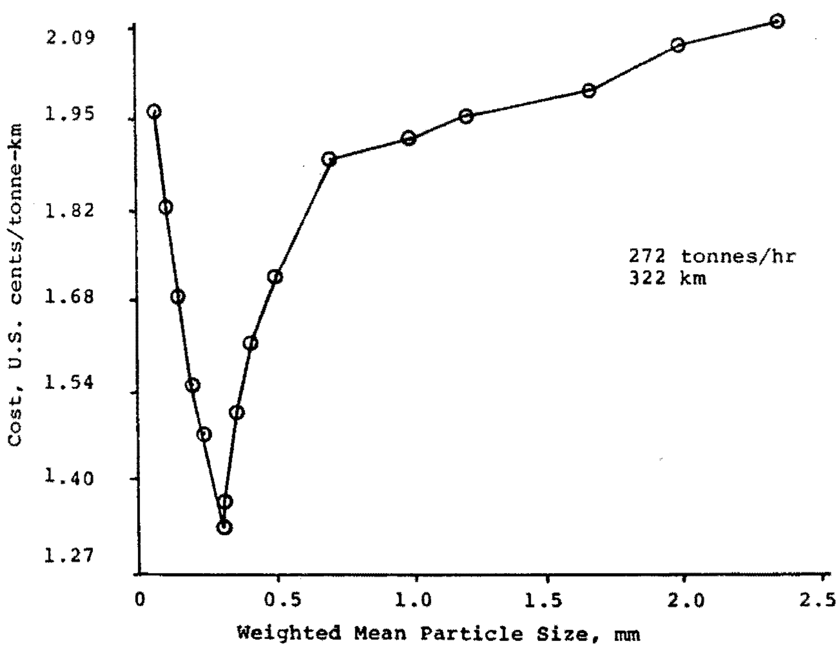

Fig. 4 - Total Cost of Coal Slurry Pipeline System

Generally, it can be said that energy requirements, particle degradation, and pipe wear are proportional to slurry velocity raised to some power, (2 to 3). Therefore, it is desirable to keep the velocity to a minimum such that deposition of solids doesn't cause cessation of flow. While there is an optimum operating point from the viewpoint of fluid mechanics it must be compromised with the economic optimum discussed previously.

The environmental impact of slurry pipelines is probably least of all the transportation modes. It will not be discussed herein except for highlighting one point, that of water contamination. There can be no slurry pipeline without water. If water availability is marginal, extensive water treatment may be necessary and recirculation of the water carrier may have to be considered (Refs. 4, 5). Coal slurries produce black water consisting of minute particles smaller than 50 microns. Removal is difficult and expensive. Woodchip slurries have the potential of imparting high chemical oxygen demand, biochemical oxygen demand, total organic carbon, turbidity levels and color to the water. In addition, pH can be lowered to about 5 (Ref. 6). In comparing the economics of various transportation modes, therefore, slurry water treatment may have to be included.

THE FUTURE

In looking to the future, the growth of slurry pipelines is excellent. In 1960, there were fewer than a dozen commercial slurry test facilities in the world. In 1980, a recent count showed over twelve test facilities in the U.S., over three dozen in Japan, as well as numerous facilities in Europe and the Soviet Union. A number of recent studies are described briefly where slurry pipeline technology shows promise of advances.

The U.S. Department of Energy has recently completed the construction of a Hydraulic Transport Research Facility, the largest in the world. It is a once-through or non-recirculating system capable of handling an initial load of 300 tonnes of coal. Three separate pipelines of 150-, 300-, and 430-mm diameter extend horizontally, declined at 45 degrees, and vertically for a total length of 230 meters. A filtration and clarification system permits dewatering of the coal slurry. The facility was constructed to generate design data and equipment for underground coal mining. Operation of the facility, located in Bruceton, Pennsylvania commenced in late 1980 (Ref. 7).

Pumps

1. The Electric Power Research Institute and the U.S. Department of Energy (DOE) have funded a study to develop a high capacity/pressure/temperature (315 L/s), (20.7 MPa), 290 C) centrifugal pump to discharge coal-oil slurries into liquefaction reactors (Ref. 8). The pump is concurrently being tested at the Colorado School of Mines Research Institute for Rockwell International under DOE sponsorship. Six modules of double-staged impellers constitute a pump set producing all the rated pressure and half the flowrate. Two sets in parallel achieve the total rated flowrate. The module being tested is designed to produce half the total flowrate and one-sixth the total discharge pressure at the rated temperature.

2. The U.S. Department of Energy has funded two studies to develop a high capacity, medium pressure, low profile coal-feeder pump to inject coal into a pipeline in an underground coal mining application (Ref. 9). In 1968, there were 14 hydraulic mines and four hydraulic complexes in operation in the Soviet Union with a total planned capacity of 14 million tonnes of coal per year (Ref. 10). The three largest hydraulic mines include surface pipelines of 10 km each. In North

America, private enterprise has been slow to adapt slurry pipelines both to hydraulic mining and underground coal mining transport. At present, there is only one hydraulic mine in Canada and one underground coal mine slurry transport system in the U.S. The Hydraulic Transport Research Facility operated for the Department of Energy is expected to accelerate interest in underground coal mining transportation by pipeline.

Pipes

1. The future will probably see an increased use of lined pipes, those containing ceramic (both chips and tiles epoxied in fiber-glass), polyurethane, and rubber, to resist erosive wear and corrosive wear in short distance pipelines. Long distance steel pipelines may perhaps be inner coated with plastics to reduce oxygen corrosion and improve hydraulic efficiency provided the joining of steel pipe by welding does not deform the plastic.

2. Work continues on the use of internal spiral ribs in steel pipe to improve the reliability of low flows of slurries. The turbulence created by the ribs re-suspends the solids and offsets the increased headloss normally associated with ribs (Ref. 11).

3. Another scheme is to install a segmented pipe. A horizontal plate is welded to the inner perimeter in the lower part of the pipe. The plate provides a wide, flat base for the solids to flow over and at the same time functions as a wear plate. It has been shown (Ref. 12) that such a segmented pipe reduces the minimum required flow velocity and the power requirements for the same solids throughput compared to a pipe without a plate.

The last two special pipes described above are installed as low-cost short sections of pipe where flow stability is hampered by bedload formation.

Instrumentation

1. Numerous manufacturers have improved the design of an ultrasonic velocity meter which is cemented to the outer wall of the pipe and connected to a digital recorder for a quick and inexpensive velocity measurement (Ref. 13).

2. A three-component sensor is under development by Science Applications, Inc., for the U.S. Department of Energy to measure coal-refuse-water concentration in a hydraulic pipeline. The sensor measures slurry conductivity, transmitted single-energy gamma rays, and transmitted neutrons (Ref. 14).

Slurry Technology and the Oceans

1. The U.S. Marconaflow system (Ref. 15) and the Japanese MIKS Flow system (Ref. 16) have been demonstrated successfully for slurrying iron ore aboard ship and off ship. Coal and woodchips are receiving attention as the next potential candidates for application of slurry pipelining technology to maritime shipping. Research is progressing on four fronts: a test facility is currently under construction in New Zealand to test the pumping aboard ship and dewatering of coarse coal slurries; Marconaflo in the U.S. has been testing the slurrying of coal off-board ship by their Dynajet system; and the Dutch are also studying port facilities for the off-loading of coal from ships. The Japanese have modified a ship for coal slurries and are studying dewatering characteristics.

2. Retrieval of manganese modules from 5 km below the ocean's surface and their hoisting to the mother ship via slurry pipeline will probably be the zenith of slurry pipelining. Several commercial ventures have been struggling with the technology for many years and to date slurry pipelines appear to be the leading contender for the transportation mode (Ref. 17).

Slurry Technology and Energy

1. Coal-oil slurries are seen as a possible means of reducing U.S. dependence on foreign oil by as much as 50 percent. Replacement of half the oil used to fuel furnaces, with coal, would achieve this goal. The U.S. Dept. of Energy has funded several programs to retrofit oil furnaces for coal-oil slurries. These include industrial and electric utility furnaces as well as kilns (Ref. 18).

2. In the process of making clean fuel (solvent-refined coal) from coal, slurries of coal and coal solvent are fed to high pressure and temperature reactors. The properties of the slurries are not well understood and represent an interesting challenge to slurry pipeline technology (Ref. 19).

3. The application of slurry pipeline technology to the transportation of raw and spent oil shales is gaining attention. Both types of shales are amenable to pipeline transportation but the shortage of water in the shale-rich areas may preclude slurry transport (Ref. 20).

4. The transportation of coal in a hydrocarbon liquid carrier over long distances to be fired by direct combustion in a power plant is being considered. This is discussed in more detail in the following section.

Energy Slurries

If direct combustion looks desirable and feasible in the immediate future, the logical extension of this thinking for the long term is to consider a total energy coal delivered in a hydrocarbon liquid carrier. The carrier would be crude oil, synthetic crude oil (Syncrude, Synthoil) or a member of the alcohol family such as methanol.

Crude oil is unlikely to be available where coal is mined. It would have to be pipelined to the coal source and mixed there for slurry transport to market. Possible customers would be utility plants which are presently burning oil and which must convert to coal as oil supplies dwindle or become excessively expensive. Retrofitting, or the modification of nozzles in oil burners to coal-oil slurry burners may be justifiable economically rather than total conversion to coal. Alaskan crude oil and Montana coal or Dakota lignite might be potential candidates for future consideration by U.S. mid-Western or Southern markets. Because of the widely different calorific content and market price of coal and oil, some proprietary research is directed at investigating the separation of coal and oil at the terminus of a pipeline but previous research (Ref. 21) suggests this may be expensive. Therefore, direct combustion of the total slurry may be the best approach.

The concept of creating a liquid hydrocarbon carrier from coal at the mine site is appealing provided more water is not used in the process than that required by coal-water slurry pipeline. Coal liquefaction has the same chemical basis as coal gasification. Only the ratio of carbon to hydrogen in the end product is different. Coal is reacted with hydrogen and oxygen by the application of heat and pressure in the presence of catalysts or chemical solvents to produce a volatile gas or synthetic crude oil. Both end products can be used either directly for combustion or as a refinery feedstock. Coal can be liquefied by four basic methods:

a) direct catalytic hydrogenation
b) solvent extraction
c) pyrolysis
d) liquid hydrocarbon synthesis

Liquefaction consumes from 0.11 to 0.72 liters of water per million Joules. By contrast a coal-fired power plant consumes 3.1 liters/million Joules and a slurry pipeline requires a little over 0.36 liters/million Jourles (Ref. 22). The economics of liquefaction are poorly understood pending further research. Consequently, the economics of producing a liquid hydrocarbon such as synthetic oil or methanol are vague. However, some preliminary work has been done which appears encouraging (Refs. 23, 24, 25).

Where pipeline transportation of energy slurries is involved the transport energy ratio may be defined as the ratio of energy required for transport to the total usable energy delivered. In terms of energy slurries, this can be simplified as the ratio of energy requirement to overcome pipewall frictional resistance, to the calorific content of the slurry transported. Thus, a common assumption inferred is that pump-motor efficiencies, and pipeline minor losses are similar for most energy slurries and are therefore, ignored. Another assumption is that the market use in each case will be combustion of fossil-derived fuel in thermal-electric generation stations. While the water that is separated from a coal-water slurry is used for cooling purposes, it has little energy value for combustion. The transport energy ratio per kilometer is:

$$\frac{\text{specific power x throughput of solids}}{\text{calorific content delivery rate}}$$

kw-hr/tonne-km x tonnes/hr / Joules/hr - kw-hr/Joule-km

where tonnes refer to the weight of dry combustible solids delivered. The specific power is the power required to overcome pipewall resistance in delivering one tonne of dry solids per hour a distance of one kilometer. The smaller the transport energy ratio, the more efficient is the energy slurry for pipeline transportation.

While a minimum ratio is desirable, it is obvious that this is achieved by increasing the concentration of the solids or liquid phase with the higher calorific content. Because the alternate fuels (oil and alcohol) are more valuable than coal, it is apparent that the choice of energy slurry for transport must be optimized in conjunction with its preparation. The availability or processing of the higher priced carrier liquid will be critical. If the oil or alcohol is derived directly from coal, it is probable that processing economics of the refining quality of the carrier will dictate a high coal-low liquid carrier mixture. On the other hand, a low coal-high liquid mix may be preferable where oil-burning power plants are retrofitted for coal-oil slurries.

For combustion purposes, no dewatering costs will be incurred, so effectively this cost can be transferred to the front of the pipeline for grinding the coal to a finer size. Since pulverization of coal to about 85 percent minus 75 microns is necessary for power plant combustion, this grinding cost is not attributable to pipeline transportation. The finely ground coal may allow higher stable slurry concentrations to be produced thus minimizing the amount of carrier liquid. Also, the affinity that coal has for hydrocarbon liquids enables easier slurry mixing, avoiding the often-encountered hydrophobic tendencies of coal in water.

The disadvantage is that if the coal is ground too finely, the slurry becomes paste-like with a high viscosity and a high energy requirement for pipelining. However, the elimination of dewatering costs means that additional costs can be allocated for increased pipeline transportation costs. Furthermore, some proprietary work on chemical additives for coal-oil slurries looks promising for developing slurry viscosity thinners.

Preliminary work suggests a strong potential for energy slurries to become an alternate power plant fuel of the future. If burned directly, this fuel, besides being higher in calorific value, would probably ameliorate the materials handling problems associated with rail-delivered coal or coal-water slurry coal. It is strongly recommended that coal-liquid hydrocarbon slurries be researched at the preparation stage, pipeline transportation stage, and combustion stage to evaluate their economics.

Because energy slurries are combustible, unlike coal-water slurries, their transportation by pipeline would probably present the same environmental and pollution consequences as oil pipelines.

Novel Coal Slurries

Several different types of slurries have been proposed recently:

1. Enlightened slurries consist of froth flotation reagents (alcohol and oil) along with air to cause bubbles of air crusted with fine particles to attach themselves to coarser coal particles thereby effecting a reduced density.

This allows easier suspension of the coarse coal resulting in higher solids concentrations being pumped with less energy. These have been tested by the writer at the Colorado School of Mines Research Institute and results will be published soon.

2. Coal-liquid carbon dioxide slurries are under study by W.R. Grace and A.D. Little, Inc. These slurries are said to offer reduced pumping requirements and easy separation of the coal by depressurizing the slurry to allow the CO_2 to vaporize.

3. Aquatrain is a system proposed by W.R. Grace and Co. to take western coal encapsulated in plastic bags and propelled by western saline water through pipelines to the west coast. There the coal would be easily recaptured while the saline water would be dumped into the ocean.

It is evident that slurry pipelines are an active technology and will continue to attract strong interest.

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SUMMARY OF MAJOR PIPELINE INSTALLATIONS - HORIZONTAL

SLURRY CODE	LOCATION/OWNER	SPECIFIC GRAV. OF SOLIDS	PSD %+-MM	OD X WALL THICKNESS MM	CONC WT.	VEL M/S	L KM	CAPACITY TONNES PER (SEE NOTE)	OPERATION DATES	PUMP TYPE	NO. OF STA	OPER. PUMPS-STANDBY	REF
ASH-T	SUNBURY PA,USA / PA.POWER & LIGHT	2.25	- - -	254.0	10.0	4.39	2.408	39.00 H	1956	CSE -	-	5	1
ASH-T	SAFE HARBOR PA,USA/PA.POWER	2.4	- - -	152.4	17.0	1.62	1.372	20.62 H	1953	CSE -	-	6	1
ASH-T	KAZINCBARCIKA,HUNGARY/BORSOD POWER	---	- - -	200.0	---	---	8.000	70 H	1967	---- -	-	-	-
ASH-T	BUNA WERKE, GDR / IAI	---	- - -	400.0	---	---	12.000	320 H	1979	---- -	-	-	-
ASH-T	NOVAKY, CZECH. / ELEKTRAREN, NOVAKY	---	- - -	250.0	---	---	7.200	300 H	1980	---- -	-	-	-
AU-T	KOLAR,KARNATAKA,IND/KOLAR AU FIELDS	---	- - -	---	---	---	---	---	----	---- -	-	-	6
BAU-T	KORBA,MADHYA PRADESH,IND/BHARAT AL CO	---	- - -	---	---	---	---	---	----	---- -	-	-	6
BO-T	BORON, CA, USA/US BORAX & CHEM CORP	2.6	- - -	127.0	16-26	1.46- 3.66	1.326	---	1957	CSE -	0	2-2	1
CE		3.15	- - -	203.2	---	11.68	0.152	---	1948	?	-	1-1	-
CO-C	BLACK MESA,AZ,USA/SOUTHERN PACIFIC	1.41	99-1.19	457.2 305	48.0	1.768	439	599 H	1970	DAPD 4	3	9-4	15
CO-C	CADIZ,OH,USA / CONS. COAL	1.4	- - -	273.0	50.0	1.52	173.8	1.18E6 Y	57-63	DAPD 2	3	13	16
CO-C	SAFE HARBOUR,PA,USA / PA. POWER	1.85	- - -	323.8	---	---	0.49	1.4E6 Y	1953	C -	-	6	17
CO-C	CHESNICK,PA,USA/ HANNA COAL CO	1.5	- - -	152.4	52.5	2.44	0.792	---	1957	C -	0	-	1
CO-C	POLAND	---	- - -	254.0	---	---	202.8	---	----	---- -	-	-	-
CO-C	CARLING, FRANCE	---	- - -	381.0	25.0	2.59	8.851	1.5E6 Y	1952	---- -	-	-	17
CO-C	NOROVOLYNSKAYA MINES, USSR	---	- - -	304.8	38.0	1.463	61.16	199.6 H	1957	---- -	-	-	-
CO-C	LONDON,ENG / HAMMERSMITH BOROUGH	---	- - -	203.0	50.0	1.200	0.540	50 H	1914	C -	1	1	14
CO-C	WESTFIELD COLLIERY, UK	---	- - -	75.0	---	---	1.100	.2E6 Y	----	---- -	-	-	17
CO-C	WALTON COLLIERY, UK / N.E.	---	- - -	127.0	34.0	2.59	2.010	600 D	1963	CE -	1	3	13
CO-C	MARKHAM COLLIERY, UK	---	- - -	150.0	---	---	0.100	.2E6 Y	1951	---- -	-	-	17
CO-O	SAFE HARBOR,USA/PA POWER & LIGHT	1.85	- - -	298.5	13.3	4.63	.488	154.2E6 Y	1953	CSE -	0	3-3	1
CO-O	ROBINSON RUN MINE WVA,USA/CONS. COAL	---	- - -	254.0	38.0	4.27	.925	60.0E6 Y	----	C -	-	2	-
CO-O	LOVERIDGE,WVA,USA / CONS. COAL CO	---	- - -	504.8	---	---	---	---	1980	C -	-	-	-
CO-O	SUNAGAWA MINE,JAPAN/MITSUI COAL CO.	1.56	- - -	300.0	3.1	4.100	2.200	339 D	1965	C -	-	-	12
CO-O	NOWOKUZNEZK	---	100-100	345.0(5)	---	3.50	10.0	3E6 Y	----	---- -	-	-	11
CO-O	LOTHRINGEN, FRANCE	---	100-1	386.0	---	2.50	8.70	.5E6 Y	----	---- -	-	-	11
CO-O	RUHRGEBIET, GFR	---	100-1	136.0	---	2.20	7.50	.3E6 Y	----	---- -	-	-	11
CO-O	PERMOMAJSK, USSR	---	100-100	200.0	---	3.30	3.00	---	----	---- -	-	-	11

SUMMARY OF MAJOR PIPELINE INSTALLATIONS - HORIZONTAL

SLURRY CODE	LOCATION/OWNER	SPECIFIC GRAV. OF SOLIDS	PSD %+-MM	OD X WALL THICKNESS MM	CONC WT.	VEL M/S	L KM	CAPACITY TONNES PER (SEE NOTE)	OPERATION DATES	PUMP TYPE	NO. OF STA	OPER. PUMPS-STANDBY	REF
CO-O	WOHYNIEN, USSR	---	100-6	300.0	---	1.00	61.0	.3E6 Y	----	---- -	-	-	11
CO-T	FAIRMOUNT,WVA,USA / CONS. COAL CO	---	- - -	101.6	40.0	2.13	.823	---	1953	CSE -	0	3-0	1
CO-T	NORTHERN, WVA, USA	1.4	- - -	101.6	4.0	3.26	.549	2.344 H	1957	CSE -	0	3-1	1
CO-T	DEHUE,WVA,USA / YOUNGSTOWN MINES CO	1.43	- - -	102.1	10.0	1.23	.533	7.312 H	1957	CSE -	0	4-0	1
CO-T	CHESNICK, PA,USA / HARMAR COAL CO	1.50- 1.55	- - -	152.4	50-55	2.438	.792	110.6 H	1957	CSE -	0	3-1	1
CO-T	CANADA	---	- - -	330.2	45.0	1.829	7.242	9090.9 D	----	---- -	-	-	3
CO-T	LIMBURG,NL	---	100-1	200.0	---	2.10	22.0	.2E6 Y	----	---- -	-	-	11
CO-T	SAARGEBLET, GFR	---	100-1	150.0	---	---	1.10	.2E6 Y	----	---- -	-	-	11
CO-T	SAARGEBLET, GFR	---	100-1	150.0	---	---	3.80	.2E6 Y	----	---- -	-	-	11
CO-T	SAARGEBLET, GFR	---	100-1	150.0	---	---	3.80	.3E6 Y	----	---- -	-	-	11
CU-C	KBI TURKEY	---	- - -	127.0	---	---	61.16	0.91E6 Y	----	---- -	-	-	-
CU-C	BOUGAINVILLE	---	- - -	152.4	---	---	27.3	0.91E6 Y	1972	VPL 3	-	2	-
CU-C	ARBITER PLANT,USA	---	- - -	101.6	---	---	---	0.18E6 Y	1974	---- -	-	-	-
CU-C	WIRA / IRIAN JAYA FREEPORT INDO INC	---	- - -	88.9	65.0	1.22	111.0	653 D	1972	VPL 3	-	1-1	5
CU-C	PINTO VALLEY,AZ,USA/CITIES SERVICE CO	---	- - -	101.6	28.0	---	17.7	0.36E6 Y	1974	PL 3	-	2	-
CU-C	ELSD-LIANTA,CHILE / ANACONDA	---	- - -	152.4	---	---	22.53	727.3 D	1959	---- -	-	-	-
CU-C	HAYDEN,AZ,USA / KENNECOTT COPPER CO	4.2	- - -	152.4	26.0	1.28	0.853	---	1958	CSE RU	0	2-2	1
CU-S	GHATSILA,BIHAR,IND/HINDUSTAN COPPER	---	- - -	---	---	---	---	---	----	---- -	-	-	6
CU-T	JAPAN	---	- - -	304.8	---	---	70.81	0.5E6 Y	1968	DAPI 2	-	3	-
CU-T	WHITE PINE,MI,USA/WHITE PINE COPPER	2.7	- - -	587.38	17.5	3.22	1.897	14783.5 D	1953	CSE -	0	4-0	1
CU-T	BUTTE,MT,USA / ANACONDA	2.7	- - -	508.0	30.0	2.844	5.632	25454.5 D	----	CSE -	-	7	3
CU-T	W. VIRGINIA, USA	1.4	- - -	101.6	---	---	---	---	1957	C -	-	4	-
CU-T	W. VIRGINIA, USA	1.4	- - -	102.1	---	---	---	---	1957	C -	-	4	-
CU-T	CANADA / U.S. BORAX	2.6	- - -	127.0	---	---	---	---	1957	C -	-	4	-
CU-T	MONTANA,USA / ANACONDA	---	- - -	508.0	---	---	---	18181.8 D	1964	C -	-	3	-
CU-T	GHATSILA,BIHAR,IND/HINDUSTAN CU LTD	2.80	100-.295 50-.074	219x 7.14	35-40	1.70- 2.2 5	1.0	96-129 H	1974	C RU	-	-	6
CU-T	KHETRI,RAJASTHAN,IND/HINUST. CU LTD	2.80	100-.20 60-.074	355.6x 7.92	50.0	1.63	1.60 1.40	9200 D 5000 D	----	C -	-	-	6
CU-T	MALANJKHAND,MADHYAPRADESH,IND/HIN.CU	2.86	100-.589 52-.074	273x 7.09	25.25	2.5(2)	2.5	252 H	1982	CSE RU	5	2-1	6
CU-T	HIGHLAND VALLEY,CA,USA/LORNEX MINING	2.60	- - -	915.0	36.0	2.00	8.00	19000 D	1975	G -	-	-	-
CU-T	TUSCON, AZ, USA / ANAMEX	2.70	- - -	500.0	30.0	2.00	---	10	1979	G -	-	-	-
CU-T	IDAHO, USA / ASARCO	2.70	- - -	203.0	27.0	2.80	---	---	1978	G -	-	-	-

SUMMARY OF MAJOR PIPELINE INSTALLATIONS - HORIZONTAL

SLURRY CODE	LOCATION/OWNER	SPECIFIC GRAV. OF SOLIDS	PSD %+-MM	OD X WALL THICKNESS MM	CONC WT.	VEL M/S	L KM	CAPACITY TONNES PER (SEE NOTE)	OPERATION DATES	PUMP TYPE	NO. OF STA	OPER. PUMPS-STANDBY	REF
FE-C	WAIPPI(LAND) / MARCONA	4.9	- - -	203.2	45.0	4.88	1.829	323 H	1971	CSE RU	-	10	3
FE-C	WAIPPI(OFFSHORE) / MARCONA	4.9	- - -	304.8	45.0	5.79	2.896	1000 H	1971	CSE -	-	6	3
FE-C	CHONGIN,N. KOREA	---	- - -	---	---	---	98.17	4.1E6 Y	1975	---- -	-	-	4
FE-C	SAVAGE RIVER,TASMANIA	5.0	- - -	228.6	55.0	---	85.30	2.3E6 Y	1967	PL 3	-	4	4
FE-C	PENA,COLORADA-MEXICO	5.0	- - -	203.2	---	---	45.06	1.6E6 Y	1974	C -	-	2	4
FE-C	SIERRA GRANDE,AGTA	5.0	- - -	203.2	---	---	27.36	1.9E6 Y	1974	PL 3	-	3	4
FE-C	LAS TRUCHAS,MEXICO	5.0	- - -	203.2	---	---	402.3	1.4E6 Y	1975	PL 3	-	3	4
FE-C	SAMARCO,BRAZIL	5.0	- - -	508.0	---	---	400.	10.9E6 Y	1977	PL 3	2	14	4
FE-C	CANADA / ANACONDA	---	- - -	---	---	---	225.3	2.1E6 Y	----	---- -	-	-	-
FE-C	LABRADOR-PT.MARMITE,CAN	---	- - -	203.2	---	---	482.8	10.9E6 Y	1974	---- -	-	-	3
FE-C	KUDREMUKH,KARNATKA,IND/KUDR. FE LTD	4.90	100-.104	457/ 406	60-70	1.80- 2.80	66.0	7.5E6 Y	1979	CSE RU	5	1-1	6
FE-T	HUNNER PLANT, USA / M.A. HANNA	3.2	- - -	406.4	16.0	2.92	5.364	---	1955	C -	1	8-0	1
FE-T	STAR LAKE,NY,USA / LAUGHLIN STEEL	2.7	- - -	298.5	20.0	3.66	1.524	---	1957	C -	0	14	1
FE-T	CALUMET,MN,USA / LAUGHLIN STEEL	2.8	- - -	406.4	14.8	2.56	2.621	---	1958	C -	0	1	1
FE-T	CANISTEO,MN,USA / CLEVELAND CLIFFS	2.8	- - -	457.2	17.5	2.68	0.783	318.5 H	1958	C -	0	2	1
FE-T	GRAND RAPIDS,MN,USA / LAUGHLIN STEEL	3.0	- - -	609.6	9.5	2.65	1.633	317.5 H	1959	C -	0	2	1
FE-T	HIBBING,MN,USA / M.A. HANNA	3.2	- - -	488.95	11.0	2.20	3.962	179.1 H	1959	C RU	0	2	1
FE-T	MINNESOTA,USA / M.A. HANNA	3.4	- - -	406.4	16.5	2.93	5.359	211.8 H	1955	C RU	-	-	-
FE-T	KEEWATIN,MN,USA / HANNA MINING CO	3.0	- - -	292.1	45.0	4.572	3.219	5636.4 D	----	C -	0	5	-
FE-T	SELLWOOD,ONTARIO,CAN/ LOWPHOS ORE,LTD	2.8	- - -	355.6	4.0	3.20	0.488	393.6 H	1957	C -	0	6	1
FE-T	MORGANTOWN,PA,USA/BETHLEHAM CORNWALL	3.0	- - -	254.0	35.0	2.10	2.663	169.0 H	1958	C -	0	4	1
FE-T	CALUMET,MN,USA / LAUGHLIN STEEL	3.0	- - -	609.6	6.0	2.40	1.737	78.97 H	1961	CPA -	0	2	1
FE-T	KUDREMUKH,KARNATKA,IND/KUDR. FE LTD	3.04	100-.147 64-.043	457x 9.52	40.0	4.20	2.50(2)	940- 1230 H	1979	CSE RU	5	2-1	6
FE-T	BAILADILLA,MAKHYA PRADESH,IND / NATIONAL MINERAL DEVELOP CORP.	---	- - -	---	---	---	---	---	----	---- -	-	-	6
GIL-O	UTAH-COLORADO,USA/AMER. GILSONITE CO	1.04	- - -	152.4	46.0	1.19	115.9	997.9 D	57-75	PL -	1	2-1	1
G-T	LORRAINE MINE-FREDDIE,RSA / LORRAINE GOLD MINES	2.7	- - -	228.6	50.0	1.33	9.449	150.4 H	1963	CSE -	0	4-4	1
G-T	- - RSA - - -	2.7	- - -	228.6	45.0	1.49	9.144	136.9 H	1957	CSE -	0	4-4	1
G-T	LEAD, SD, USA / HOMESTAKE	3.1	- - -	203.0	47.0	1.85	4.67	1.3	1978	CSE -	-	16	9
G-T	LEADVILLE,CO,USA / ASARCO	3.0	- - -	300.0	30.0	2.00	3.00	---	1975	---- -	-	-	-
GS-T	CREIGHTON,PA,USA/PITSBG.PLATE GLASS	2.5	- - -	101.6	31.0	1.95	1.707	23.45 H	1949	CSE -	2	6-6	1

SUMMARY OF MAJOR PIPELINE INSTALLATIONS - HORIZONTAL

SLURRY CODE	LOCATION/OWNER	SPECIFIC GRAV. OF SOLIDS	PSD %+-MM	OD X WALL THICKNESS MM	CONC WT.	VEL M/S	L KM	CAPACITY TONNES PER (SEE NOTE)	OPERATION DATES	PUMP TYPE	NO. OF STA	OPER. PUMPS-STANDBY	REF
HM-C	AUSTRALIA/TITANIUM & ZIRCONIUM LTD.	1.3	- - -	152.4	---	---	5.633	21.8 H	----	---- -	-	-	-
HM-C	FLORIDA,USA / E.I. DUPONT	3.4	- - -	101.6	---	---	---	40.9 H	1955	C -	-	2	-
HM-C	LAWTEY FL,USA / E.I. DUPONT	3.4	- - -	101.6	40.0	2.47	4.828	41.30 H	1955	C -	8	16-0	1
KC-O	GEORGIA,USA / PHILLIPP CORP.	2.6	- - -	203.2	25.0	1.22	17.70	41.12 H	1951	C -	1	2-0	1
KC-O	GEORGIA,USA / PHILLIPP CORP.	2.6	- - -	203.2	33.0	1.22	25.75	86.31 H	1959	C -	0	2-1	1
KC-O	GEORGIA,USA / PHILLIPP CORP.	2.6	- - -	304.8	25.0	1.22	8.047	137.0 H	1940	C -	0	2-0	1
LI-O	CALAVERAS	---	- - -	177.8	---	---	27.3	1.4E6 Y	1971	DAPI 2	-	2	-
LI-O	RUGBY,ENGLAND	---	- - -	254.0	---	---	91.7	1.5E6 Y	1964	DAPI 2	-	3	-
LI-O	TRINIDAD	---	- - -	203.2	---	---	9.6	0.5E6 Y	1959	DAPI 2	-	2	-
LI-O	COLUMBIA	---	- - -	177.8	---	---	---	0.36E6 Y	1944	---- -	-	-	-
MA	SZENTEGAT,HUNG/SZENTEGATI STATE FARMS	---	- - -	150.0	---	---	8.000	---	1973	---- -	-	-	-
MA	RABAFUZES,HUNG/SZOMBATHELY STATEFARMS	---	- - -	200.0	---	---	4.000	---	1974	---- -	-	-	-
MA	VAROSFOLD,HUNG/VAROSFOLDI STATE FARMS	---	- - -	150.00	---	---	3.000	---	1975	---- -	-	-	-
MA	PIROSKA, HUNG/SZOLNOKI STATE FARMS	---	- - -	150.00	---	---	4.500	---	1976	---- -	-	-	-
NI-C	CANADA	---	- - -	203.2	28.0	1.829	12.07	1818.2 D	----	---- -	-	-	2
NI-T	WEST MINNESOTA,USA / WESTERN MINING	---	- - -	101.6	---	---	6.920	.091E6 Y	1970	---- -	-	-	-
ORE	HUNGARY / ERCBANYA VALLALAT	---	- - -	250.00	---	---	7.000	---	1979	---- -	-	-	-
PHM-O	BARTOW,FL,USA/ARMOUR AGRIC. CHEM. CO	2.75	- - -	406.4	25.0	3.658	3.200	544.31 H	1955	C -	3	4-0	1
PHM-O	FLORIDA,USA / SMITH-DOUGLAS CO INC	2.7	- - -	406.4	25.0	3.658	3.200	---	1960	C -	-	4	-
PHM-O	NORALYN MINE,FL,USA/INT. MIN&CHEM CO	2.6	- - -	457.2	35.0	5.029	7.62	---	1974	C -	-	7	-
PHM-O	NORALYN MINE,FL,USA/INT. MIN&CHEM CO	2.6	- - -	508.0	35.0	5.029	7.62	6.2604E6 Y	1974	C -	-	7	2
PHM-O	NICHOLS FL,USA / MOBIL CHEMICAL CO.	2.7	- - -	457.2	35.0	3.658	2.743	1056.1 H	1971	C -	4	3-1	2
PHM-O	LEE CREEK,NC,USA / TEXASGULF	2.7	- - -	457.2	35.0	3.322	4.420	4.754E6 Y	1966	C -	5	2-3	2
PHM-O	WHITE SPRINGS FL,USA/OCCIDENTAL CO.	---	- - -	508.0	37.0	5.090	5.273	1674.7 H	1965	C -	4	4-0	2
PHM-O	BONNY LAKE MINE,USA / W.R.GRACE	2.6	- - -	457.2	32.5	4.572	8.230	5.622E6 Y	1946	C -	10	10-0	2
PHM-O	FORT MEADE,FL,USA / USS AGRICHEM. CO.	2.65	- - -	508.0	30.0	4.724	3.658	1373.8 H	1968	GIW -	4	4-0	2

SUMMARY OF MAJOR PIPELINE INSTALLATIONS - HORIZONTAL

SLURRY CODE	LOCATION/OWNER	SPECIFIC GRAV. OF SOLIDS	PSD %+-MM	OD X WALL THICKNESS MM	CONC WT.	VEL M/S	L KM	CAPACITY TONNES PER (SEE NOTE)	OPERATION DATES	PUMP TYPE	NO. OF STA	OPER. PUMPS-STANDBY	REF
PHM-O	TAPIRA-UBERABA,BRAZIL / VALEP	3.2	- - -	244.5	61.0	1.658	119.0	2.0E6 Y	1978	REPL 3	-	2-1	2
PHM-O	TENOROC MINE FL,USA/SMITH-DOUGLAS CO	2.7	- - -	406.4	35.0	3.962	3.962	792.1 H	1960	CSE -	4	4-0	1
PHM-O	COLUMBIA,TN,USA / MONSANTO CHEM. CO.	---	- - -	254.0	25.0	3.719	0.137	12.07E6 Y	----	C -	2	2-2	-
PHM-O	SLIVER CITY,FL,USA/SWIFT AGRI CHEM CO	2.5	- - -	508.0	30.0	4.511	2.164	---	----	C -	-	3	2
PHM-O	WATSON MINE,FL,USA/SWIFT AGRI CHEM CO	2.5	- - -	406.4	30.0	4.267	8.717	734.7 H	----	C -	-	7-7	2
PHM-O	MANATEE CO.,FL,USA/BEKER PHOSPHATE CO	2.65	- - -	635.0	34.0	5.500	3.962	15.42E6 Y	----	C -	-	5-0	2
PHP-O	CONDA,ID,USA / JR. SIMPLOT CO.	2.95	- - -	127.0	50.0	5.014	2.295	191.9 H	----	CRU -	0	1-1	2
PHP-O	CONDA,ID,USA / JR. SIMPLOT CO.	2.95	- - -	203.2	50.0	5.014	2.295	---	----	CRU -	0	1-1	2
PHP-O	SYDNEY MINE FL,USA/AMER. CYANAMID CO	2.65	- - -	406.4	35.0	3.63	6.096	787.2 H	1949	CSE -	1	7-3	1
PHP-O	ACHAN&NORALYN MINE FL,USA / INT. MIN & CHEM CO.	2.7	- - -	508.0	40.0	3.66	6.437	---	----	C -	9	9-5	1
PHO-C	MATON,RAJASTHAN,IND/HINDUSTAN ZN LTD	2.95	100-.30 90-.053	73x 7.14	58-68	1.25- 1.9 5	10.5	15 H	1982	V PL 3	1	1-1	6
PHO-T	MATON,INDIA / HINDUSTAN ZN LTD.	2.8	- - -	127.0	40.0	0.488	1.500	8.913 H	1976	WSP -	1	1-1	2
PHO-T	FLORIDA,USA / CHEMICAL CO.	2.6	- - -	406.4	---	---	---	---	1959	C -	-	5	-
PHO-T	FLORIDA,USA / CHEMICAL CO.	2.6	- - -	355.6	---	---	---	---	1952	C -	-	7	-
PHO-T	/ PA. POWER & LIGHT	2.1	- - -	254.0	---	---	---	---	1953	C -	-	2	-
PHO-T	SULLIVAN MO,USA/ MERAMEC MINING CO.	4.2	- - -	101.6	15.0	---	0.274	---	1964	CRU -	-	1-0	-
PHO-T	NICHOLS,FL,USA / VI-CAROL CHEM. CORP.	2.65	- - -	355.6	35.0	2.896	7.724	610.8 H	52-55	C -	0	7-0	1
PHO-T	NICHOLS,FL,USA / VI-CAROL CHEM. CORP.	2.65	- - -	406.4	25.0	4.237	6.287	596.9 H	58-59	C -	0	5-0	1
PHO-T	CAPE PROV.,RSA / CHEMFOS LTD.	2.6	- - -	152.4	30.0	1.890	3.060	46.79 H	1965	C -	5	9-9	2
PHO-T	WHITE SPRINGS,FL,USA/OCCIDENTAL CO.	2.72	- - -	508.0	25.0	5.243	2.967	1070.4 H	1965	C -	3	3-0	2
PHO-T	KINGSFORD MN-FL,USA/INT. MIN&CHEM. CO	2.65	- - -	457.2	32.0	4.511	4.267	6.532E6 Y	1975	C -	4	4-1	2
PY-C	GMCL, RSA	3.0	- - -	127.0	---	---	---	181.8 D	----	C -	-	4	-
SI-T	BLACKBIRD,ID,USA / CALERA MINING CO	2.7	- - -	152.4	45.0	1.387	2.262	52.28 H	46-60	CSE -	9	18-0	1
SI-T	BRALORNE,BC,CAN / BRALORNE PIONEER MI	2.7	- - -	76.2	28.0	1.646	1.341	9.749 H	1960	CSE -	0	3-0	1
SI-T	KELLOGG,ID,USA / BUNKER HILL CO.	2.75	- - -	127.0	40.0	1.661	2.865	40.41 H	1961	CSE -	0	4-0	1
SI-T	TATABANYA,HUNG / COAL MINE TATABANYA	---	- - -	200.0	---	---	8.500	240 H	1969	---- -	-	-	-
SI-T	- - - / QUEBEC CARTIER MIN. CO	---	- - -	298.5	40.0	4.267	2.092	1814 H	----	C -	-	-	4

SUMMARY OF MAJOR PIPELINE INSTALLATIONS - HORIZONTAL

SLURRY CODE	LOCATION/OWNER	SPECIFIC GRAV. OF SOLIDS	PSD %+-MM	OD X WALL THICKNESS MM	CONC WT.	VEL M/S	L KM	CAPACITY TONNES PER (SEE NOTE)	OPERATION DATES	PUMP TYPE	NO. OF STA	OPER. PUMPS-STANDBY	REF
SR-T	JAPAN / DOWA & NIPPON MINING	1.57	- - -	318.8	18.8	1.311	70.6	1212.1 D	1968	DARE -	-	3	-
SR-T	SUNBRIGHT,VA,USA / FOOTE MINERAL CO.	1.8	- - -	101.6	30.0	1.158	0.366	11.908 H	1952	CSE -	0	3-1	1
SS-T	THOMPSON,MANITOBA,CAN / INT. NICKEL	3.5	- - -	127.0	15.0	3.658	0.305	---	1959	CSE -	0	2-2	1
SS-T	CLIMAX, CO, USA / AMAX	2.70	- - -	1067.0	30.0	2.10	6.00	19E6	1982	---- -	-	-	7
SS-T	KITSAULT BC, CAN / AMAX	2.70	- - -	500.0	20.0	2.00	---	2.5E6	1980	---- -	-	-	8
SS-T	MICHIGAN, USA / HANNA MINING	3.00	- - -	560.0	30.0	4.00	---	---	----	---- -	-	-	-
SS-T	HENDERSON MINE, CO, USA / AMAX	2.70	- - -	760.0	30.0	2.00	1.20	15E6	1974	---- -	-	-	-
UP-C	RSA / ANG-TRS-CON-INV CO.	3.0	- - -	127.0	51.0	1.372	5.224	42.47 H	1957	C RU	0	4-4	1
UP-C	DAGGAFONTEIN,RSA / DAGGAFONTEIN MINES	3.0	- - -	101.6	---	1.859	2.853	---	1957	C RU	0	1-1	1
UP-C	DAGGAFONTEIN,RSA / DAGGAFONTEIN MINES	3.0	- - -	127.0	---	1.356	2.853	---	1957	C RU	-	1-1	1
UR-TO	EAST CHAMP D. OR,RSA /	2.7	- - -	152.4	50.0	0.750	10.21	870.9 D	1957	CSE -	0	2-2	1
UR-TO	BABROSCO,RSA / GEN MIN & FINA CORP	2.7	- - -	152.4	50.0	0.972	19.00	1110.4 D	1957	PL -	0	1-1	1
UR-TO	FREDDIE-N-S,RSA / FREDDIES CONSOL. MI	2.7	- - -	304.7	50.0	1.152	8.138	5334.3 D	1957	CSE -	0	2-2	1
UR-TO	FREDDIE S-WELCOM,RSA/FREDDIES CON. MI	2.7	- - -	406.4	50.0	1.207	11.12	7228.5 D	1957	CSE -	0	3-3	1
UR-TO	PRES. STEYN-WELCOM,RSA / PRES STEYN GOLD MIN CO.	2.7	- - -	228.6	50.0	1.128	6.401	125.7 H	1957	CSE -	0	3-3	1
UR-TO	PRES.BRAND-RES.STEYN, RSA / PRES STEYN GOL MIN CO	2.7	- - -	254.0	50.0	1.384	3.673	185.5 H	1957	CSE -	0	2-2	1
UR-TO	PRES.BRAND-SAAIPLAAS,GMCL, RSA /	2.7	- - -	228.6	50.0	1.384	10.46	5.44E6 Y	1963	CSE -	-	5	-
UR-TO	DOORFONTEIN, RSA / NEW CONSOL. GO FIELD LTD	2.7	- - -	215.9	50.0	0.872	10.67	77.8 H	1957	CSE -	-	2-2	1
UR-TO	ELLATON-STILFONTEIN, RSA / GEN MIN & FINA CORP	2.7	- - -	228.6	50.0	1.027	15.26	107.0 H	1957	PL -	-	6	1
UR-TO	RSA /CO. SUR VAAL REEFS	1.28	- - -	---	---	---	---	2.73E6 Y	----	DARE -	-	4	-
UR-TO	PRES.STEYN-WELCOM, RSA / PRES. STEYN GOL MIN CO	2.70	- - -	228.6	50.0	1.128	2.743	125.7 H	1957	CSE -	0	2-2	1
URN-T	JADUGUDA,BIHAR,IND/UR CORP OF INDIA	---	- - -	---	---	---	---	---	----	---- -	-	-	-
ZN-T	ZAWAR,RAJASTHAN/HINDUSTAN ZINC LTD.	2.85	100-.42 45-.074	273x 7.14	28-40	2.00	2.30	3500 D	----	CSE RU	3	2-1	6
ZN-T	ZAWAR,RAJASTHAN/HINDUSTAN ZINC LTD.	2.85	100-.42 45-.074	219x 7.14	28-40	2.00	2.30(2)	2000 D	1977	CSE RU	3	1-1	6
ZN-T	RAJPURA DARIBA,RAJASTHAN/HIN. ZN LTD	2.85	100-.600 42-.074	---	---	---	---	---	----	---- -	-	-	6

SUMMARY OF MAJOR PIPELINE INSTALLATIONS - VERTICAL

SLURRY CODE	LOCATION/OWNER	SPECIFIC GRAV. OF SOLIDS	PSD %+-MM	OD X WALL THICKNESS MM	CONC WT.	VEL M/S	L KM	CAPACITY TONNES PER (SEE NOTE)	OPERATION DATES	PUMP TYPE	NO. OF STA	OPER. PUMPS-STANDBY	REF
CO-C	GREISENAU,DORTMUND,GFR	---	- - -	200.0	---	---	0.700	1E6 Y	1971	---- -	-	-	17
CO-O	EGERCSEHI, HUNGARY / COAL MINE BORSOD	---	- - -	150.0	---	---	.212	60 H	1966	---- -	-	-	-
CO-O	GNEISENAU, W.GERMANY / BERGBAU AG	---	- - -	150.0	---	---	.670	150 H	1971	---- -	-	-	-
CO-O	HANSA, W. GERMANY / BERGBAU AG	---	- - -	250.0	---	---	.850	250 H	1977	---- -	-	-	-
CO-O	DEBIENSKO MINE, POLAND	---	- - -	250.0	---	---	.309	100 H	1957	---- -	-	-	-
CO-O	SIERZA MINE, POLAND	---	- - -	---	---	---	.110	---	1958	---- -	-	-	-
CO-O	ANDALUZJA MINE, POLAND	---	- - -	---	---	---	.300	120 H	1958	---- -	-	-	-
CO-O	SUTOGAN MINE, USSR	---	- - -	---	---	---	.400	41 H	1959	---- -	-	-	-
CO-O	SELIDOVUGOL MINE, USSR	---	- - -	---	---	---	.130	21 H	1959	---- -	-	-	-
CO-O	ST. ETIENNE, FRANCE	---	- - -	200.0	---	---	.178	50 H	1960	---- -	-	-	-
CO-O	MITSUI-SUNAGAWA MINE, JAPAN	---	- - -	190.0	---	---	.515	100 H	1965	---- -	-	-	-
CO-O	YOSHIMA MINE, JAPAN	---	- - -	165.0	---	---	.253	110 H	1970	---- -	-	-	-
CO-O	LU-CHA-TO MINE, CHINA	---	- - -	400.0	---	---	.473	41 H	1974	---- -	-	-	-
CO-O	ROBINSON RUN MINE, USA	---	- - -	250.0	---	---	.035	270 H	1974	---- -	-	-	-
CO-O	KARL FUNK MINE, W. GER.	---	- - -	140.0	---	---	.762	73 H	1974	---- -	-	-	-
CO-O	GNEISENAU, W. GER.	---	- - -	200.0	---	---	.700	127 H	1974	---- -	-	-	-
CO-O	HANSA, W. GER.	---	- - -	240.0	---	---	.840	209 H	1976	---- -	-	-	-
CO-O	LOVERIDGE MINE, USA	---	- - -	300.0	---	---	.274	---	1979	---- -	-	-	-
CU-O	BANCROFT MINE, RHODESIA	---	- - -	200.0	---	---	.400	143	1961	---- -	-	-	2
G-T	BAAL REEFS KLERKSDORF MINE, RSA	---	- - -	150.0	---	---	2.200	50	1970	---- -	-	-	4
ZN-O	SHULLSBURG,WI, USA / CALUMET & HELCA CONS. COPPER	---	- - -	250.0	---	---	.111	220	1952	---- -	-	-	-

NOMENCLATURE

SLURRY CODE: C=CONCENTRATES,T=TAILS/REFUSE,O=ORE

ASH-T = FLY ASH;T
AU-T = GOLD TAILS
BAU-T = BAUXITE TAILS
BO-T = BORAX;T
CE = CEMENT
CO-C = COAL;C
CO-O = COAL;O
CU-C = COPPER;C
CU-T = COPPER;T
FE-C = IRON;C
FE-T = IRON ORE;T
GIL-O = GILSONITE;O
GS-TO = GLASS TAILINGS;T,O
G-T = GOLD;T
HM-C = HEAVY MINERAL CONCENTRATES;C
KC-O = KAOLIN CLAY;O
LI = LIMESTONE
MA = MANURE
MIL-T = MILL TAILINGS;T
NI-C = NICKEL;C
NI-T = NICKEL;T
ORE = STERILE ORE
PHM-O = PHOSPHATE MATRIX;O
PHP-O = PHOSPHATE PEBBLES;O
PHO-C = PHOSPHATE CONCENTRATES
PHO-T = PHOSPHATE TAILINGS;T
PY-C = PYRITE CONCENTRATES;C
SI-T = SAND TAILINGS;T
SR-T = SULFIDE ORE FLOTATION;T
SS-T = SMELTER SLAG;T
UP-C = URANIUM PYRITE CONCENTRATES;C
UR-TO = URANIUM SLIME;T,O
URN-T = URANIUM TAILS
ZN-O = ZINC ORE
ZN-T = ZINC TAILS

LOCATION: STATES

THE STATES ARE CODED USING THE
US POSTAL SERVICE SYSTEM CODES

E6 = ONE MILLION

S = SECONDS
M = MINUTES
H = HOUR
D = DAY
Y = YEAR

PUMP TYPE:

C = CENTRIFUGAL
DA = DOUBLE ACTING
G = GRAVITY
H = HORIZONTAL
ME = METAL
PA = PARALLES
PD = POSITIVE DISPLACEMENT
PI = PISTON
PL = PLUNGER
RE = RECIPROCAL
RU = RUBBER
SA = SINGLE ACTING
SE = SERIES
V = VERTICAL
2 = DUPLEX
3 = TRIPLEX
4 = QUADRAPLEX
5 = QUINTUPLEX

LOCATION: COUNTRY

ARG = ARGENTINA
AUS = AUSTRALIA
BRAZIL = BRAZIL
CAN = CANADA
CHILE = CHILE
COL = COLUMBIA
ELSAL = EL SALVADOR
ENG = ENGLAND
GDR = EAST GERMANY
GFR = WEST GERMANY
HUNG = HUNGARY
IND = INDIA
INDO = INDONESIA
JAPAN = JAPAN
MEX = MEXICO
NKOR = NORTH KOREA
NL = NETHERLANDS
POL = POLAND
RSA = REPUBLIC OF SOUTH AFRICA
TAS = TASMANIA
TRIN = TRINIDAD
USA = UNITED STATES
USSR = USSR
WIRA = WEST IRIAN

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COMPOSITE BEAMS WITH WEB OPENINGS

David Darwin[1]

ABSTRACT

The research and current analysis tools for composite beams with web openings are reviewed. The behavior and failure modes at openings are described and the major remaining questions are listed. Research has demonstrated that the concrete slab contributes to the shear strength as well as flexural strength at openings. Taking advantage of this contribution to shear strength should significantly lower the cost and simplify the construction of web openings in composite beams.

INTRODUCTION

Composite floor systems allow considerable savings in multistory buildings because of the lighter, and sometimes shallower, floor that may be used when compared with noncomposite systems. Economies in high-rise steel frame buildings have been achieved by introducing web openings in the floor beams to permit the passage of utility ducts and pipes, thereby reducing the story height. However, openings weaken the sections and usually require costly reinforcing.

Prior to 1977, considerable research had been conducted on composite beams and on beams with web openings, but no comprehensive investigation of composite beams with web openings had been undertaken. Beginning with work at the University of Kansas, a number of experimental and analytical studies have been aimed at determining the behavior of composite beams at web openings and translating that behavior into a usable design approach. A number of those studies are still under way.

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It is the purpose of this paper to summarize the current state of knowledge in the field of behavior, analysis and design of composite beams with web openings. The paper describes the behavior at web openings, summarizes past and current research, offers an overview of the current analysis methods and lists what appear to be the major remaining questions.

BEAM BEHAVIOR

This section gives a brief overview of the forces that act on a composite beam in the vicinity of a web opening and describes the response of the beam to these forces.

Forces Acting at Opening. - The forces that act at an opening are illustrated in Fig. 1. For the usual case of positive bending, the steel section below the opening, or bottom tee, is subjected to a tensile force P_b, shear V_b, and secondary bending moments M_{bl} and M_{bh}. The section above the opening, or top tee, is subjected to a compressive force P_t, shear V_t, and secondary bending moments M_{tl} and M_{th}. Based on equilibrium

$$P_b = P_t = P \qquad (1)$$

$$V = V_b + V_t \qquad (2)$$

$$2V_b a = M_{bl} + M_{bh} \qquad (3)$$

$$2V_t a = M_{tl} + M_{th} \qquad (4)$$

$$M = Pz + M_{th} + M_{bh} - Va \qquad (5)$$

in which V = the total shear acting at the opening; M = the primary moment acting at the opening center line; $2a$ = the length of the opening; and z = the distance between the plastic centroids in the tees.

Deformation and Failure Modes. - The deformation and failure modes for beams with solid slabs are illustrated in Fig. 2. The behavior at an opening depends on the ratio of moment to shear, M/V.

For a high M/V ratio the opening deforms primarily in a flexure (Fig. 2a), with the steel in tension and the concrete in compression. Shear and secondary bending do not play a major role.

As the M/V ratio decreases, the shear and secondary bending moments increase, causing an ever increasing differential, or Vierendeel, deformation to

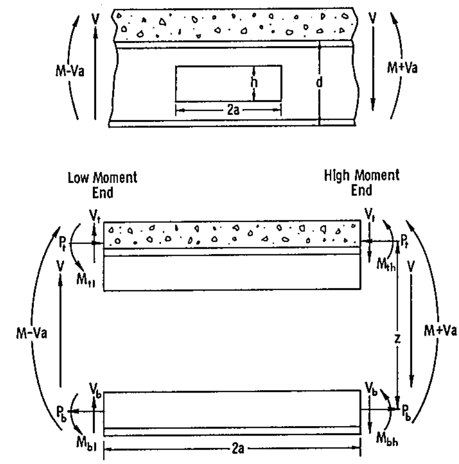

Fig. 1. Forces Acting at Web Opening (Ref. 4)

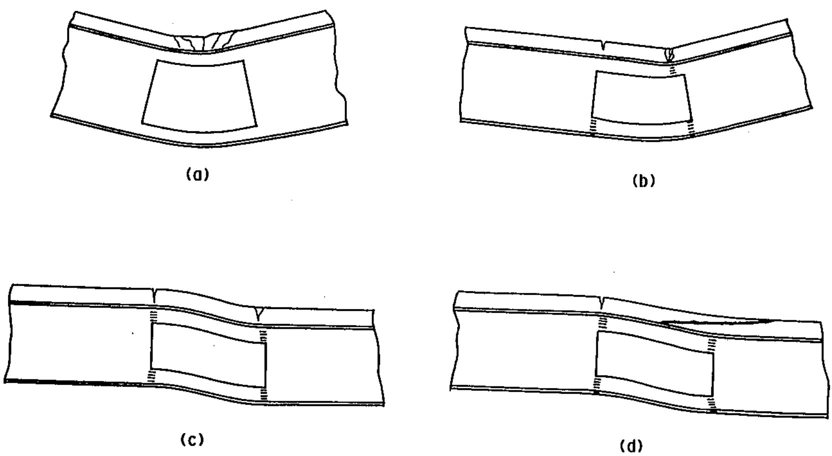

Fig. 2. Failure Modes at Web Openings in Beams with Solid Slabs (a) Pure Bending, V=0; (b) High M/V; (c) Lower M/V, Concrete Crushes; (d) Low M/V, Diagonal Tension Failure in Concrete

occur through the opening (Fig. 2b,c,d). The sections above and below the opening usually exhibit a well defined change in curvature, as shown in Fig. 2c,d. In these cases, the concrete cracks above the low moment end of the opening due to the secondary bending moment. Depending on the M/V ratio, the concrete at the high moment end of the opening will either crush or undergo a diagonal tension failure due to the prying action across the opening.

Under pure bending ($V = 0$), the top and bottom tees will be in a uniform state of stress along the full length of the opening. For $V \neq 0$, the tees will be subjected to a general state of stress due to axial force, shear and secondary bending moments.

The behavior at openings in composite beams with formed metal decking is generally similar to beams with solid slabs. However, there are a number of important differences. Beams with ribbed decks normally have considerably less concrete compression area and a lower shear stud capacity. Failure is preceded by rib cracking over the high moment end of the opening (Fig. 3), as well as transverse cracking over the low moment end. Failure is governed by concrete failure around the studs, which may vary from a pullout type of failure at the high moment end of the opening, to a shear failure at the low moment end and between the low moment end and the point of zero moment.

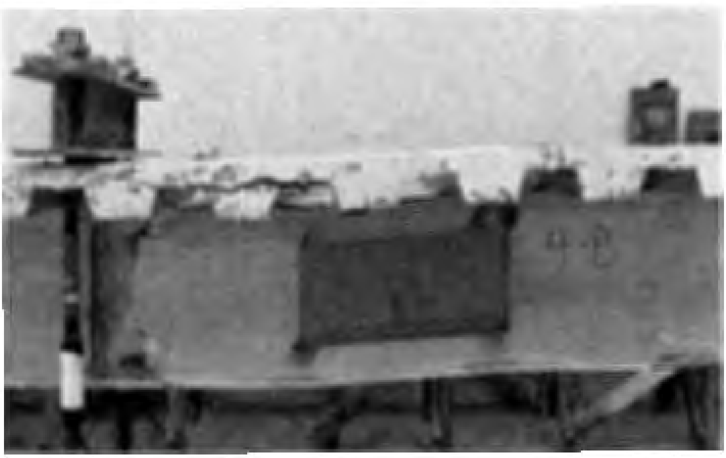

Fig. 3. Failure at Web Opening in Beam with Ribbed Slab (recent test at University of Kansas)

Even for very high M/V ratios, large amounts of slip occur between the concrete deck and the steel section over the opening, with both solid and ribbed decks. As illustrated in Fig. 4, this slip is enough to place the lower portion of the slab in compression at the low moment end of the opening, although the adjacent steel is in tension.

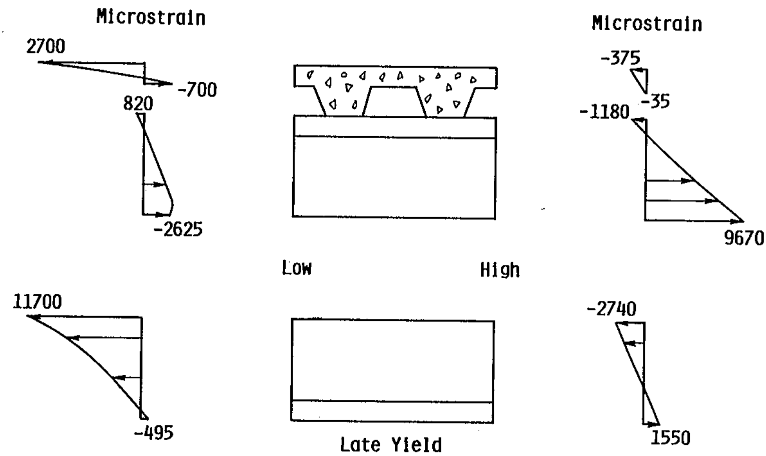

Fig. 4. Strain Distributions at Web Opening in Beam with Ribbed Slab (recent test at University of Kansas)

The tests that have been run to date (2,3,5,7,11,12) uniformly show that the concrete slab makes an important contribution to the shear strength at the opening. This contrasts with standard practice in composite beam design (1), where the concrete deck is used to resist the bending moment but shear is assigned solely to the web of the steel section.

With this information as a background, the next section describes the research that has helped develop the current state of knowledge.

RESEARCH

Composite Beams with Solid Slabs. - The first tests of composite beams with web openings were made by Granade (7). He tested two beams with rectangular web openings, and attempted to predict the experimental stresses using the Vierendeel method. In his analysis, he assumed the points of contraflexure in the tees to be at the opening center line. The stresses obtained from this elastic analysis were not accurate.

Todd and Cooper (15) developed an ultimate strength model for composite beams with web openings, using the assumption that the shear force is carried only by the web of the steel section. They used their model to generate interaction diagrams to represent beam failure at different combinations of moment and shear. In a comparison with the experimental results of Granade, the model greatly underestimated the shear strength at the openings (Fig. 5). Their work, however, played a useful role and clearly pointed the way for later models.

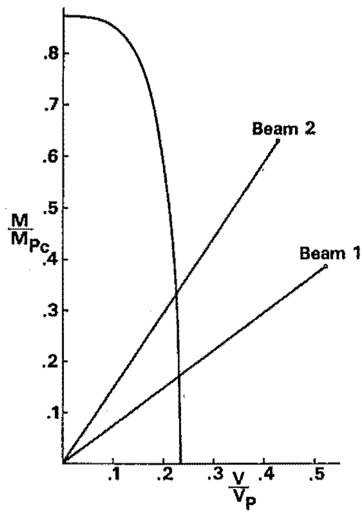

Fig. 5. Comparison of Todd-Cooper Model with Granade's Beams (Ref. 15)

Swartz and Eliufoo (14) developed a method for determining the neutral axis at web openings in composite beams using the Vierendeel method while considering the cracked concrete section. Their method compared reasonably well with finite element solutions.

Clawson and Darwin (2-4) undertook an experimental investigation to study composite beams with rectangular web openings and developed a strength model to predict the behavior of the beams.

They tested six composite beams with solid slabs (Fig. 6) and observed that the compressive strains in the concrete remained low, well after the steel had begun to yield. They found that the load at first yield did not give a good representation of the strength of the section, with the load at first yield varying from 17 to 46 percent of the failure load. As a general rule, the failure of the beams was ductile, that is they obtained large deformations and sizeable concrete cracking prior to failure.

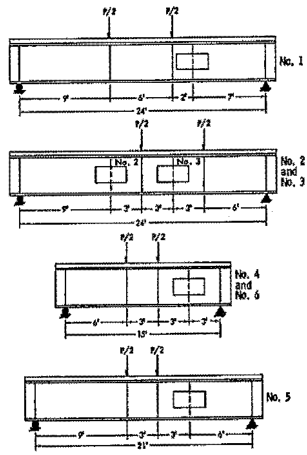

Fig. 6. Beams Tested by Clawson and Darwin, not to scale (Ref. 3)

The peak loads were governed by failure of the concrete slabs. Prior to failure, large slips occurred between the concrete and the steel. It was not clear to Clawson and Darwin as to what impact this slip had on strength. The nature of the slip is illustrated by the strain distributions in Fig. 7, which show that even for beams designed for full composite action, a sizeable strain discontinuity exists between the concrete and the steel at both ends of the opening.

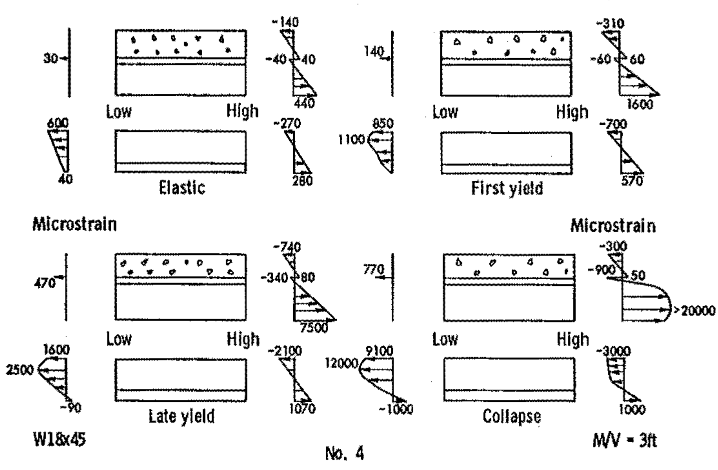

Fig. 7. Strain Distributions at Web Opening in Beam with Solid Slab (Ref. 3)

Perhaps the key observation of their tests was that the concrete contributes to both the shear and flexural capacities of the beam at the web opening, and that therefore, the contribution of the concrete to the shear strength must be considered to accurately predict the strength at the section.

Their test results also demonstrated that the moment capacity at web openings is relatively unaffected by shear until the shear reaches the maximum shear capacity (Fig. 8).

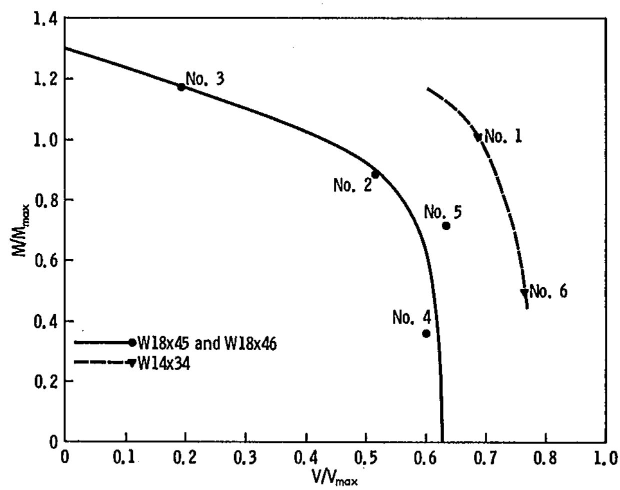

Fig. 8. Moment-Shear Interaction for Test Specimens with Solid Slab (Ref. 3)

Clawson and Darwin also observed that the M/V ratio at the opening had a prominent effect on the failure mode (Fig. 2). For openings under high bending stress and low shear, failure tended to be governed by crushing of the concrete, while beams under moderate or high shear exhibited a Vierendeel action, with a great deal of differential deformation through the opening. They also found the point of inflection was not at the center of the opening, but had displaced towards the low moment end.

Their strength model (4), provided satisfactory predictions of strength and failure mode (Fig. 9). The model was based on full composite action and assigned a portion of the shear to the concrete slab. The concrete slab was assumed to be fully cracked above the low moment end of the opening. Although this assumption did not match the test observations, it did not appear to be detrimental to the model.

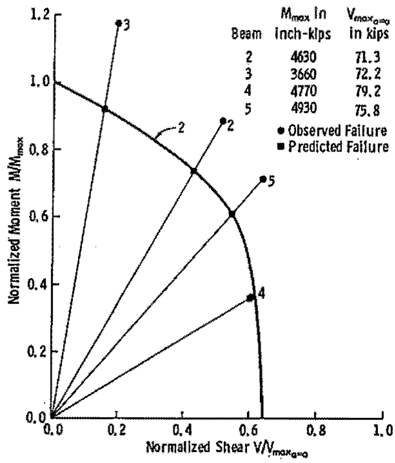

Fig. 9. Comparison of Predicted with Observed Failure - Clawson and Darwin (Ref. 4)

Clawson and Darwin also developed a simplified version of their model for use in design (2), which provided reasonably good agreement with the interaction diagrams developed using the full strength model (Fig. 10).

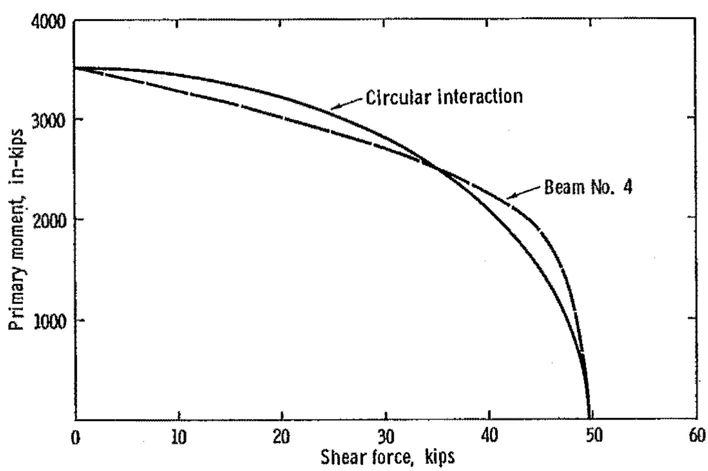

Fig. 10. Comparison of Simplified (Circular) and Full Strength Model Moment-Shear Interaction Diagrams (Ref. 2)

In 1982, the experimental work of Clawson and Darwin was largely duplicated by Cho (5) who arrived at virtually the same conclusions.

In 1983, Momeni (8) modified the model developed by Clawson and Darwin to include web reinforcement in the analysis. His model allowed the cracked portion of the slab at the high moment end of the opening to carry shear. The model produced unconservative results for beams with low M/V ratios, high shears and a shallow steel section.

Composite Beams with Ribbed Slabs. - In contrast to the earlier tests that used solid slabs, Redwood and Wong (11,16) tested composite beams with slabs constructed with formed steel decking, keeping with current practice in composite building construction. They tested six sections with web openings (Fig. 11) and developed a simplified, conservative strength model.

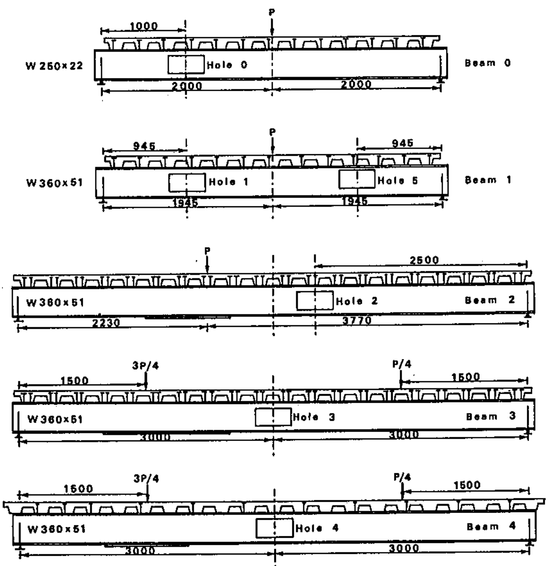

Fig. 11. Beams Tested by Redwood and Wong, not to scale (Ref. 11)

From their study, Redwood and Wong found, as did Clawson and Darwin, that the moment-shear ratio played an important role in the mode of failure. At high M/V ratios, the mode of failure was primarily flexural, although Vierendeel action was evident. As the M/V ratio at the opening decreased, the amount of shear deformation through the opening increased and became dominant for openings located in high shear regions.

Failure at the openings was also governed by failure of the slab. However, the mode of failure was distinct from that in solid slabs, in that rib separation occurred in all tests (Fig. 12). They obtained compressive failures in the slab for high and medium M/V ratios and separation of the slab and beam near the high moment end of the openings for high shear (low M/V) cases.

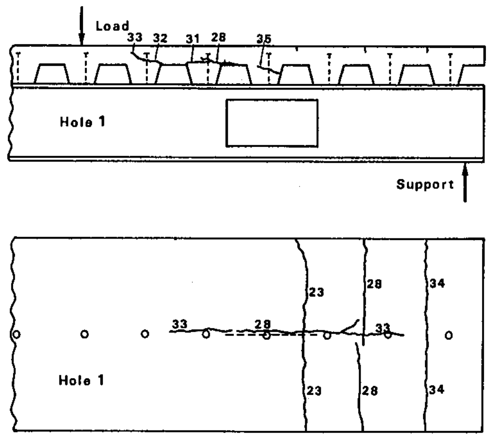

Fig. 12. Crack Patterns in Ribbed Slab (Ref. 11)

They concluded from observing their test specimens that a strength model based on the formation of four hinges, one at each corner of the opening, was satisfactory, but that analytical models must account for the shear in the slab. They also pointed out that the rib separation would be difficult to include in an analytical model. They used an assumption, similar to that used by Clawson and Darwin (2,4), that the concrete carries no stress at the low moment end of the opening. Based on their comparison with test data, however, they felt that it was important to model the compressive stresses in the slab that occur at the low moment end of the opening. They also felt that the effects of differing amounts of composite action (shear connection between the slab and the beam) should be studied. Their model, along with the simplified version of Clawson and Darwin's model and a model based on non-composite behavior, is compared against four of their tests in Fig. 13.

In terms of serviceability, Redwood and Wong expressed concern about the possibility of cracking at working loads over the low moment end of openings subjected to low M/V ratios.

More recently, Redwood and Poumbouras (12) performed three additional tests to study the influence of studs over the opening on beam strength and the effect of noncomposite loads acting on the beam prior to the initiation of composite behavior. The openings in these beams were subjected to high shear and had a relatively low number of studs between the opening and the point of zero moment.

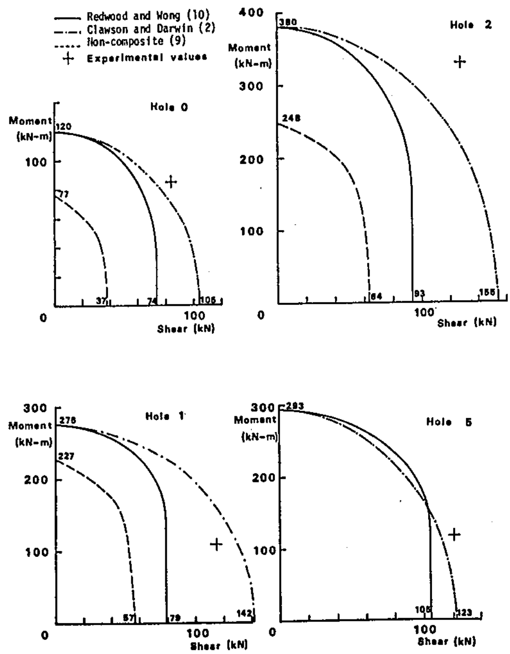

Fig. 13. Moment-Shear Interaction Diagrams for Beams with Ribbed Slab Compared to Test Results (Ref. 11)

Based on these tests, Redwood and Poumbouras concluded that the absence of shear connectors within the length of the opening will produce a large reduction in strength and that construction loads do not appear to affect the strength at the opening for loads up to 60 percent of the predicted ultimate load for the noncomposite section.

Redwood and Poumbouras (13) developed an analysis procedure for beams at web openings that includes the compressive stresses in the concrete at the low moment end of the opening that are caused by slip between the concrete and steel. Their model provides a good match with their tests (12) and those of Redwood and Wong (11). However, Redwood and Poumbouras express some concern about the applicability of their procedure when applied to composite beams that consist of a heavy steel section and a thin slab.

Donoghue (6) recently presented a design procedure that neglects the contribution of the concrete slab to the shear strength at the opening and, instead, strengthens the opening by adding reinforcement (Fig. 14).

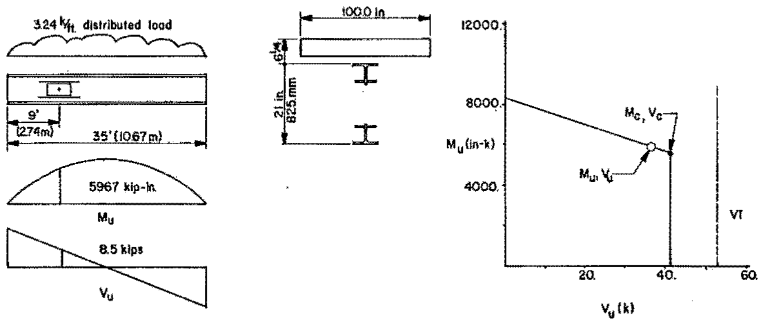

Fig. 14. Example Problem and Interaction Diagram for Reinforced Web Opening (Ref. 6)

Ongoing Research. - Work on composite beams with web openings is continuing at the University of Kansas. To date, a total of eleven openings in composite beams with formed metal decking have been tested. These tests indicate that the nature of failure is ductile, but that in all cases, including high M/V ratios, a rib separation takes place as observed by Redwood and Wong (11). Based on observations after failure, rib separation appears to be caused by concrete failure around the studs. The Vierendeel deformation through the opening pries the studs at the opening, but appears to reduce their contribution only slightly.

A series of tests specifically designed to study the influence of studs on strength seems to indicate that studs between the opening and the point of zero moment, as well as studs over the opening, make an important contribution to the capacity of sections subjected to high shear. When the studs between the opening and the point of zero moment are "heavy", the relative contribution of the studs over the opening appears to be small, while for beams with a lower number of studs between the opening and the point of zero moment, the studs over the opening appear to play an important role.

INTERACTION DIAGRAMS

Models to represent the strength of composite beams at web openings (2,4,6,9,11,13,15) do so through the construction of moment-shear interaction diagrams (Fig. 5,9,10,13,14). There are a number of similarities between models, although the details involved in constructing the diagrams differ. As a minimum, the analysis usually starts with the determination of the pure moment capacity (i.e., V = 0) and the pure shear capacity (i.e., M = 0) at the opening. Once these values have been obtained, the simplier models (2,11,13) then utilize curves, such as an ellipses, to construct the balance of the interaction diagram.

The more complete strength models generate the full diagram, point by point, based on an analytical representation (4,9,15). For these models, the interaction diagrams are developed by calculating the primary moment, M, that can be carried as the shear, V, is increased from zero to the maximum value. For each value of shear at the opening, a portion is assigned to the top and bottom tees. The axial force and secondary bending moments in the bottom tee are then obtained. An axial force of equal magnitude, but opposite sign (Eq. (1)) is assigned to the top tee. The shear in the top tee is distributed between the concrete and steel at the high and low moment ends, based on the assumptions inherent in the model. The shear distributions between the top and bottom tees, and between the concrete and steel within the top tee may be varied to maximize the primary bending moment, M.

For the models designed to predict the strength of unreinforced openings (2,4,9,11,13,15), there is virtually no disagreement on the strength of the sections under pure bending. The various models differ in how they handle the high shear cases and how they represent the interaction diagram between pure bending and pure shear.

Clawson and Darwin (2,4) assume full composite behavior for beams with solid slabs and generate the interaction diagram by first determining the distribution of shear between the top and bottom tees for the case of zero axial force within the tees ($P_b = P_t = 0$). This ratio is then held constant as the value of total shear, V, is increased from zero to the maximum value. The corresponding bending moment, M, is maximized for each value of V, since the procedure is an equilibrium method which produces a lower bound solution.

For their simplified model, Clawson and Darwin (2) generate only the pure bending and pure shear strengths and then connect the two with an ellipse (Fig.

10). This model has recently been adapted to include partial composite action and is proving to be a useful research tool.

Redwood et al. (11,13) calculate the maximum bending and shear strengths. Using a procedure developed by Redwood (10), Redwood and Wong (11) calculate the maximum moment that can be sustained at the maximum shear. Redwood and Poumbouras (13) obtain the moment corresponding to the maximum shear, using Eq. (5). In each case this generates a vertical line on the right side of the interaction curve (Fig. 13). The curve is closed with an ellipse.

THE MAJOR QUESTIONS

A number of major questions must still be answered before the development of a comprehensive model for the strength of composite beams at web openings can be completed. First among these questions is the contribution of the studs at the opening and between the opening and the point of zero moment. Current work at the University of Kansas seems to indicate that there are some conditions in which studs over the opening can increase strength, and others where they have only a small effect.

Redwood and Poumbouras (13) have expressed some concern about beams that combine a large steel member with a relatively small slab, a case which may occur for main flexural members in buildings. They are also concerned with the applicability of their model to openings with large downward eccentricities.

The subject of serviceability criteria is important. Exactly what the criteria should be, deflection and/or cracking, is being addressed at the University of Kansas.

Another important area of research is the development of low cost reinforcing procedures that can be used when the strength at the opening is not satisfactory. Work here should offer attractive alternatives to the addition of stiffeners around the opening.

SUMMARY

This paper has given a brief review of the research and the current analysis tools for composite beams with web openings. A great deal of progress has been made during recent years in both understanding the behavior of the beams and representing their strength. Research has demonstrated that the concrete slab contributes not only to the flexural strength, but also to the shear capacity of composite beams at web openings. Taking advantage of this contribution to shear strength should significantly lower the cost and simplify the construction of web openings in composite beams.

ACKNOWLEDGEMENTS

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PROFITABILITY AND PRODUCTIVITY OF STRUCTURAL ENGINEERING COMPUTER SYSTEMS

Gary R. Koser

INTRODUCTION

Computers bring out the best and worst in people because there is a large range of thought and feeling about them: what they can do, what they can't do, how they do it, and what they do it with. My background is primarily in consulting, and in that capacity I have spent 10 years working with people either getting actual drawings out the door or helping them install the computer systems that can. My purpose is to provide you with a brief overview of where we are; i.e., state of the art information on hardware and software. There are over 400 companies making computer systems today: - all different price ranges, speeds, quality, etc. It is just a phenomonal and an exciting field to be in. What was true yesterday may not be true tomorrow and it is up to you to research and find out about it.

I am going to talk about profitability and productivity in terms of using computer systems. Let me start with a little background. Where did we start? I started with the slide rule, log tables, and different mathematical formulas, etc. In that same time frame the first computers were being put together at the University of Pennsylvania. The new dawn came in 1972 when HP came out with its electronic slide rule, the HP-35. My parents were interested in furthering my education so they spent $400 for this calculator. A few years later the price was $150 and now you can get it for $10. It is simply amazing how rapidly the market changes. This was the start of one type of revolution - the calculators and the basic chips that go into this kind of machine. In 1972 our company started with the WANG 2200 computer system from Dr. Wang (who is right up the road a little bit from where we are). This was one of the first BASIC language mini-computers. We wrote engineering software for the Wang 2200 because there wasn't anything available in 1972 when it first came out. Suprisingly enough,

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that machine still works in our office after ten years. However, it seems that nobody wants to use it anymore because we have other machines that are faster, better, and solve bigger problems.

COMPUTER PARAMETERS

Basically, what we look for and the things that you should be looking at with regard to computer systems relate to the following:

1) Number crunching -- computers obviously have the ability to do complex calculations. That is what they are really built for and this is where most of the use and progress in terms of structural engineering software has been. We find that many programs today are doing things that by hand we wouldn't even dream of doing.

2) Storing data -- Most systems are strong in retrieving the data from disks, diskettes, tapes, etc.

3) Driving peripherals -- Various kinds of disk drives, printers, plotters, graphics, CRT's, and other pieces can be attached to the system.

4) Controlling intruments -- These are related to failure investigations or R & D types of things.

The computer system today can do so much more than we can.

But there are things a computer can't do. These considerations revolve around the application of ingenuity in solving a problem. Just how do I want it to solve the problem, where do I want it to lead, and what does the result mean. In many cases there are hundreds of different paths to solve any particular problem. This is where human reasoning comes in. It is human imagination and creativity that will make this computer system into a tool that you can use. A tool that will become part of your office just as the slide rule was ten years ago and what the computer aided drafting machine might be ten years from now.

COMPUTER APPLICATIONS

As a consulting engineer the major emphasis revolves around having the computer do structural analysis and design calculations for us. We have a 25 man firm which includes 15 professional engineers. We have six terminals available either on the WANG system or the personal computer systems in the office. At any time, one of us can walk up to a machine and run an analysis or go through a design process. The machine does the numbers and the engineer provides the concept and the ideas that he wants to test as the solution.

In addition to engineering applications we are doing word processing.

Everyone should be aware of what computers can offer in terms of word processing, spec writing, proposals, etc. Our word processing software ended all repetitive typing and proof reading in our office. Accounting is another big area for computer usage in a consulting firm. Probably the most time consuming aspect of an engineering office in relationship to office management functions is the posting of time cards and expense information into a job record so that the client can be billed. Obviously, billing is necessary for us to be paid.

Another application for a computer system is for data processing (in terms of marketing and data base management). Questions such as for what clients have we done what jobs and where we have done a certain type of building can be easily answered. For example, a surveying office that we work with has all of their surveys and places where they have done surveys on the computer system so if they are proposing to work for somebody, they can look at what benchmarks they have and what reference points are already set. They can come back with a much more precise answer regarding what it would take to do that particular job.

The last item to mention is the automated drafting function. Many firms, the larger firms in particular, are starting to get into this primarily due to governmental pressure. A rather large firm in Houston had to buy a certain computer aided drafting system because they are going to do work for the Air Force in San Antonio. There was no choice. They had to buy this particular system and that was it because the government mandated it. Fortunately, the project was big enough that they could put the $200,000 price tag into the project cost. Not many of us can do that. We are starting to see the computerized, automated drafting function move into the smaller firms but the transition will be fairly slow. Then, as hardware prices once again take another cycle downward, software will be available that will justify this economic investment for a firm of five to ten people.

COMPUTER HARDWARE TERMS

More specifically, regarding hardware I know I might be using terms that may be new to a few people. Obviously, the key thing I am going to be discussing hardware-wise revolves around the Central Processing Unit. There are, as I said, 400 firms making "CPU's" right now, ranging from the popular ones such as the

Apple and IBM to such up and comers as Pixel, Plexus, Apollo, and many others.

Mass storage corresponds to the magnetic storage medium of the system, be it a flexible disk, a hard disk, or tape drive. There are systems available which allow you to put millions of characters of information on 5-1/4" surfaces. Also coming are 3-1/2" diameter surfaces which make the system small enough to fit on a desktop and still be extremely powerful.

The CRT, the display message center, is the heart of any computer system. This is where you are going to know what's going on and where you are going to tell the machine what you want done. Probably the key thing happening here is the influence of graphics on the CRT. Graphics will make the system easier to understand. Even the answers are more informative by using graphics.

Memory is in the central processing unit and the place where programs are executed. Recently memory has dropped in price dramatically. When we first bought our WANG system, an 8K memory board was about $2,500. Now I can buy 128K memory boards for $500. There has also been a dramatic shift in the memory available on the machines. Most of the personal computers that you see coming out today start at 128K or 256K; in fact, some of the HP systems start at 512K. This is phenomonal compared to ten years ago when 4K was a big deal.

There are great differences in keyboards as well. Obviously, for an engineering function you want a numeric keypad so you can key in joint, load, and member numbers quickly and easily. Some of the systems such as Apple II do not have a numeric keyboard. You have to use the upper row of keys on the typewriter for the numbers. There are great differences in the keyboard with regard to how they feel and operate.

Printers range over the price spectrum from $250 up to thousands of dollars depending on quality, speed, and accessories that you might want for your computer system.

COMPUTER TRENDS

At this time I would like to discuss some trends with computers. One trend is that computer hardware costs are going down, and a decline of 20% a year is not unbelievable. Manufacturers are not changing their prices but rather they are putting in things that last year were options or extras to the systems. I think that pricing has bottomed out for business professional systems. There is tremendous competition on the home/hobby level at this time. In the home machines, four of the five major manufacturers lost money last year, ~~so~~ they won't survive very long or they will be raising their prices.

The other side of the graph is labor and this corresponds to the software. The cost of producing and maintaining software is very labor intensive. I know that our programming people want to get paid more every year. Therefore, the software costs will continue to increase in specialized areas such as structural engineering. If you are looking at word processing, there is a wide open market and the prices are coming down. Database management information systems also have a wide open range of applications and, therefore, the prices are coming down. On the specialized side, whether you are a doctor or a lawyer or an engineer, the software costs aren't going to come down. Prices will increase in proportion to labor costs involved.

Another thing that is happening is the computer need explosion. As Forbes, Business Week, and others have predicted, by 1985 there will be fivefold increase in computer units sold, taking the market from roughly a billion dollars to five billion per year over the next three years. The phenomonal growth in this market has one very confusing aspect, namely, you don't know who to believe anymore with regard to what is going on.

The start of the personal computer revolution (and I am going to orient myself to the personal business level machine and the software available for it) began with Apple. The interesting part of this is that the people who started Apple initially worked for Hewlett-Packard so we could all be talking about Hewlett-Packard machines if the people at HP had said "that sounds like a good idea." Apple really started the revolution in 1977. The IBM people legitimized it by bringing out their PC. The marketing expertise of IBM, has made this market what it is today, more so than anything Apple or any of the other competitors have done. IBM is selling almost 800,000 units in 1983. But even at those production levels, they are talking about a four to six week delay in getting machines to people. The demand has been outstanding and it has created a whole series of compatible types of machines (clones) -- Compact, Franklin, Eagle, Corona, etc. Even older companies such as Digital, Wang, Altos, HP, and others are emulating what IBM does. So, IBM has legitimized the personal computer and has brought software as well as a lot of good things to the marketplace. Everybody is waiting to see what they do next. In my opinion, the PCJr. is really not a business/professional type machine we would want in our office; however, it is an interesting machine.

One of the other major manufacturers, particularly in engineering, is Hewlett-Packard. The HP-86 system has been around for two or three years. It has matured to having a fair amount of software available for it. It is a good unit as are the other ones. You can't really knock the hardware. There is a lot of sameness, if you will, about the systems. They are using the same hard disks or they are using the same chips from Motorola, Intel or whoever. The difference comes from how the operating systems work. The speed with which a machine runs is not necessarily in the chips or the disks or the printers that are used on it. There are many variables involved.

Business Week has predicted the following sales figures for 1984: IBM at 2 million units, DEC with 300,000 units, HP with 300,000 units, Wang at 100,000 units - the figures are phenomenal. One of the reasons for this awakening demand is that there are advantages to owning a system, the major one being convenience. When I worked for the State of Wisconsin, and I believe this is applicable to most large groups and organizations, we felt it was easier for us to get our own system, do our own thing internally and fix our turnaround to something we controlled rather than working through a third party. In addition, the fact that a company may not need to hire or replace a person also affects the value. Another reason to purchase a system is the expensive cost of time sharing. Even beyond that, the IRS has certain tax advantages that make it more equitable to invest in hardware and software. So, there are many reasons to invest in a system.

COMPUTER CONSIDERATIONS

When deciding to purchase a system these are some considerations to keep in mind:

1) Expandability - Expandability is a key concept because typically when people buy a system, and as they mature with it they want to have more disk capacity and more memory. Various aspects come in to play so it's a good idea to ask yourself -- "what is the future of this system" or "how expandable do I want this system to be". Initially, you will pay more for a system that allows you to expand.

2) Modularity - This refers to the ability to interface a variety of peripheral (modules) with your system. For example if you buy an HP-150 with the thermal printer built into it and you decide you really need a faster printer, you can't replace your printer with something faster. There is only one speed to the printer so you have to buy a separate unit. You should have bought a separate unit to begin with so that you could sell it later and get the higher speed one with a minimal investment. This same idea applies to disks. If the disks are built in (such as an Apple III or a Lisa) and you decide that you need more disk capacity, you are stuck. When you do get the 10 megabyte disk, the floppies will be unused. Some modularity should be considered. Again, an all-in-one-unit, a portable unit such as the Kaypro or Compacq is not bad -- depending on what you want to do.

3) Compatibility - This is an important consideration particularly when you are talking about software. Compatibility of software means that the dBase II I bought for my Digital Rainbow will work when I buy a Digital Micro-Vax. However, the price of software for general applications is not that critical so if you spend $500 on Lotus for your HP-150 and then you need the version for your IBM PC, you are out $500 which is not as great an amount. If you are paying $8,000 or $10,000 for a Finite Element Analysis program compatibility is an important question and should be considered. Related to hardware compatibility becomes "Can that printer plug into this other system that I may buy in the future?"

SOFTWARE CONSIDERATIONS

The critical item here is software. This is what I am going to spend most of my time discussing. In terms of software the main concept revolves around a proven package. You don't want to be a guinea pig in any software that you are using. The ability to use a program to run your problem and to verify that the system does what you want is the key factor. Most firms supply demo disks to prospective buyers because they understand the "touch and feel" aspect is important to prove that the system will do what you want it to do. Also, you will learn how fast it solves the problem. In terms of providing a proper solution, the software should ask the questions in a logical sequence. So you should be aware of these considerations when purchasing software.

Testing the program will give you a feel for what installation and support procedures are. Does the vendor have an 800 number? Are there support personnel available? And other related questions are very important considerations.

Another item to consider are enhancements. Are there changes being made that will make the software more powerful or that will keep it up with the latest techniques. For instance, if the AISC code changes are the programs modified to reflect those changes? This is a very important question to ask the software people that you are going to be dealing with.

Is the software transportable? For instance, as you enhance or upgrade your machine will the software still work or do you need to buy another version of it? Also, what are the policies across hardware manufacturers, i.e., if I buy a program for an IBM PC, is there a similar program for those of us in the office who have an HP-86 at their disposal. Do I have to retrain people to use the different machines or is there a consistency in that software so that when you sit down at any machine you will be familiar with the questions and your respones to the system. Obviously, transportability is an interesting concept.

Another key consideration is ease of operation. If I have to spend ten minutes getting the program up and running to solve a simple steel beam, then the system is useless. Some programs are written to be all encompassing and therefore require a waste of time answering questions which do not apply to the solution. On the other hand, there may be need for an all encompassing program. So ease of operation is important and something that should be considered as you look at systems.

SUPPLIER CONSIDERATIONS

With regard to both hardware and the software, a key consideration is the strength of the distributor. In other words, will the company that you are going to work with be here five years from now? I think you can pick which ones are going to be around for sure in terms of hardware but what about in terms of software? If you are dealing with a one man operation the odds of him being here five years from now to support your software are pretty slim. If you are dealing with a 15 man organization that has been around for ten years, then you have a shot at it at least. Still, there are no guarantees in this business. Typically, the firms that have been around longer will charge more for their software. This is how they survive and maintain their profitability. If support is not a concern and if you want to take a little more risk and pay a little less money, that is another route to take. You pay your money and take your chances all the way across the line.

Both your choices of a hardware and software company should have a proven record of success. What technical expertise is behind their systems? What are they doing to make sure that they are going to be there when you need service in a year or three, or when you need a new system? If they have been around for a while, they should have a user base that you can talk to. You should ask the company to provide you with a reference list of users, which is something you should check out. However, I find it hard to believe that it is economic for anyone to spend 200 hours researching a $3,000 computer system and software when that time is worth $4,000. You are better off to take a flyer in some cases and see what happens rather than spend the $4,000 in administrative overhead.

Also, consider where the maintenance is coming from for the hardware. Is there a four hour response for on-site service or do I have to mail it back to the manufacturer? The level of expertise and support that you can expect from the manufacturer or vendor is dependent upon the particular piece of hardware or software.

INTEGRATED SYSTEM CONSIDERATIONS

Of course, as we mentioned previously data processing and word processing can be integrated. We use the word "can" as this is not necessarily the best solution. There are occasions where it makes sense to put all the accounting, the word processing, and the engineering on one system and get a larger system with multiple terminals. On other occasions; for reasons of security, backups, or use (depending on the applications, etc.), it would be better to split the system onto discrete machines. Today's market indicates that these are going to cost you about the same either way. Typical systems are going to cost $3,000 to $4,000 or up to $8,000 per terminal whether it is a discrete system, such as an IBM or an HP, or whether it is a multiple terminal system like the WANG 2200 or DEC PDP/11. Again, there is a wide range of choices.

In terms of accounting, a computerized system can coordinate the confusion on the accountant's desk and turn it into an organized display. Everybody is happy because the project reports are on time rather than three or four weeks late, and your firm is getting its billing out on time. Beautiful things happen when you automate the accounting functions in an engineering firm.

Word processing can also be a big part of computer system justification. The system takes the repetitive manual typing of proposals, specs and other things and puts it on the CRT for review and editing purposes. Then print it off on a daisy wheel printer so that you have the typed copy coming back quickly and correctly. One of the other developments I saw while in Las Vegas for a computer dealer show was multiple speed printers. These printers will go 400 characters per second in draft mode so that you can get a rough copy very quickly. They also will slow down to 40 or 50 characters per second and do a near letter quality in typewriter style. This way you have the best of both worlds in one printer.

Getting back to what we started with -- the profitability and productivity of a computer system. In terms of structural engineering, even projects of minimal complexity justify a computer system. A project is typically not going to be just one run, as much as we would like it to be. Therefore, having it on the machine makes that second, third or fourth run much quicker and easier to deal with. Even with a small structure it makes sense to use the machine.

The design of structural elements, beams, columns, prestressed beams, post tensioned slabs, and whatever, makes sense on a small computer system. The machine gives the ability to do ten different elements in the same time that it would have taken to do one by hand or on a calculator. You get a professional looking printout that I can show to other people. One of the key things I learned about the business of engineering was that I would always guess wrong about the right answer. You spend all this time computing and doing the numbers that you were taught in college. The project engineer says "Naw, that should be a W12x50." There was always an information gap there that I never understood until I finally started to use the computer system and do a range of answers. I felt a lot better by coming in with more positive reasoning than just my hunch.

One of the other uses that we tend to overlook is the ability to create load tables with the computer system. We can create our own tables that relate to specific products with specific designs that we are using everyday. That is a good application for the computer because you are dealing with repetitious calculations and taking them away from time wasting, error prone hand calcs.

<u>SYSTEM COST CONSIDERATIONS</u>

Obviously, the question of money comes into all of this. What is the investment in this system? Depending on your perspective, it could be a little, it could be a lot, it could be major or minor, it could spread out over a few years, or it could be all done in one payment. Different things come into play when you talk about the investment.

When thinking in terms of money the first item to discuss is hardware costs. Whether you are going to purchase or lease the system is an important question. In most leases you will get the tax advantages from the IRS passed through. There are other definite advantages to leasing. We find about 50% of our sales are going to leasing companies, using leasing money from local banks or national concerns such as U.S. Leasing. People are writing 60 month leases for computer systems at a rate of 2 to 3% per month; therefore, take the $10,000 system that you really need for the office and break it down to a $200 to $300 cost per month over a five year time frame. This figure is more manageable. To purchase or lease have come into consideration as probably the number one aspect of the hardware.

When you do spend that $10,000 as one payment, it is capital you are removing from the firm since you are buying an asset for the firm. There is a cost associated with that capital. As engineers we do not think of the economic costs, the opportunity cost, if that $10,000 was put into a money market fund at 11% it would represent $1,100 that is lost. The machine has to be able to overcome that cost of capital involved in its purchase.

In some cases as you buy bigger equipment, you have to modify the site, put in air conditioning, put in special electrical circuits for special grounding, and maybe go into humidifying the room to cut down on the static electricity. There is a wide range of site preparations that may be done and may be necessary.

Also, one should consider the cost of consultants, management personnel, and staff, etc. As I said, if I spent 50 hours researching this computer system (just obtaining literature and reading requires many hours) and my six partners and I spend another 10 hours apiece at board meetings deciding what we want to do, we've just taken the cost of the system from $4,000 on up to $10,000 or $12,000 by the time we actually make the decision. Many of us overlook the cost of research and management involved in just making the decision to purchase the hardware.

From the software standpoint, the cost of application software is the major factor. If that is the route you are going, the cost of modification should be a consideration. Will the provider of that software modify it? Will he make it fit to your particular needs and recommendations? Or, are you going to have to modify your mode of operation to work with that system?

An alternative is in-house written software. In-house software development brings with it many other responsibilities that we probably do not think of immediately. For example, the maintenance of a piece of software and the documentation of the software are all things that will come if it is purchased from outside the office. If it is written internally and then the programmer leaves the firm or is too busy to provide support then we have invested in a piece of software that will not bring the expected return. Software must be maintained and explained to the users if they are going to be using it on a daily basis.

The cost of training is also an important consideration. What does it take to get up to speed with that piece of software? This relates to the ease of use of the machine with that software.

Furthermore, consider the cost of data collection, particularly related to accounting functions. Somebody has to put all the job cost information, time card information, open jobs, open invoices, etc., onto the system before it becomes usable in any way, shape or form. We should consider what that cost is. Some firms will do that for free as they include it in the software price, and other firms are going to charge separately for that service. These are all things you have to consider as you're purchasing the computer system.

OTHER COST CONSIDERATIONS

Other items for review include documentation for the system. How do I get the software to operate in my office? If I'm buying software; are we getting manuals and will I have to do other things to document how to use the system in my office? Also consider the cost of software management. There obviously is a management function involved in any system. Knowing when to say it's a software problem, knowing when to say it's a hardware problem, and knowing who to call requires expertise. Just managing system usage promotes some costs whether it be a $3,000 Apple system or a $100,000 VAX.

Your system will have some one-time startup costs you should consider. What is the operating system going to cost and what will it take to get it up and running? What other communications equipment do I need (such as telephone lines or modems)? If we are putting terminals around the office, do I get cables included, or buy them?

Management becomes involved during the initial start-up and during the training sessions. Also, what does it cost to disrupt the organization and put this system in? One of the biggest things, particularly with drafting systems, is that as soon as one comes in every client that comes in the door gets a walk through to look at the graphics system. Furthermore, every employee has to go over and see what's being drawn, particularly if it is a fast plotter. This is true in our office and it's true in every office. As soon as the plotter comes alive, the productivity of the drafting room drops to zero as they all come over and observe what the plotter is doing.

There are also ongoing costs. What is the maintenance cost of the hardware system? What is the maintenance cost of the software? This varies with what support level you are looking for. Another cost is utilities, which also comes into play and should be considered. Some systems when they are turned on will take 4,000 or 5,000 watts, while other systems such as an HP85 only require 25 watts. There is a big difference in what the utility costs are when we have the big system turned on all the time. The cost of supplies should be considered. Paper, discs, plotter pens, and all kinds of things are not a part of our standard office supplies. Perhaps we need special filing cabinets to keep the materials in. It is possible that a special area to keep accounting records secure such as fireproof rooms or fireproof safes, etc., come into play. Coming back to the planning and management of that system, there should be one person who will keep up to date on the latest operating system and will keep us up to date on what software additions are available and whether or not the firm should have them. Which hardware upgrades are available and whether or not the firm should have them must be evaluated. There are many different things that revolve around each aspect of an ongoing system.

So, you can see from these major categories that there are many things to think about in the selection of a computer system. Yet, not any of them are overwhelming when approached systematically. It is something that we must do to stay efficient and profitable.

PROFITABILITY ASPECTS

Profitability, as it is defined by economists, is the net income for the firm divided by the total assets. When you invest in a computer system you are increasing the assets of the firm so the denominator is going up. To maintain the same level of profitability, the net income also has to go up. The net income is revenue less expenses. Therefore, the firm has to increase income or reduce expenses to be as profitable after the computer system is installed as it was before the computer.

To increase revenues one must do more marketing by going after larger projects, winning more bids, etc. The other option is to decrease costs. Typically in the engineering firm the major cost that we are dealing with is labor. Therefore, for the equation to work out, the computer system either has to improve revenue by getting jobs or allowing more jobs per minute, or I have to eliminate personnel to maintain the same profitability and to stay competitive. As an engineer, I really hate the latter alternative. It is important for us to realize that when a computer system comes in, we have to go out and promote. We have to do some very serious marketing to make this investment pay off in any environment, whether it is a small computer system or a major investment.

Some of the problems that a system may present include basically four items. These represent the traps the typical firm will fall into when using computers. By falling into these traps, you will have eliminated the gain in profitability and, in turn, the revenue you were planning on.

Trap number one is the iteration trap. This is reflected in the fact that the computer system allows the user to run 20 or 30 frames through it when you might have been done in one or two cycles. You have probably not gained a whole lot by doing those additional 28 runs if you came in with good judgements to begin with. One of our rules in the office is if you don't know the answer, don't use the computer. Otherwise, you are just going to waste a lot of time getting down to the solution. A better way is to make that first guess reasonable and get it within 20 to 30 percent. Then you need only two cycles to be at a good solution rather than wasting 20 or 30 cycles through the system. So always watch out for the iteration trap.

Trap number two concerns being overwhelmed by data. For instance, in designing a crane building, you will have dead, live, and wind load combinations. You are also dealing with horizontal loads from the crane, the impact loads, wheel loads on the girders, and all kinds of combinations. If you try to analyze all the combinations at one time, you're going to be very confused by the output. The procedure we find to be effective is to go on a unit load basis with all the different loads and look at what effects the structure the most. Then we combine those cases into the combination so as not to lose the feel for what's happening to the structure. In this way, we prevent the tendancy to become overwhelmed by data in the analysis.

Trap number three is the overanalysis trap which is probably the most common trap to fall into. A computer system will do 13 significant digit calculations and will carry them out with more precision than is practical. It seems ridiculous to worry about one half of one percent overstress when we know the loads or materials properties are not that precise. So, it is easy to overanalyze with a computer system, which will decrease profit, increase expenses, and waste time.

Trap number four is the "shouldn't have used the computer" trap. Again, this is fairly common as we forget about using all previous analysis and design aids such as tables, charts, etc. We have a steel beam design program that we wrote but it only makes sense to use that program when you are working with a strange loading or a strange bracing on that particular beam. If there is a uniform load on the beam, then we shouldn't use the machine because the A.I.S.C. Manual will give the answer directly. There are numerous occasions when the C.R.S.I. or A.I.S.C. Manuals or other design aids make more sense to use rather than wasting time and effort on the computer. This is one of the concepts you learn as you become experienced with a system. Working with a system will educate the user with regard to the various traps that should be avoided.

Computers can generate tremendous amounts of information and they can do many good things for us. It's a matter of "how do you spell relief?" Is it through the computer system and all the output data or is it using your engineering judgment? Our belief is that engineering judgment is the better way of going and we use the computer system as the tool to get us there. The result is that the microcomputer and the mini-computer can increase profits and productivity.

DIFFERENCES OF COMPUTER SYSTEMS

Two of the concepts we've been discussing are the mini and microcomputer systems. Actually, there are very few differences between computer systems anymore because they are all using the same technology and many of the same chips. The biggest difference revolves around the marketing and packaging of the system. Is it a desk top, a floor unit, a rack mount, etc.? Economics greatly affects the cost of the machine and how easy it is to repair. Today, we are beginning to see "throw it away when I'm done" systems. For instance, the keyboard on an HP-150 costs about $11 to make; therefore, they are not going to spend any time repairing it. They are going to throw them in the garbage and send you a new one. On other systems you may be working with more complicated communications between the keyboard and the terminal so they may try to repair it.

Marketing differences reflect varying levels of support. If you buy a PC at a store, you should expect that you are going to have to take it back to the store to get it fixed. You're going to have to put it in the car and haul it around, taking your time and money to get it to them for repairs. If you buy a different type of system, such as a Digital Rainbow, you can get an on-site service contract which dictates that they will come to your office within four hours to fix it. What is the value of having that response time and your investment protected? This is something for you to evaluate. Support is a key difference between the types of machines that are in use.

The manner in which a computer is marketed varies from manufacturer to manufacturer. Personal/business computers are generally sold going through retail channels. In a store environment don't expect the salesperson to know a great deal about your needs. Generally, one cannot be very technical in a retail store because they cannot afford the time and effort to answer a lot of sophisticated questions. However, if you're dealing with the manufacturer's salesperson (the guy in the 3-piece suit), you can expect him to either know the answers or to be able to get the answers in a reasonably short time. You are paying for that service because his machine is going to be higher priced than the one that is in the store.

COMPUTER SPEED RELATIONSHIPS

Another concept I want to discuss is speed. There is tremendous capability with almost every computer system but to make use of this power requires speed. The operating system in combination with the architecture of the machine will make a big difference in how that machine operates. For instance, a typical 8 bit machine (such as Apple IIe or Apple II+) will take almost an hour to solve a 40 joint two-dimensional frame. If you put that same problem on a Wang personal computer, the time will drop to eight minutes. That's 52 minutes saved. The fact that you have to wait that extra hour will make a difference in the value of the machine for the office. The Wang 2200 system will do the same problem in four minutes.

While speed can vary dramatically, the price variation generally is fairly small. You'll probably spend $2,800 to $3,200 including dual disk drives and printer for an Apple IIe system. The Wang personal computer is around $4,400 and the Wang 2200 sells for about $10,000. There's not as much variation as there used to be in system costs.

Regressing a moment to our frame analysis example where the program ran for an hour on the Apple, eight minutes on the Wang PC, and four minutes on the Wang 2200; the IBM PC takes 26 minutes to solve that same problem. The HP-9816, which is a Motorola chip based 16 bit machine, takes ten minutes to solve it. The Radio Shack Model II will take about 30 minutes. Differences in price, performance, and support can be important.

The "right" machine for you is dependent upon the types of solutions you want. If you want discrete two-dimensional analysis, an 8 bit machine will probably do the job at a rate of 40 to 50 joints an hour. If you want to run three-dimensional problems, an 8 bit machine will solve only 15 joints an hour; therefore, this system may not be "right" for you. Even a 16 bit machine may not be appropriate considering these will solve only 30 to 40 joints of a space frame per hour. That's why there is a place for mini-computers and main-frame systems in the world. There will always be a place for bigger, faster computers for major number-crunching projects.

The main frames started out in 1946 and have continued to grow in power, size, and speed while becoming less expensive. The talk about processing 100,000,000 instructions per second through those machines, is simply unbelievable. Also, it is said that they can run 10 sets of those hundred million items simultaneously to get a billion items processed in a second.

The mini-computers are going the same route as the main frames. We started out with the the WANG 2200, a small mini. Now, we have the Supermini (WANG VS, Digital VAX and PDP-11, and the Data General Nova). There is a whole new generation coming.

On a smaller scale the hobbyist machines, such as Heathkit, are now growing into micros. The new buzz word now is supermicro where you are hearing names like Pixel, Plexus, Altos, Apollo, etc. I'm not sure what a micro is, and therefore I'm not sure what a supermicro is but it must mean something to these firms. Apparently, the difference revolves around speed, support, expansion, and marketing.

The 32 bit machines are starting to become an economic reality for the engineering firm. The HP 9000, the IBM 9000, the Wang VS, and various other brands are the start of this generation. These are all going to be in the $25,000 to $30,000 bracket but you can expect the prices are going to drop over the next two years. Here again is an increase in speed. Instead of solving 80 joints an hour as one does on a Wang personal computer, I can now solve 300 joints in an hour on my desktop. This means structural software will provide you with the results you are looking for, at a rate of 150 to 200 joints an hour for three-dimensional analysis.

Finite Element analysis is another step up and we will have to wait to get that much power on the desktop economically. There are some microcomputer programs that do Finite Element analysis and if you only need to do 100 nodes this is probably acceptable.

COMPUTER INFORMATION RESOURCES

One of the best software books that is available right now is put together by the American Consulting Engineers Council and is called Major Software Sources for Consulting Engineers. It lists approximately 400 different sources for software. It also lists what machines are compatible with a particular program. There is an abstract of each company and the software. The book is an excellent reference guide. So, I recommend it to you.

How current is this book? Since it is computer generated, I would say that it is fairly current as they have already issued three or four volumes. I believe it is issued quarterly.

There are numerous other sources and directories available. If you walk into a computer store you will find an Apple directory that lists all the software available for Apple. There is an IBM directory and a book called the Source (another book that comes out periodically). If it's current, it's good.

There was a time when we had three or four years to rest up from a major change in our software. Now, we may have six months breathing room before going to the next step, the next machine, the next generation -- it is a fast paced transition.

CONCLUSION

In summary, I would like to reiterate several concepts that we have covered. First, I want to make sure that you understand that support is the key to a successful installation. The support of the software, the support of the hardware, whether it's in-house, whether it's software you purchase. In other words, the who, what, why, when, and how of maintenance is a very key factor regarding your system.

The next aspect that we should think about in a computer installation and use are the legal implications. Who is responsible for the results? As an engineer using software, you may believe the software house is responsible but that's not true. Since you are stamping the drawings and doing the engineering calcs, it is your responsibility. At this time, the courts have not had any cases presented to them to test this.

Which brings me to the next point, which is that anybody who says their software has no bugs is a fool. Every piece of software has bugs in it. You may not be able to find them or they may be very small, very isolated bugs. Our programs on the Wang have been in existence for almost 10 years and we currently have 800 installations. Three weeks ago a user found a way to end up with answers that were absolutely ridiculous for his problem. It was a particular set of input that led to this bug. It wasn't something that he did wrong as an operator, although I believe that 99 percent of the "bugs" are operator errors which stem from not reading the manual or not working with the software properly. In terms of ethical and legal considerations, there is a paper out that was published a few years ago by ASCE entitled "Ethical Considerations in Computer Practices." It is being updated by the Computer Practices Committee, as is the computer pricing guide.

In conclusion, what is the best system for an engineer? The choice is based on your applications: what you want to do, how much money you have to spend, how valuable that system can be in your office, what kind of growth you are looking for, and what kind of support and maintenance you want on that system. The decision may include such minor things as color. Do you want to have the status of a name brand or are you willing to take a chance on somebody who has a good product but may not have the reputation yet? Is the salesman going to make a difference to you? In general, the hardware may be much the same, and in a lot of cases the software is going to look very similar. So, it's a matter of who are you going to be more comfortable with and that will be the right system for your office.

Thank you for your attention. We will go to questions and comments at this time.

Q: IS THERE ANY SOFTWARE FOR BRIDGE DESIGN AND ANALYSIS? ECOM does have a program for bridge analysis on the Wang 2200 that we're testing in three sites, Illinois, Louisiana and Indiana. All indications are that it is a useful program. Over the next year you will see a lot of programs coming out for bridge design, bridge analysis, bridge economics, and other related topics because of the need to replace bridges, the gas tax, etc. Right now the best program I know of for bridge analysis and design is the US Steel program, SIMON. It is going to take a while to market software with any quality or stature and hopefully, we have one that is not too far away.

Q: WHY IS THERE SUCH A WIDE VARIANCE IN SOLUTION SPEED? The application run on all the systems was the same: ECOM'S General Frame Analysis Program. We put in the same structure, same number of joints (35 joints), same number of members, the same loads and combinations, etc., and just let the machine solve away. The difference in speed is a function of the operating system. The Wang P.C. is using the same chip that IBM uses and basically the same MS/DOS operating system that IBM uses. Whatever Wang did to make their machine run three times faster than the IBM P.C., it was successful. If I knew their secrets, I'd be in the hardware business. For some reason, Wang came up with a winner. Unfortunately, Wang is probably one of the worst marketing organizations in the world for computer systems. They have great hardware and their growth has been primarily oriented around that fact. If they did an effective job of telling the world about their systems Wang would be growing at an even faster rate than they are today.

Most manufacturers have chosen to be relatively compatible with IBM so that they are not bucking the trend. Digital learned the hard way. They tried to go with CP/M as its main operating system on the Rainbow and PRO Basic on the 300 series system. The PRO 350 have been stones; nobody is selling them. On the Rainbow, DEC found that with CP/M the system was selling ok. As soon as they announced the MS/DOS operating system on it (compatible to IBM), sales accelerated.

Q: COULD YOU PLEASE TELL ME THE DIFFERENCE BETWEEN A MIRCO AND A MINI COMPUTER? I use those words interchangeably because I don't think there is a difference between them anymore. There used to be a difference in terms of the size of the CPU and the chips used but now not even that is true. Another old dividing line related to the number of terminals present on the system. If it had multiple terminals it was a mini; if it had only one terminal that was a micro. However, even that is gone today so the definition is wide open. One difference may be the price and how you are buying it. If you're buying it in a store, it's probably a micro; if you're buying it from the manufacturer, its probably a mini.

Q: HOW DO I FIND THE BEST SYSTEM? There are two computer rules that come to mind: Rule No. 1 is to find the software first and buy whatever hardware it runs on; and Rule No. 2 is to see Rule No. 1. Find the software that you want, whether it is Finite Element analysis, space frame structural analysis, concrete beam design, post-tensioned slabs or whatever first. It doesn't matter what hardware system the software runs on, the hardware is not going to be that much different in price over what system you might think would be the best. For instance, Victor is in the press about their financial troubles. The Victor is an excellent machine. If you are willing to take the risk that one year from now there might not be service on it, it is probably a great investment. But does it have the right software to do what you want to do? What do you want it to do, what do you need it to do, and what different aspects of support do you require for that system must be considered and evaluated. Find the software first and you'll find some hardware that will be acceptable.

Q: WILL COMPUTERS REPLACE ENGINEERS AND LOWER THE DEMAND FOR ENGINEERS? There is no doubt that our economy is changing to an information oriented economy; a data processing economy if you will, and away from the manufacturing base of the past. I think that structural engineers are not going to fall in demand. There will always be a demand for good engineering people and with the aid of a computer system that engineer can do a great deal more. I worry about the draftsman as that's where the decline will occur. As machines are linked the next step in the evolution will be that the machine can take my solution and make the drawings. For example, metal building manufacturers have super systems that make building drawings come out on their automated drafting systems easily and efficiently. I would be more worried about the future if I was a draftsman than an engineer. The engineer is going to be needed, no doubt about it.

Q: WILL WE THROW OUT MIRCOCOMPUTERS IN THE MANNER THAT WE THREW OUT THE SLIDERULES A FEW YEARS AGO? As long as a tool is useful one will keep using it. The computer will continue to do its job for many years. It is you who decides when you want the latest tool or a faster tool. Yes, I believe that you will want to change machines every three or four years due to improvements in hardware, software, and price. The answer is you're going to throw it away. If you can get five years out of it, that is a great deal. In terms of a justification or payback cycle, we tell our clients to use two years for a personal computer. Then, the third is free, and the fourth year is gravy. If you get five out of it that is great. For the bigger systems when you spend over $15,000, you want to get five years out of it to justify it. The computer decision is not a once-in-a-lifetime choice; it is similiar to buying a car only not as expensive any more.

Q: WILL THE SOFTWARE REVOLUTION AND ARTIFICAL INTELLIGENCE BEGIN TO SUPERCEDE THE HARDWARE REVOLUTION? Five to ten years from now you will see analysis software feeding into design software which feeds into drafting software. I don't think that many firms will be able to afford it in five years but maybe it will be affordable in ten years as the cost comes down. The hardware is here right now to communicate and make drawings. It is a matter of somebody sitting down and funding the software development. ECOM cannot afford to do that development because of our size. A small engineering firm needs to look at a very quick payback and resonable investments to stay in business. It is important that the software people you are dealing with are also living in that environment and understand your needs so that day to day improvements are made with an eye to the future. You should not be forced beyond your capabilities or funds.

Q: AREN'T THERE ALREADY COMPANIES THAT HAVE ALL THE FUNCTIONS INTEGRATED AS WAS SHOWN IN AN E.N.R. ARTICLE? I remember the article you are referring to in "Engineering News Record." That article was somewhat misleading. S.O.M. has an outstanding program that will put a building into the cityscape and let you look at it from all different views and different angles. However, they are still doing design by hand in some cases. They have not integrated all the pieces together -- yet. Again, it is a matter of funding. The pizzaz of showing the owner his building in the cityscape is promotion and marketing. They are one of the firms that can afford to invest the time and effort to do work with it.

Q: ARE WE GOING TO USE THE COMPUTER TO DO RUN AFTER RUN JUST BECAUSE WE HAVE TIME AVAILABLE? IS IT A GOOD TIME TO BE IN THE PAPER BUSINESS? There is no doubt that the paper or the phone business will be a good investment when related to computers. It does take a while for the average firm to really use their system efficiently on an everyday basis. The one thing that scares me about the computer revolution and all the paper it produces is the loss of feel for the structure and what you are doing. You put your numbers into a black box and the solution comes out the other end with 24"x 36"drawings numbered S1 through S5. You are not sure that the machine is doing what you want the way you want it done. That is a little scary and I am not sure how we as professional engineers are going to confirm the design. One way is to stop and look at the intermediate stages of a solution. We cannot let the black box do it all and see the end result without evaluation. This is a major concern for our future.

Some people are going exceed their limits of expertise or extend beyond their capabilities. There is a user of ours in Texas who recently bought our Space Frame Analysis Program. There is no way on earth he should be using it. He does not have the expertise to understand the required input much less the answers. This goes back to my earlier discussion regarding knowing the answers before you start working with the system. Getting a feel for the structure and knowing what the results should be must be a requirement for any engineering process.

Q: ARE THE EDUCATORS DOING A GOOD JOB IN PREPARING GRADUATES TO DEAL WITH EXPERTISE, FEELING FOR THE ANSWER, AND THE COMPUTER? They are doing a better job than ten years ago, but it is still not great. Ten years ago when I came out of school I was unprepared. Having taken the advanced steel, the advanced concrete and the advanced structural analysis courses in school, I still had no feel for what was happening in that structure until I sat down and worked with an engineer who had the experience and the background to help me understand it. Educational institutions have not kept up with the pace of knowledge the profession requires nor the practical application of that knowledge. In the last couple of years more universities are buying software and putting in computer systems for the students to use. The schools are starting to realize that once the students get out the door they are going to be using systems of some sort. Some colleges such as Penn State and Arizona State are setting up Software Centers to show the student (and the faculty, hopefully) what is available & in use today. After you've done two or three concrete beams by hand you should understand the calcs and time required. Going to the computer system and doing 15 or 20 beams gives you much better feel for what the shear requirements are, what size beam makes sense, and how much steel you need. Education is not doing the job it should; however, they are doing a better job than they were ten years ago.

Q: CAN ONE OR SHOULD ONE REQUIRE ACCESS TO THE PROGRAMMING CODE BEFORE BUYING SOFTWARE? When you buy a piece of software, you should always run sample problems and compare the results to some other standard solution procedure such as on a time-sharing system. This should be done whether or not you have access to the source code. On some machines ECOM will provide the source code so the user can go in and look at the program. On other machines we will not because it is too easy to pirate. When a user obtains the source code from us, he can look at the program and nine times out of ten he can't figure it out. There are so many overlays of coding or interwoven variables in the program to make it fit in a 24k or 32k memory, that it is often difficult for us as the originator to understand what is happening. Sometimes when we fix a bug, we find out that the variable is used in other places and we now have more bugs.

The best source of information in terms of verifying whether a program does it right or not is looking at the manual. The manual associated with the program should reference the code provisions and solution methods being used and what assumptions are being made in that software. If the manual is poorly written, hard to follow, xeroxed on a liquid copy machine, and sticks together, I wouldn't advise getting involved with that program. If it is printed up or is a nice photocopy and has a decent flow to it, then that represents a company who has put time into the manual. This program should be considered. You get what you pay for in this market. Don't take anything for granted; test it by doing old problems and see what the results are. If the answers are not better than what you did by hand, you do not need that software.

Q: HOW COMPATIBLE ARE THE VARIOUS OPERATING SYSTEMS? CAN I TAKE A PROGRAM FROM ONE MACHINE TO ANOTHER? There are advantages and disadvantages to every operating system. For instance, the Wang 2200 is very fast, but it also requires that its own BASIC-2 language be used. There is nothing else in the world that is compatible with it. On the other hand, the Apple is very generic and just about anything written for an Apple will transfer either directly with a diskette or through telephone communication lines to any other CP/M machine. The best way to proceed is to assume that there is no compatibility in terms of the software.

Each machine should be examined on its own available software. Do not buy future promises of compatibility. Our software is available on 14 different machines and we have 14 different versions of software that make use of the advantages of each system. For example, graphics on the IBM are different than on the HP which are different than the graphics on the Wang, Apple, Radio Shack, etc. There is no commonality across those machines (despite what the hardware salesman told us). We made a corporate decision to go to the CP/M and MS/DOS Basic languages as a base to get to something that is more generic. Recently, we had the first direct compatibility ever when we took an IBM P.C. diskette and put it in the Wang P.C. and ran the program. That is the only time we have ever been able to do something like that.

Everybody has different screen formatting, everybody has different diskette capacity, everybody has a few different operating commands, etc. so that we need to maintain 14 different versions and 14 machines for testing. The typical salesman doesn't know that as he believes all CP/M's or MS/DOS's are the same. Do not buy a system and get caught without software. It goes back again to our discussion on finding the right software. If you find the right software and it runs on a particular machine then you know it works. Do not expect it to transfer; it may, but don't expect it to happen.

Q: IS THERE ANY SOFTWARE FOR THE DESIGN OF CONNECTIONS? It is much easier to put a note on a plan that says "connection design by fabricator". I save lots of time and have minimum risk. ECOM does have a program that designs a steel girder bolted connection. We use other utility type programs for welded connection design. Whether a software program will be developed or not is generally dependent upon a commonality of procedure and results. It is easy to do a steel beam because everybody uses the same code and the same procedures. On the other hand you can give a connection design problem to 45 different people and you get 45 different solutions. Most of the time connections are a very individual design and there is not any commonality or routine other than code guidelines from which to create a marketable program. So, I do not see any connection design software being developed in the near future. I like having the fabricator design connections because he knows what makes the most sense based on his operation and costs.

Thank you very much.

EAST BOSTON WASTEWATER PUMPING SYSTEM

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INTRODUCTION

The East Boston Pumping System is part of the Boston Metropolitan District Commission's (MDC) North Metropolitan sewerage system. Its service area includes the communities of East Boston, Chelsea, Revere and Winthrop. Major facilities of the East Boston Pumping System include: the Chelsea Creek Headworks, the Chelsea Screen House, the Chelsea Creek Siphons, the East Boston Steam Pumping Station, the East Boston Electric Pumping Station, the Winthrop Terminal Facilities, the North Metropolitan Trunk Sewer, the East Boston Branch and Low Level Sewers, the Chelsea Branch Sewer and the Revere Extension Sewer. These service area communities and facilities are identified in Figure 1.

For nearly 100 years the Boston Metropolitan District Commission (MDC) and its predecessor agencies have provided sewerage services to the City of Boston and surrounding communities. The MDC's wastewater pumping system for East Boston is one of the oldest systems built by the MDC. In 1889, the Massachusetts State Legislature created the Metropolitan Sanitary District (MSD) to provide sewerage services to Boston and its surrounding communities. By 1895, the North Metropolitan Sewerage System, consisting of intercepting sewers, pumping facilities and outfalls, was built to serve the northern communities of Boston including East Boston, Chelsea and Winthrop. The East Boston Steam Pumping Station, the North Metropolitan Trunk Sewer, the Chelsea Branch Sewer, and the Old Deer Island Pumping Station were built during this period. In 1904, sewerage services were extended to Revere through the construction of the Revere Extension Sewer. The Chelsea Screen House and the East Boston Electric Pumping Station were built about 1938 as temporary facilities to supplement the East Boston Steam Pumping Station primarily during wet weather. The planned construction of (a) the

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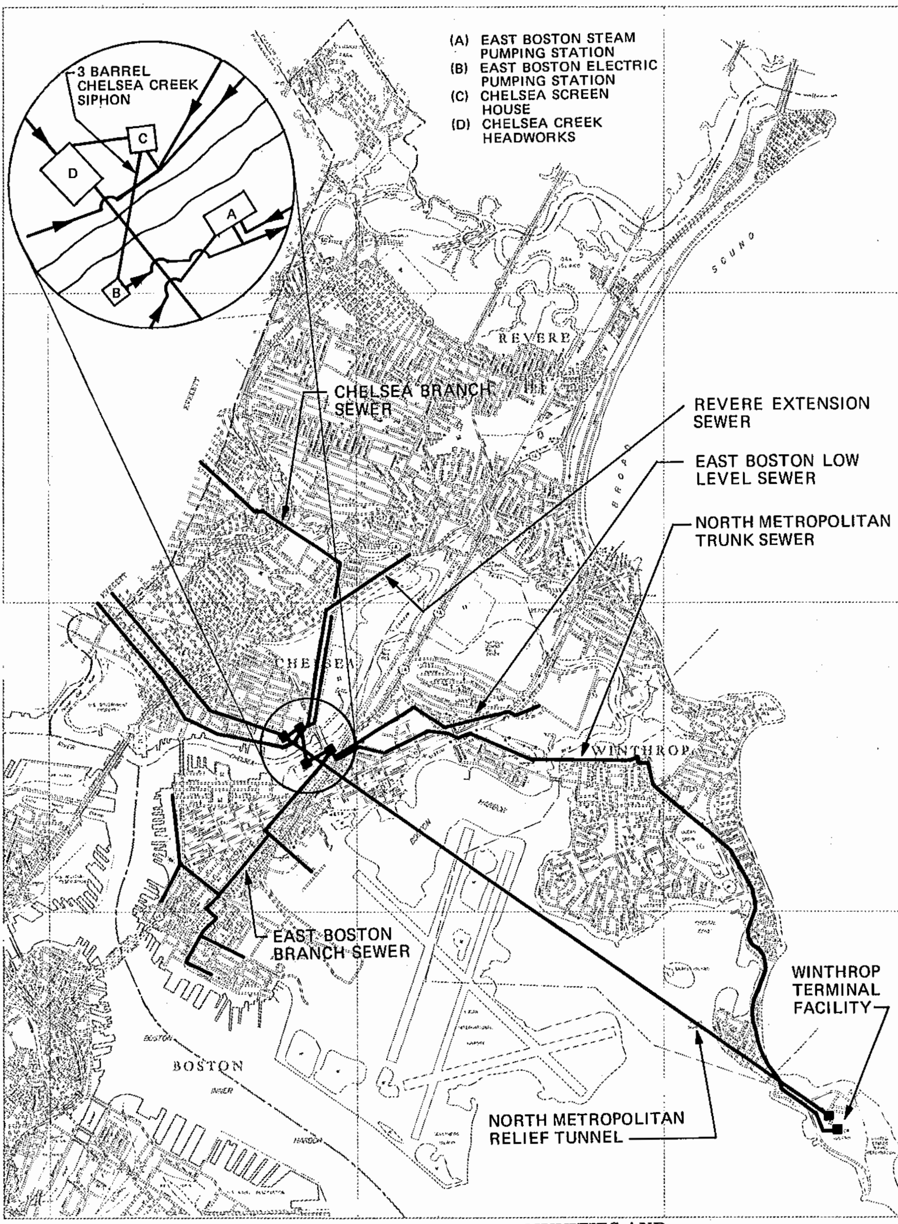

FIG. 1 SERVICE AREA COMMUNITIES AND FACILITIES OF THE EAST BOSTON PUMPING SYSTEM

Chelsea Creek Headworks, (b) the North Metropolitan Relief Tunnel, and (c) the Deer Island Main Pumping Station was intended to replace these temporary facilities. The East Boston Electric Pumping Station was designed to pump primarily wet weather flows while the steam station continued to pump primarily the dry weather flows from the North Metropolitan Sewerage System. The new Winthrop Terminal Facilities were built in 1970 to pump and pretreat flows from the North Metropolitan Trunk Sewer prior to discharge to the Deer Island Wastewater Treatment Plant.

To provide improved sewerage services to its member communities, the Massachusetts Legislature, the MDC and its predecessor agencies conducted numerous studies and investigations (1, 2, 3, 4, 5, 6, 7, 8). The most recent and comprehensive study (7) of existing sewerage facilities and future sewerage service needs was conducted by the MDC in 1976. This study, known as the Eastern Massachusetts Metropolitan Area (EMMA) Wastewater Engineering and Management Study (7), identified and prioritized wastewater collection, transport, pumping and treatment needs of one hundred and nine (109) communities in and around Boston including the communities of East Boston, Chelsea, Revere and Winthrop. The EMMA study recommended that detailed investigation and facilities planning be carried out for the East Boston Pumping Stations to provide improved dry and wet weather pumping which directly affects sewerage service to these four communities. In accordance with the EMMA recommendations, the MDC initiated a facilities planning study in 1981 (8) on the existing Wastewater pumping system for East Boston. The results of these investigations are briefly presented here.

SERVICE AREA CHARACTERISTICS

The service area of the East Boston Pumping System includes approximately 10,400 acres (4209 hectares) with a 1980 total population of about 119,300. East Boston is a high density residential area surrounded by and interspersed with transportation, heavy industrial and commercial uses as well as the Logan International Airport. The City of Chelsea is a large multi-family residential community with some scattered light industry. Revere is a residential community north of Boston with primarily single-family housing units, with the exception of some multi-family housing units located in the downtown area. One of the most densely populated towns in Massachusetts, the Town of Winthrop is primarily residential in character with business, institutional and recreational areas scattered throughout the town.

CRITICAL PUMPING SYSTEM PROBLEMS

The existing East Boston Pumping System is very old with inadequate and inoperative facilities and equipment at the pumping stations and appurtenant structures. The components of this system that are currently having functional problems include:

1. Chelsea Screen House
2. East Boston Electric Pumping Station
3. East Boston Steam Pumping Station
4. Winthrop Terminal Facilities
5. North Metropolitan Trunk Sewer
6. East Boston Branch Sewer
7. Chelsea Branch Sewer
8. Revere Extension Sewer

Figures 2 and 3 schematically illustrate the functions of these facilities.

The Chelsea Screen House, which was built in 1938 to protect the pumps at the East Boston Electric Pumping Station, contains two inoperable mechanically cleaned bar screens. The rake, wiper and rake guides in both screens are badly corroded with many bars missing. All motors, starters and controls are badly corroded and cannot be operated. Poor design and lack of proper operation and maintenance are the main reasons for the deteriorated condition of the Chelsea Screen House and its equipment.

The East Boston Electric Pumping station, also built in 1938 as a temporary facility, contains two large sewage pumps for pumping mostly wet weather flows from the North Metropolitan System. The larger pump has a capacity of 75 mgd (3.29 m^3/s) and the smaller one has a capacity of 50 mgd (2.19 m^3/s). These pumps are installed at the bottom of a 21-foot (6.40 m) diameter 60-foot (18.29 m) deep shaft. Electric motors, motor control center and two vacuum pumps are installed in an above ground structure. Most of the equipment in this facility is in reasonably good condition. However, access to the below ground shaft is very difficult (through vertical ladders) and the work environment is very hazardous for operators and maintenance staff as this pumping station

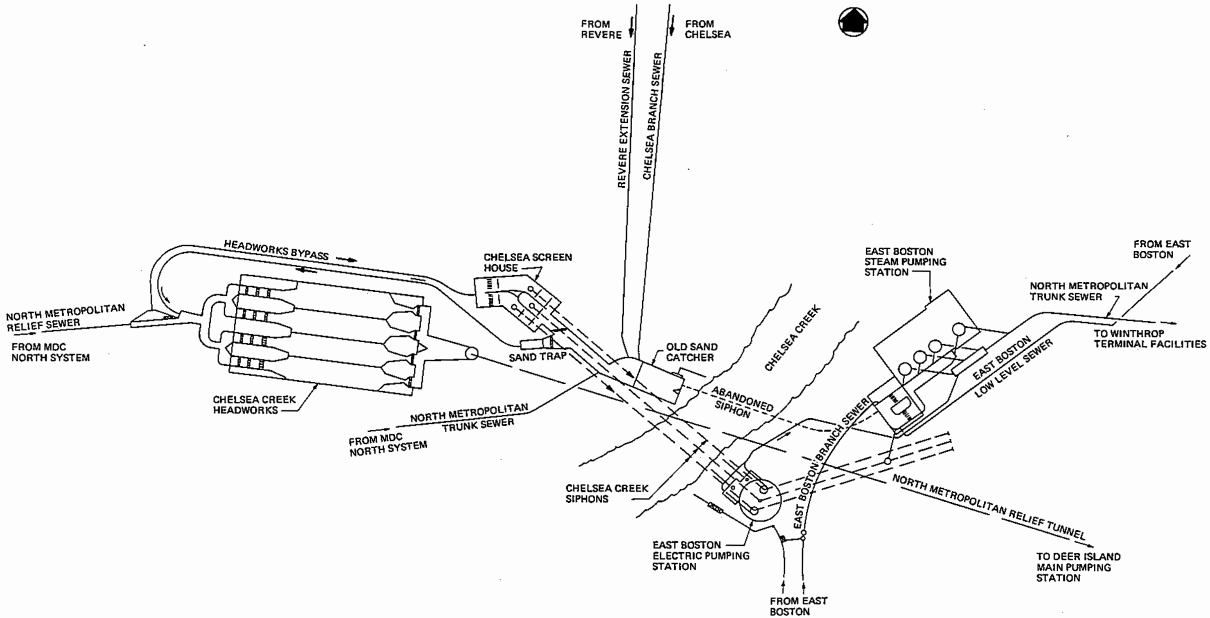

FIG. 2 FLOW SCHEMATIC OF THE EXISTING EAST BOSTON PUMPING SYSTEM

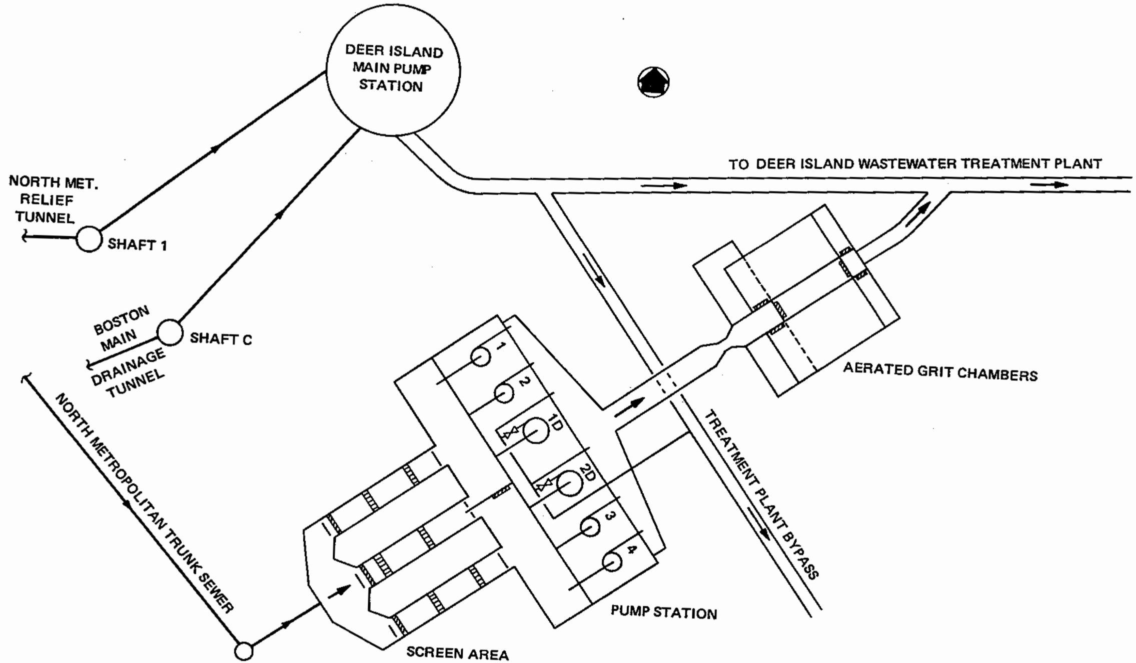

FIG. 3 FLOW SCHEMATIC OF THE EXISTING WINTHROP TERMINAL FACILITIES

does not meet current safety standards of OSHA. The equipment in this station is also not sized for dry weather operation because the station was designed to pump wet weather flows only.

The East Boston Steam Pumping Station was put into service in 1895 and contains equipment which is old and antiquated. Two of its four pumps are inoperable. It contains two old triple-expansion steam engines, one of which is operable. This operable engine has been requested by the Smithsonian Institute of Washington D.C. for museum display. This station has been kept in operation way beyond its useful operational life. Since this pumping station building is eligible for listing in National Historic Register, no major modifications to this structure can be made without concurrence from the Massachusetss Historic Commission and the Advisory Council for Historic Preservation.

The Winthrop Terminal Facilities, put into service in 1970, contain both pumping equipments and pretreatment facilities. The pumping station has six (4 electric motor driven and 2 diesel engine driven) pumps with a total capacity of about 120 mgd (5.26 m^3/s) while the pretreatment facilities have a capacity of about 60 mgd (2.63 m^3/s). As a result, flows in excess of 60 mgd (2.63 m^3/s) are by-passed and discharged without treatment. The screening equipment, grit collectors and the diesel engine driven pumps at this facility are in very poor condition. Poor design and lack of adequate operation and maintenance resulted in the deteriorated condition of these equipments. The heating and ventilation system in this facility is inadequate and the hazardous and non-hazardous areas are not adequately isolated.

The North Metropolitan Trunk Sewer is a 9 feet (2.74 m) diameter (circular and horseshoe) brick interceptor built in 1895 with a capacity of about 125 mgd (5.48 m^3/s). Although it used to convey wastewater flows from all or part of 26 communities north of Boston, it currently transports pumped flows from the East Boston Steam and Electric Pumping Stations as well as flows from local connections in East Boston, Winthrop and Deer Island. Television inspection of this interceptor showed that it is generally in excellent condition. However, in sections of this interceptor bricks have fallen off and debris have accumulated.

The East Boston Branch Sewer, built in 1895, transports flows from a combined sewer service area in East Boston to the East Boston Steam Pumping Station. During wet weather flows in excess of the capacity of this interceptor overflow through regulators into the harbor. Due to lack of dry weather flow pumping capacity at the East Boston Steam Pumping Station there is normally flow backup and surcharging in this interceptor. This has resulted in deposition of sediments and sewage solids in the sewer and reduced its carrying capacity.

The Chelsea Branch Sewer serves a primarily combined sewer service area and transports dry and wet weather flows from parts of Chelsea, Everett and Revere to the Chelsea Creek Headworks. At times flow carried by this interceptor is diverted to the East Boston Electric and East Boston Steam Pumping Stations. This interceptor frequently surcharges, particularly during wet weather, causing basement and street floodings with wastewater. Malfunctioning tide gates, excessive sea water inflow, and inadequate operation of the East Boston Pumping system are primarily responsible for this flooding.

The Revere Extension Sewer serves a separate sewer area and conveys wastewater flows from parts of Chelsea and Revere to the Chelsea Creek Headworks. At times, Revere Extension Sewer flows are diverted to the East Boston Electric and East Boston Steam Pumping Stations. There is excessive infiltration/inflow (I/I) in the service area tributary to the Revere Extension Sewer. During wet weather this excessive I/I and operation of the Chelsea Creek Headworks and the East Boston Pumping System cause surcharging of the Revere Extension Sewer. This results in flooding of basements and low lying areas by wastewater.

PROBLEM SOLVING REQUIREMENTS

During analysis of the existing East Boston Pumping System, it became clear that a number of critical problems would have to be addressed in order to provide reliable sewerage service to the four communities. These included:

1. Existing outmoded, inefficient and hazardous facilities would have to be replaced with new facilities;

2. Inoperable and/or inefficient equipments would have to be replaced with properly sized efficient new equipments;
3. Modifications of existing facilities would be required to provide treatment to all flows as well as for isolating hazardous areas;
4. Pumping of flows from combined sewer systems would have to be isolated from essentially separate area flows to prevent surcharging of interceptors; and
5. Excessive infiltration/inflow in separate sewer areas would have to be reduced to eliminate flooding of basements and low lying areas.

To fulfill the above requirements a number of alternatives were develped and evaluated. This resulted in a recommended plan for the future East Boston Pumping System.

FUTURE EAST BOSTON PUMPING SYSTEM

Following detailed analysis and evaluation of various options to upgrade the East Boston Pumping System the Boston Metropolitan District Commission adopted a plan to provide reliable and improved sewerage service to these four communities. This plan would provide reliable pumping during both dry and wet weather and would eliminate sewage backup and flooding in East Boston, Chelsea, Revere and Winthrop caused by present operations of the MDC.

The plan adopted by the MDC for upgrading the East Boston Pumping Stations and appurtenant facilities has the following components:

1. A new Screen House in Chelsea,
2. A new Circular Pumping Station in East Boston,
3. Diversion of overflows from the Chelsea Creek Headworks to the new Screen House in Chelsea,
4. Diversion of the Chelsea Branch Sewer and the Revere Extension Sewer flows to the new Screen House in Chelsea,
5. Conduit connections from the new Screen House in Chelsea to the two low level existing siphons (there are three siphon pipes one lying on top of the other two encased in a horse-shoe shaped steel and concrete tunnel) under Chelsea Creek,
6. Inspection and cleaning of the two low level siphons under Chelsea Creek,

7. Connection of the two 60-inch low level siphon extensions in East Boston to two separate wet wells in the new Pumping Station in East Boston,
8. Diversion of flows from the East Boston Branch Sewer and the East Boston Low Level Sewer to the dry weather flow (east) wet well in the new Pumping Station,
9. Connection of the discharge conduit from the new Pumping Station to the North Metropolitan Trunk Sewer,
10. Modification and upgrading of the existing Winthrop Terminal Facilities and its equipment,
11. Cleaning of debris and rehabilitating the North Metropolitan Trunk Sewer,
12. Abandonment of the existing Screen House in Chelsea, and the East Boston Steam and East Boston Electric Pumping Stations in East Boston, and
13. Conversion of the East Boston Steam Pumping Station into work shop and maintenance facilities for the MDC.

Figures 4 and 5 illustrate the proposed modifications and two schematics of the proposed East Boston Pumping System. The estimated capital cost of all facilities and appurtenant structures of the proposed pumping system is about $22.1 million based on ENR index of 4180. Future operation and maintenance costs for the proposed system is estimated to be about $810,000 per year. The MDC has initiated the final design and preparation of plans and specifications for the new East Boston Pumping System. It is expected that all design work will be completed by the end of July 1985 and all construction work completed by the middle of 1988. This new pumping system is expected to be fully operational by the end of 1988.

CONCLUSIONS

The existing East Boston Pumping System is a very complex, old, outdated and inefficient system. It does not currently provide adequate and reliable sewerage service to its four tributary communities. The service area communities also have excessive sea water inflow and/or infiltration/inflow in

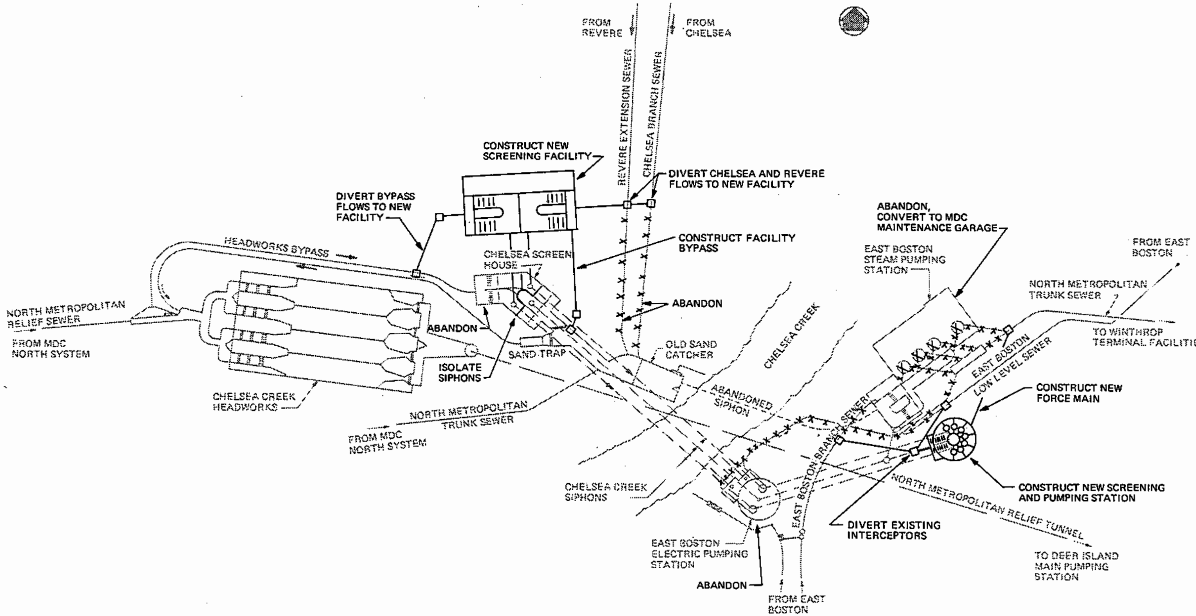

FIG. 4 PROPOSED MODIFICATIONS AND FLOW SCHEMATIC OF EAST BOSTON PUMPING SYSTEM

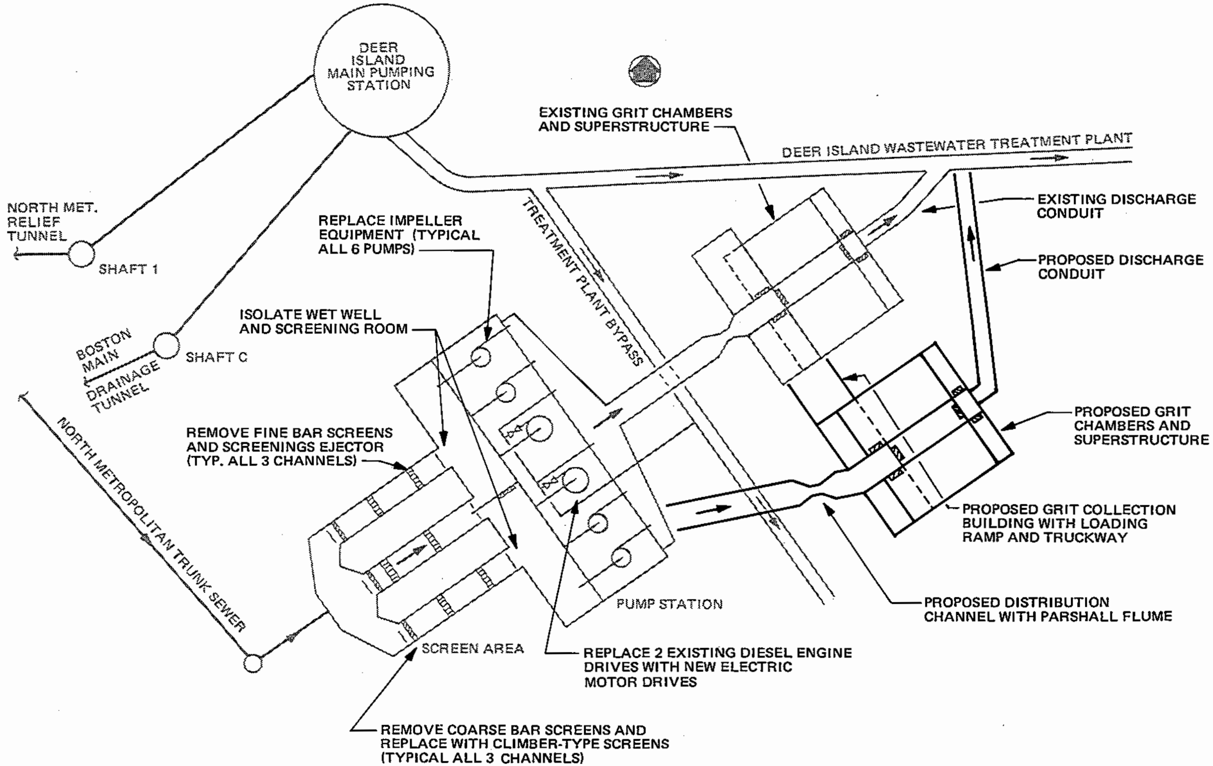

FIG. 5 PROPOSED MODIFICATIONS AND FLOW SCHEMATIC OF WINTHROP TERMINAL FACILITIES

the community sewer systems. This combination results in surcharging of the interceptors, sewage backup and flooding of basements and low lying areas. To remedy this situation the Metropolitan District Commission has adopted a plan to upgrade the existing East Boston Pumping System. This plan incorporates a new screen house, a new circular pumping station, upgrading of the Winthrop Pumping and Pretreatment Facilities, and cleaning and rehabitation of interceptors and siphons. It also includes abandonment of two existing pumping stations and an existing screen house. This upgrading plan will provide reliable and efficient sewerage service to the four communities and will eliminate wastewater backup and flooding caused by current MDC operations. Elimination of excessive infiltration/inflow in community sewers will also be needed to completely eliminate sewage backup and flooding. Each community is expected to carry out reductions in excessive I/I in its sewer system.

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KEY WORDS

Bar Screens, Controls, Diesel Engines, Flooding, Headworks, Infiltration/Inflow; interceptors, motors, outfalls, Pumping Stations, Pretreatment Facilities, Rakes, Screen House, Sewers, Sewerage Facilities, siphons, starters, steam engines, Surcharging, Treatment Plant, Wastewater and wipers.

ABSTRACT

Boston Metropolitan District Commission's (MDC's) East Boston Pumping System is a very old system. Historical background of the development of this complex pumping system together with the existing condition of its facilities are briefly discussed. Existing system is found to be outdated and inefficient. Some of the existing screenings, pumping and pretreatment facilities and their equipments are currently inoperable. Detailed investigations and testing demonstrated that three of the existing facilities need to be abandoned, two new facilities need to be built and major modifications to seven other facilities are needed in order to provide reliable sewerage service to service area communities. Boston MDC's plans to modernize and upgrade this complex system are briefly outlined. Some of the specific details of the upgrading plan are identified and discussed.

SUMMARY

Historical background of Boston Metropolitan District Commissions very old East Boston Pumping System is presented. The findings of current conditions of various components of this system are discussed. It is determined that some of the existing facilities should be abandoned. Some facilities should be modified and two completely new facilities should be built to provide reliable service in the future. Details of Boston MDC's modernization plan for this complex wastewater pumping and delivery system are briefly discussed.

RESIDENTIAL WASTEWATER-GROUND WATER INTERACTIONS IN THE VICINITY OF MARES POND, FALMOUTH, CAPE COD

Ralph F. Vaccaro, Nathaniel Corwin and James R. Mitchell

Abstract

Time-related measurements of selected conservative and nonconservative aquatic parameters from the vicinity of Mares Pond, Falmouth are used to quantify the extent of domestic wastewater infiltration to the local ground water. A fractional comparison between the relative importance of physical as opposed to biological processes which together account for the observed degree of wastewater attenuation is presented. Indications are that the total amount of leachate infiltration detected at the sampled well point varied between 8 and 12 percent and that physical processes such as dilution and nonbiological chemical attenuations accounted for about 90 percent of the qualitative difference between the well water and septic leachate compositions. Regarding the remaining 10 percent of the overall attenuation, biological processes are assigned about 95 and 60 percent respectively of the observed organic carbon and combined nitrogen mineralization. Because organic carbon regeneration proceeded more rapidly and completely than that of combined nitrogen, nitrogen contamination appears to pose the more insidious threat to ground water destined for domestic usage in the Mares Pond area.

Introduction

BACKGROUND

Maritime Cape Cod, a hook-shaped peninsula of easternmost Massachusetts extends about 60 miles into the Atlantic and includes 15 townships distributed over an area of 440 mi^2. According to the U. S. Geological Survey, the remote source of all fresh water for the entire Cape is atmospheric precipitation (ca 2.4×10^6 gals/mi^2/day) and its recharge (ca 1.1×10^6 gals/mi^2/day) to

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Contribution No. 5665 from the Woods Hole Oceanographic Institution.

ground water (Palmer, 1977). The interior aquifer currently supplies about 100 large municipal-type wells plus several thousand private wells located within serviced and unserviced water and wastewater districts.

Historically Cape Cod ground water has provided a reliable and safe domestic water source both for the native population (currently ca. 150,000) and the annual ten-fold increase in temporary residents encountered during summer. However, unprecedented demand for quality domestic water and provision for its ultimate disposal have aroused serious concerns regarding future ground water abundance and quality. Clearly, the incidence of complaints citing ground water adversities such as changes in subsurface elevation, salt water intrusion, eutrophication of surface waters and the intermittent presence of suspiciously high concentrations of carbonaceous and nitrogenous organic derivatives is increasing. To counteract this trend and to clarify the local ground water outlook, the federal government has conferred "Single Source Aquifer" status over the entire Cape as recorded in the Federal Register, 1982.

To predict and minimize adverse ground water impacts from unbridled residential and commercial construction is an important responsibility of the environmental and public health oriented regulatory agencies. On Cape Cod, much of the impetus for new construction stems from a combination of multi-unit residential subdivisions and from the seasonal demands of transient visitors. Procedural decisions regarding go or no-go construction at specific locations, however, often proceed with only quasi-relevant soil and ground water information of questionable merit. Common deficiencies include incomplete site-specific data on soil composition along with inadequate information on percolation characteristics, and other relevant hydraulic peculiarities of the aquifer.

A second complication affecting freshwater distribution and availability on Cape Cod is the constant discharge to the sea of relatively large volumes of low salinity ground water as opposed to river water which occurs along the entire coastal margin. Maintenance of highly stable offshore salinity gradients requires that a fixed but illusive volume of ground water be permanently transported to the ocean within each tidal cycle. Finally, it is not unusual to encounter delicately buoyant freshwater lenses overlying denser layers of deeper seawater within the interior of the peninsula. Disruption of this sensitive layering can result in saltwater intrusion into shallow wells. Many believe that these environmental peculiarities have led to an unwarranted reliance on ever increasing lot sizes as the principle ground water protection strategy.

Excessively high concentrations of nitrate in the drinking water of infants can, under certain conditions, lead to a reduction in the blood's oxygen carrying capacity. This potentially fatal disease, called methemoglobinemia, originates in the lower intestinal tract when nitrite produced from the reduction of nitrate becomes abnormally associated with the victim's circulatory hemoglobin. Although extremely rare on Cape Cod, the epidemiological evidence associated with this disease remains a very important quality criteria which is applied to all potable waters. A typical residential wastewater leachate on Cape Cod contains a nitrate-nitrogen potential of 35-90 mgs/liter while a similar estimate for dissolved organic carbon ranges between 150-250 mgs/liter (U. S. Environmental Protection Agency, 1980). However, under current conditions nitrate-nitrogen concentrations in excess of 10 mgs liter and dissolved organic carbon concentration above 5 mgs/liter are rarely encountered in any Cape Cod drinking water (Vaccaro et al., unpublished). This situation, while currently satisfying, does not preclude the need for continued and improved ground water vigilance especially in view of the accelerating population level.

In planning this study two procedural options, consistent with our investigational resources, were considered. First among these was to conduct a highly intensive short-term survey which would encompass multiple sampling locations but minimize chances of detecting long-term causal interrelations. A second and more challenging possibility was to undertake a more rigidly controlled empirical experiment wherein a single ground water source would be monitored for carefully selected parameters over an extended period of time. An inherent advantage of the latter approach was the promise of minimizing background noise due to the periodic influence of additional environmental phenomena. Added consideration was given to our prior possession of abundant data on local ground water compositions which was still awaiting a more sophisticated level of interpretation. _In toto_ the above considerations led to our adoption of single well point monitoring over an extended period of time as the format for this study.

Specifically in this report we address some relevant quality changes observed over an extended period of time for a single ground water source associated with a particular residential well located within an established community near Mares Pond, Falmouth, on Cape Cod. Comparisons of three natural water parameters: nitrate-nitrogen, conductivity and dissolved organic carbon in septic effluent, recharge dilutent water, and in the well water itself are used as a basis to quantify the extent of wastewater transport and infiltration within a hopefully stable geological regime. The ultimate ground water assessment of the field situation addresses, in order, the fractional amounts of recycling and attenuation for combined domestic wastewater, sewage effluent, dissolved organic carbon and combined nitrogen along with the relative contributions of physical as opposed to biological processes which in combination account for the observed ground water composition at the selected sampling location.

THE WESTERN CAPE COD AQUIFER

The western extremity of the Cape Cod peninsula lies within an area designated as the Mashpee Pitted Plain which encompasses the townships of Falmouth, Bourne, Sandwich and Mashpee. An irregular bedrock basement of varying depth is overlain by unconsolidated sediments of Pleistocene and Holocene age (Oldale, 1976, 1982). Because the original deposition of overburden proceeded in a north-south direction, the sedimentary material at the northern apex, near the Cape Cod Canal, is somewhat coarser than that at the Falmouth coastal extremity, 12 miles to the south. In order of abundance, the composition of overlying soil structure consists of gravel, sand, pebbles, cobbles and boulders.

The surface of the Mashpee Plain is intermittently inundated by depressions or kettle holes, such as Mares Pond in Falmouth which is a prominent topographical feature of our study area. Such ponds were formed when isolated blocks of ice, left behind by the retreating glacier, were temporarily buried under outwash deposits. Once water-filled, these depressions or ponds became dynamically associated with ground water which initiates their flushing.

In general, the broad hydrogeology of our study area has been described as a single, homogeneous anisotropic aquifer having a maximum hydraulic conductivity in the north-south direction roughly parallel to the original direction of deposition of the out wash sands and gravel (Palmer, 1977).

The regional behavior of ground water on Cape Cod, as projected from a series of three-dimensional finite-difference ground-water-flow models has recently been reviewed by the U.S. Geological Survey (Guswa and LeBlanc, 1981). Attendant mass balance calculations for five modeled areas indicate a total steady-state recharge rate of 412 ft^3/sec. and a total discharge rate to streams, marshes and oceans of 387 ft^3/sec. However, the large geographical scales employed in this model study are but marginally suited for generalized hydrologic projections to smaller, more restricted situations such as the Mares Pond area.

SITE CHARACTERISTICS

The single on-site well selected for this study is located just west of Mares Pond, on Site 34, Locustfield Pond, Falmouth as shown in Fig. 1 (adapted from Report to the Town of Falmouth by K.V. Associates, 1983). Ground water flow at the above location is peripheral to and generally downstream from a cluster of more than thirty neighboring homes, all on half-acre lots and all serviced by private wells. Each home employs on-lot wastewater disposal via cesspools and/or septic tanks with or without leaching facilities. The minimum distance between any one septic source and the nearest well is 100 ft. in accordance with regulations of the Commonwealth of Massachusetts. Since the approval and completion of this subdivision, the minimum lot size for this area has been increased from 20,000 to 40,000 square feet.

A convenient, nearby topographical transect describing local soil characteristics west of Mares Pond is shown in Fig. 2 (Camp, Dresser and McKee, 1982). The transect originates about 3500 ft northwest of Site 34 and extends about 2400 feet in a northerly direction, parallel to the western side of Locustfield Road. The indicated depth of the water table is about 50 feet below the ground surface which corresponds to an elevation of 20 feet above sea level. Soil characteristics within the upper 110 feet indicate a highly uniform distribution of fine to coarse sand, gravel and some occasional silt along with a minor variation in small cobbles at depths above the water table. Records compiled by the U.S. Geological Survey indicate that the annual oscillatory range of ground water elevations for this part of Cape Cod is 3-4 feet.

The projected hydraulic gradient for the ground water immediately west of Mares Pond is in a southwesterly direction (Palmer, 1977). Ground water

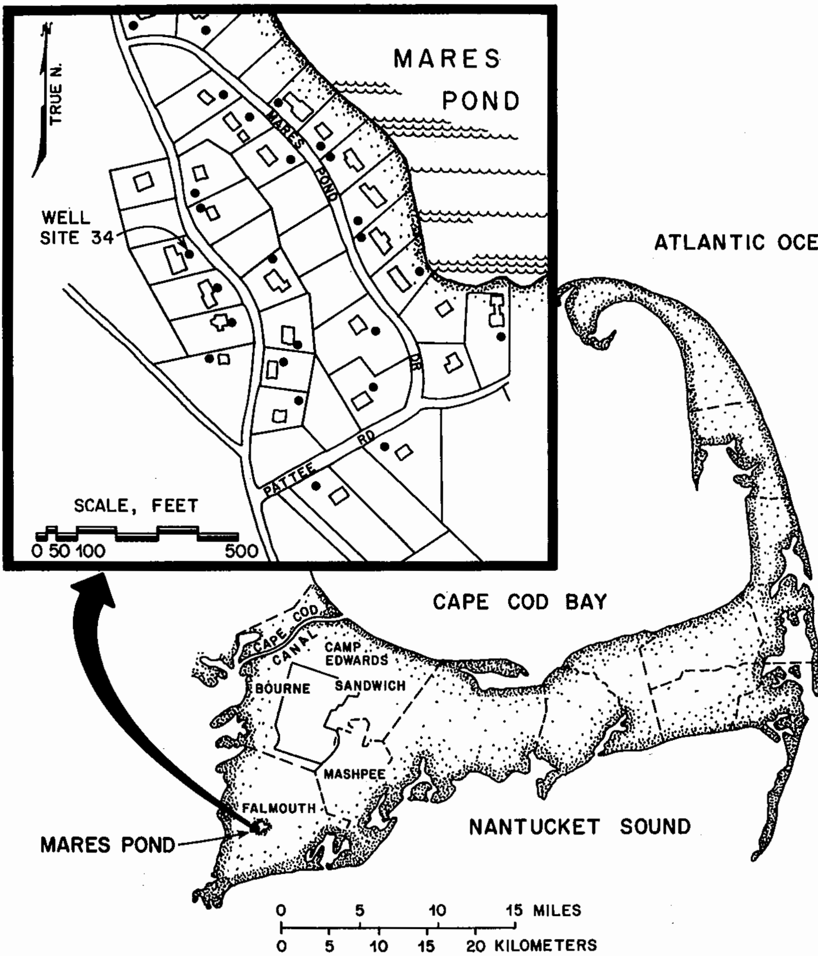

Figure 1. Mares Pond, Falmouth, Cape Cod and the specific location of sampling well on Site 34 at the Pond's southeastern extremity.

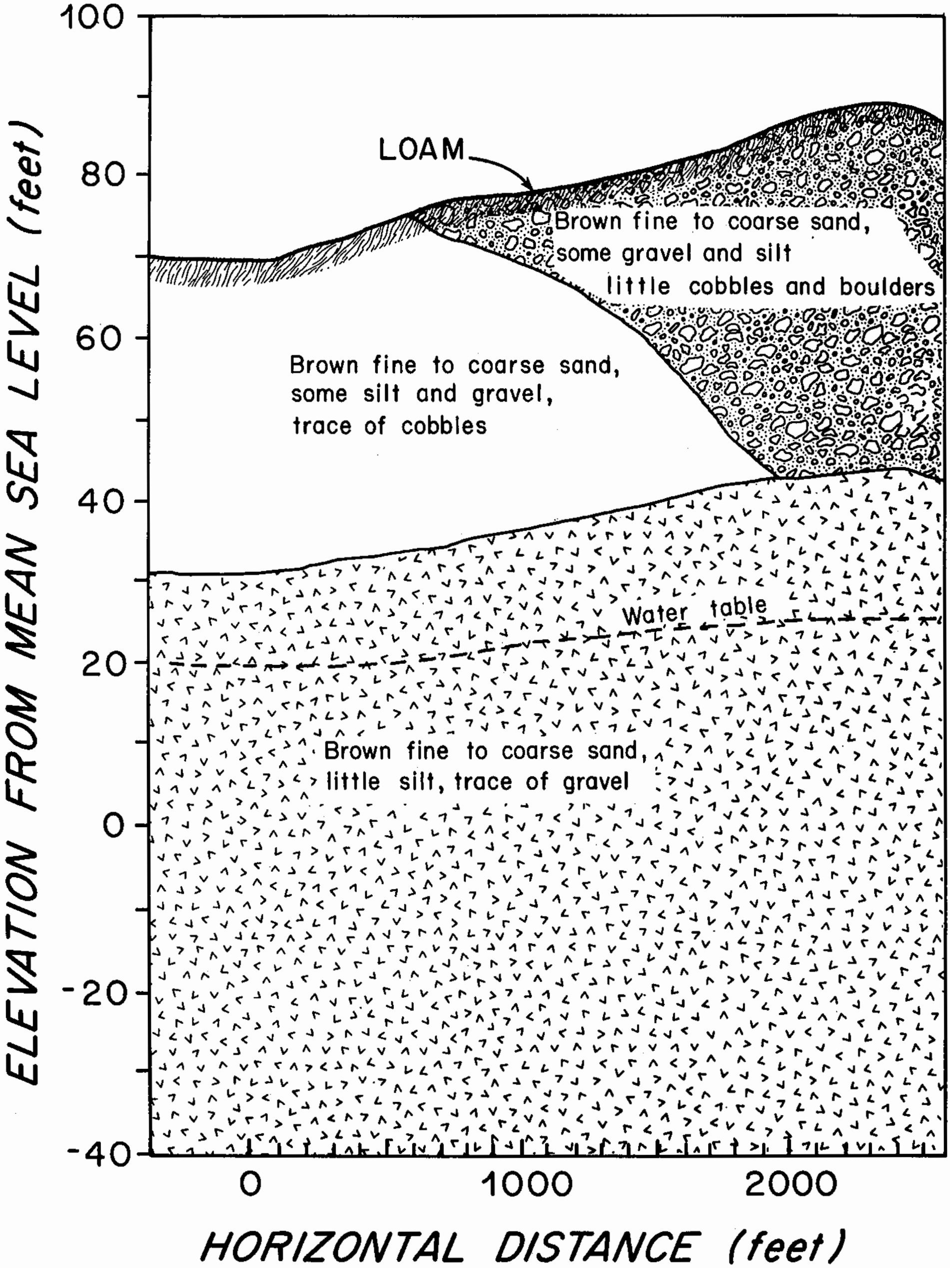

Figure 2. Upper surface geology typical of the Mares Pond area at a geological cross-section less than a mile north of Site 34. Original data by Camp Dressler and McKee in accordance with Report of K.V. Associates, 1983.

contours recorded for Mares Pond in the earlier cited Report of K.V. Associates, 1983, tend to confirm the above observation despite some seasonal departures attributed to changing surface elevations in near-by Mares Pond. Apparently gravity-leveling at the surface of the pond promotes flushing via ground water recharge at the northern end and ground water release at the southern pond extremity. This interpretation is consistent with the exposure of well water at Site 34 to impaction by septic plumes originating from a number of more easterly and upstream on-site sources.

Within the past two years the Town of Falmouth has acquired considerable information on the status of ground water quality in the Mares Pond residential area. Selective information provided by the Barnstable County Health Department, 1982, and cited by K.V. Associates, 1983, scrutinized the ground water from about 100 private wells in this locality. About 40% of these water samples originated within a half mile of Mares Pond and included all of the residences shown in our Fig. 1. This County information and its subsequent review by K.V. Associates stress the importance of short-circuiting from neighboring septic systems as the most likely explanation for the moderate to high levels of inorganic ammonia- and nitrate-nitrogen encountered periodically in Mares Pond ground water. Together, these studies aroused our interest in compiling complementary information centering on long-term monitoring of a single well having a high probability of experiencing intermittent wastewater incursions. Ultimately the private well located at Site 34, whose earliest determined characteristics also appear in Table 1, was selected as the most appropriate water source for our analysis due to a prior history of persistently small but measurable impaction.

Table 1

Ground Water Quality Characteristics[1] for
the Area West of Mares Pond
Falmouth, Mass

	No Wells	Above Background Concentrations, Percent
General Area		
Ammonia-nitrogen	44	23
Nitrate-nitrogen	"	18
Conductivity	"	14
Iron	"	34
Test Well, Site No. 34		Concentration
Ammonia-nitrogen mg/L		0.14
Nitrate-nitrogen mg/L		2.56
Conductivity µmhos/cm		92.
Iron mg/L		0.05

[1]Data of Barnstable County, Department of Public Health Adopted from Report of K.V. Associates, Inc. to the Town of Falmouth, 1983.

An additional and highly useful revelation regarding the above Mares Pond data was the demonstration by K.V. Associates of a positive linear correlation between total inorganic-nitrogen (combined concentrations of ammonia- and nitrate-nitrogen) and conductance within septic plumes. The derived relation is consistent with the equation;

$$\text{Conductivity} = 13.2\ (\text{Inorg. N}) + 57, \qquad (1)$$

where conductivity is expressed in µmhos/cm and nitrate-nitrogen in mgs/liter. Since conductivity is a readily measurable property of both ground water and septic effluent, its concentration in well water as compared with that of the contributing water types can be exploited to estimate the fractional amounts of wastewater and recharge water present in a given well water sample.

BIOLOGICAL CONSIDERATIONS

Biological transformations affecting the ultimate distributions of nitrogenous and carbonaceous derivatives are important public health and environmental concerns of wastewater management. In concentrated domestic waste, the above chemical elements typically occur in unoxidized form such as ammonia and organic acids both of which are amenable to further biological modification. The nature of the ensuing biological changes have important implications regarding health hazards, environmental aesthetics, recycling and renovative efficiency.

Many microbes although denied free oxygen can utilize oxygen atoms combined with other elements such as nitrogen, sulfur, and iron for their respiration. Thus, when water containing nitrate infiltrates an oxygen deficient environment rich in organic matter, denitrifying microbes can utilize the oxygen content of nitrate with the ultimate release of gaseous nitrogen. Indications are that denitrification proximal to a watewater source can account for 30-80% of the nitrogen removal in waste water renovation (Kardos et al., 1965; Merrell et al., 1967). As shown below, during denitrification nitrite-nitrogen appears here as a transient intermediate between nitrate and gaseous nitrogen. The simplified reactions are as follows:

$$NO_3^- + 0.33\ CH_3OH \text{ -----}\rangle\ NO_2^- + 0.33\ CO_2 + 0.67\ H_2O \text{ and} \qquad (2)$$

$$NO_2^- + 0.5\ CH_3OH \text{ -----}\rangle\ 0.5N_2 + 0.5\ H_2O + OH^- + .5CO_2. \qquad (3)$$

On the other hand, in the presence of free oxygen, reduced carbonaceous and nitrogenous compounds are further mineralized and terminally oxided to carbon dioxide and nitrate as follows:

$$CH_4 + 2O_2 \text{ -----}\rangle\ CO_2 + 2H_2O \text{ and} \qquad (4)$$

$$NH_4^+ + OH^- + 2O_2 \text{---}\rangle H^+ + NO_3^- + 2H_2O \qquad (5)$$

Taken on a weight basis, the above equations indicate that the oxidation of each unit of methane-carbon and ammonia-nitrogen requires about 5 units of oxygen to complete an oxidation. In nature, that nitrate which escapes denitrification is either utilized for plant growth or alternatively accumulates in a receiving water. Thus nitrate-nitrogen, the end product of the nitrification process, ultimately assumes a conservative behavior not unlike that of a water's conductive characteristics.

Normally even ideally functioning septic systems release some nitrate via a connecting leaching field or the surrounding subsoil from whence it percolates downward to the water table. The ultimate amount of nitrate enrichment to the down-gradient ground water represents the net effect from a variety of biological and physical processes. The presently enforced standard for nitrate-nitrogen in potable water is 10 mg/liter as jointly recommended by the Commonwealth of Massachusetts and the U.S. Environmental Protection Agency.

ASSESSMENT OF WASTE WATER ATTENUATION

Physical phenomena such as dilution, adsorption and other inert chemical transformations can also play an important role in the recycling of domestic wastewaters. Of primary concern here is the estimated ratio of composition, i.e. wastewater: recharge water, which characterizes a given water sample. Conductivity which measures a substance's ability to carry an electric current, can be usefully exploited for this purpose as follows:

$$F_{SE} = \frac{C_{OBS}}{C_{SE} + C_R} \quad (6)$$

$$F_{RW} = 1 - \frac{C_{OBS}}{C_{SE} + C_R} \quad (7)$$

where F_{SE} and F_{RW} respectively correspond to the fractional presence of septic effluent and recharge water; C_{OBS}, a sample's observed conductivity C_{SE} the original, reference, conductivity of concentrated septic effluent and C_R, the conductivity of unadulterated recharge water.

For an idealized situation describing a strictly conservative parameter whose presence in a given sample reflects mixing only, the degree of non biological attenuation has been estimated from:

$$P_{PA} = (F_{SE}P_{SE}) + (F_{RW}P_{RW}). \quad (8)$$

where P_{PA} is the predicted concentration for a given parameter following its physical attenuation and P_{SE} and P_{RW} the concentrations of the same parameters respectively associated with septic effluent and recharge water.

Finally, a measure of the degree of biological attenuation beyond that contributed by purely physical interventions can be approximated by:

$$P_{BA} = (P_{PA}) - (P_{OBS}). \quad (9)$$

where P_{BA} is the estimated additional effect of non-conservative behavior for a given parameter and P_{OBS} the observed level of the same parameter as measured in a particular sample.

Successful applications of the above relations presupposes an ability to assign realistic values for conductivity, dissolved organic carbon and total combined nitrogen to both septic effluent and recharge along with dilutent water. Weighted values descriptive of the above parameters are shown in Table 2, and reflect a variety of pertinent data sources including the U.S. Environmental Protection Agency, the Barnstable County Health Department and our own laboratory measurements. For added insight some of our own corresponding measurements for Cape Cod rain water also appear in Table 2.

WATER SAMPLING AND ANALYTICAL CHEMISTRY

With few exceptions our ground water sampling at Site 34 was biweekly throughout the 330 days of this study. Sampling protocol included prolonged flushing of the 60 foot well head, and the use of separate pyrex glass containers for nitrate and dissolved organic carbon samples. Nitrate samples were immediately refrigerated and stored frozen pending laboratory analyses by cadmium reduction and nitrite-nitrogen colorimetry (Wood et al. 1967). Dissolved organic carbon water samples were collected in precombusted (1 hour at 550°C) pyrex test tubes, preserved with phosphoric acid, later sparged with CO_2-free air and subjected to persulfate oxidation of triplicate subsamples to isolate the carbon dioxide of organic origin via a non-dispersive infrared technique (Menzel and Vaccaro, 1964).

Table 2

Assigned Values for Dissolved Organic Carbon, Total Combined Nitrogen and Conductivity in Septic Effluent, Recharge Water and Atmospheric Precipitation.

	Septic Effluent	Recharge Water	Cape Cod Rain
Dissolved Organic Carbon, mg/L			
Range	150–250[1,2]	0.50–0.90	0.20–0.50[2]
Mean	200[4]	0.70[4]	0.35
Total Combined Nitrogen, mg/L			
Range	35–90[1,2,3]	0.10–0.20[2]	.11–.24[2]
Mean	63[4]	0.15[4]	.18
Conductivity, µmhos/cm			
Range	519–1245[3]	56–58[3]	--
Mean	889[4]	57[3,4]	

[1]Data of U.S. Environmental Protection Agency Design Manual 625/1-80-012
[2]Data of Woods Hole Oceanographic Institution.
[3]Data from Barnstable County projected as per K.V. Associates, Inc. Report, 1983
[4]Value used to calculate ground water attenuation in this report.

Results

The total precipitation measured during the entire 330 days of this study amounted to 41.1 inches which closely approximates the historical average for Cape Cod. Biweekly changes in the combined amount of rainfall along with a few measurements of the attendant changes in ground water elevation are shown in Fig. 3. The latter measurements relate to a Town operated well, pumping at a constant rate, at a location about 2 1/2 miles east of our ground water test site. The maximum encountered variation in ground water elevation was the 34 inch drop noted between the March-April depth and that recorded for late September.

Time-related changes in conductivity along with estimates of the ground water leachate percentages are respectively shown in Fig. 4. In accordance with the previously discussed equations (1), (6) and (7) both of the above parameters show proportionality to the corresponding changes in nitrate-nitrogen shown in Fig. 5. Significantly, the data on leachate percentages indicate that "tainted" water, most likely of septic origin, accounts for more than 8% of each ground water sample analyzed; the over-all range of impaction being 7.9-12.3%. The above distribution pattern is consistent with the intermittent arrival of measurable but unpredictable amounts of septic effluent at the point of sampling. The unlikelihood of gaining such information regarding a particular ground water source from a less coordinated and less definitive areal sampling effort is readily apparent from these data.

Nitrate-concentrations measured over a 335 day period for the ground water at Site 34 are also shown in Fig. 5. The overall range of concentrations was 1.1-4.4 mg/L with higher nitrate observations corresponding to late spring and drier summer months. Despite inherent irregularities there is a suggestion of sequential nitrate pulses having periods of 60 days duration. Comparable results for dissolved organic carbon, also shown in Fig. 5, varied from 0.4-4.6 mg/L and displayed more pronounced short-term oscillations than did nitrate. Like nitrate, however, higher organic carbon levels tended to appear during the warmer and drier summer months. The incidence of short-term changes for each of the above parameters suggests the intermittent arrival of significant pulses of nitrogen and carbon enrichment as opposed to an extended exposure to ground water of a consistent chemical composition.

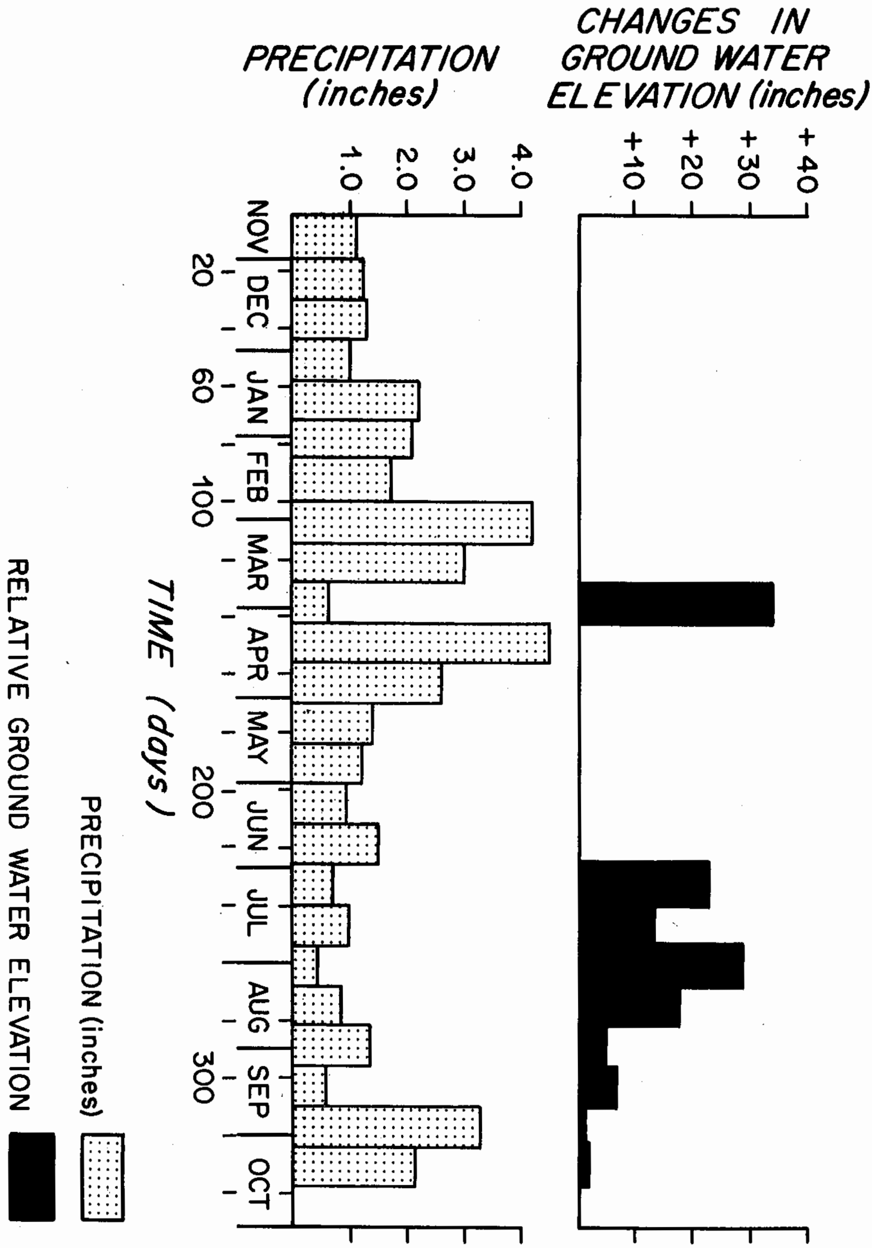

Figure 3. Biweek variations in precipitation, Long Pond, Falmouth and some corresponding changes in ground water elevation observed in a municipal well near Fresh Pond. Dept. Publ. Works, Town of Falmouth.

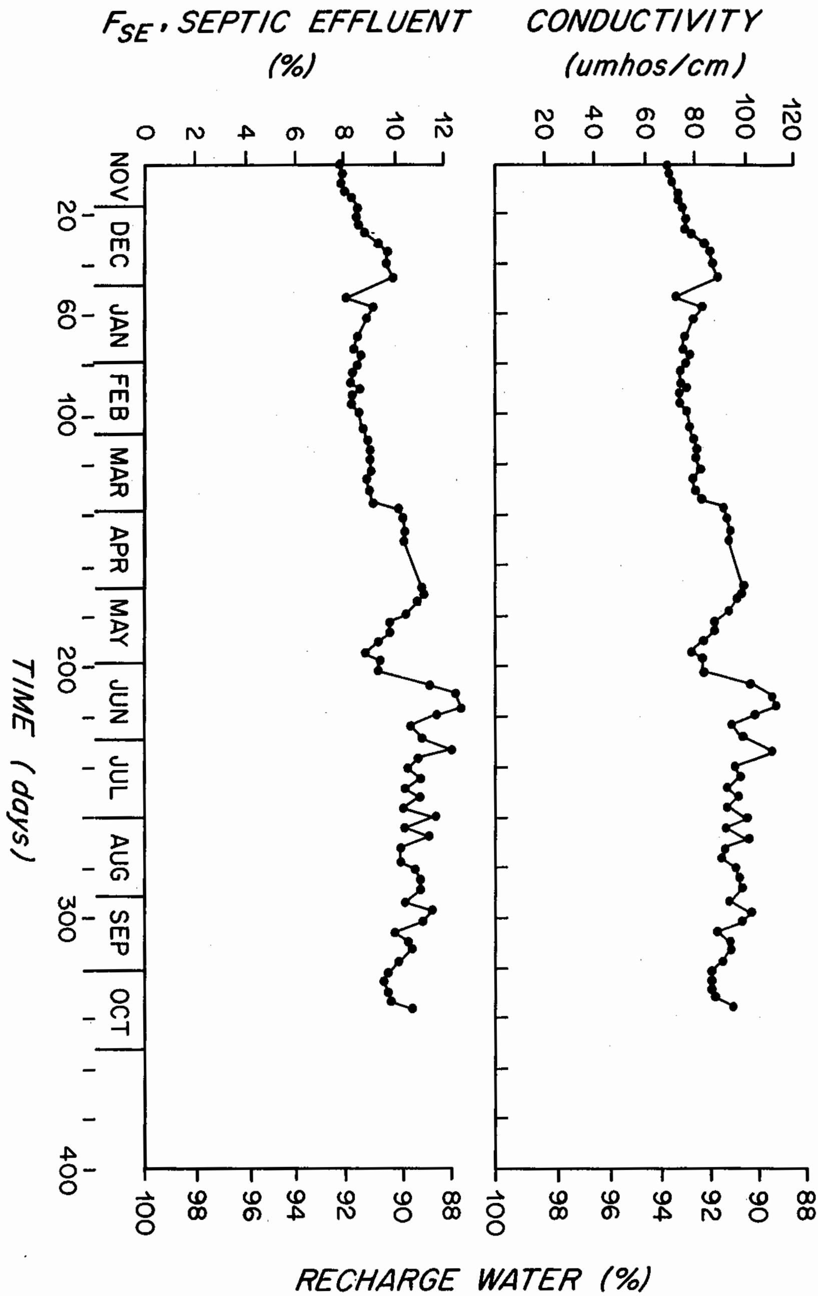

Figure 4. Seasonal variations in ground water conductivity and the fractional residuals of wastewater calculated for Site 34 ground water.

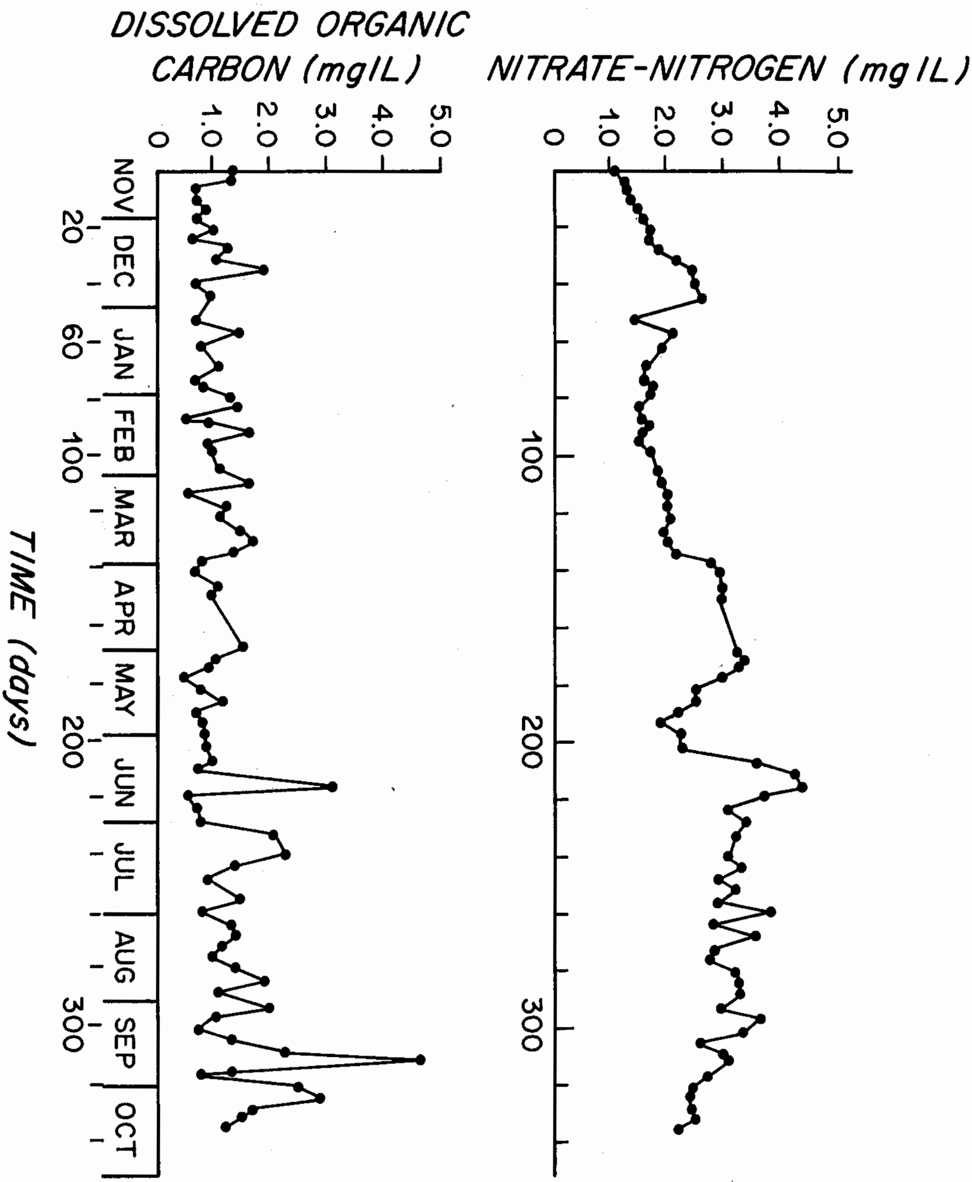

Figure 5. Seasonal variations in nitrate-nitrogen and dissolved organic carbon measured for ground water samples from Site 34.

Figure 6 relates only to dissolved organic carbon (DOC) and differentiates between the *in situ* concentrations assigned to dilution and other physical attenuation processes as opposed to that amount of carbon removal assigned to non conservative, biological, activity. (See Equations (8) and (9) above). The single linear relation shown in this figure describes the calculated concentrations of dissolved organic carbon based solely on the dilution of septic effluent with low background recharge water. Also shown are the concentrations of organic carbon actually measured for each ground water sample. The difference between any corresponding pair of the above concentrations provides a useful measure of the amount of organic carbon removed by biological activity in excess of the anticipated physical interventions. Our observations suggest that biological transformations account for the removal of essentially all of the remaining and detectable dissolved organic carbon above that anticipated on the basis of dilution *per se*.

A similar analytical approach has served to estimate the extent of biologically induced combined nitrogen regeneration. As shown in Fig. 7 the biologically assigned decomposition of organic carbon consistently exceeded that of the nonconservative removal of combined nitrogen. Most of the above values for combined nitrogen were significantly below 80 percent as opposed to biological removals consistently in excess of 90 percent for organic carbon.

DISCUSSION

About 25% of the U.S. population lives in rural or semi-rural areas where on-lot septic tanks exclusively account for the disposal for household organic wastes. Nationally, such facilities generate about 0.23 million tons of nitrogenous wastes per year (USEPA, Technology Transfer Report, 1975) along with an equivalent 1.50 million tons of organic carbon. Given favorable circumstances, almost all the dissolved organic material associated with septic leachate undergoes terminal oxidation to water, carbon dioxide and nitrate. A prominent public health criterion of ground water quality is that amount of terminal nitrate which percolates downward to ground water and then intercepts shallow wells being used for domestic drinking water.

A growing environmental concern on Cape Cod is the fear that unrestrained

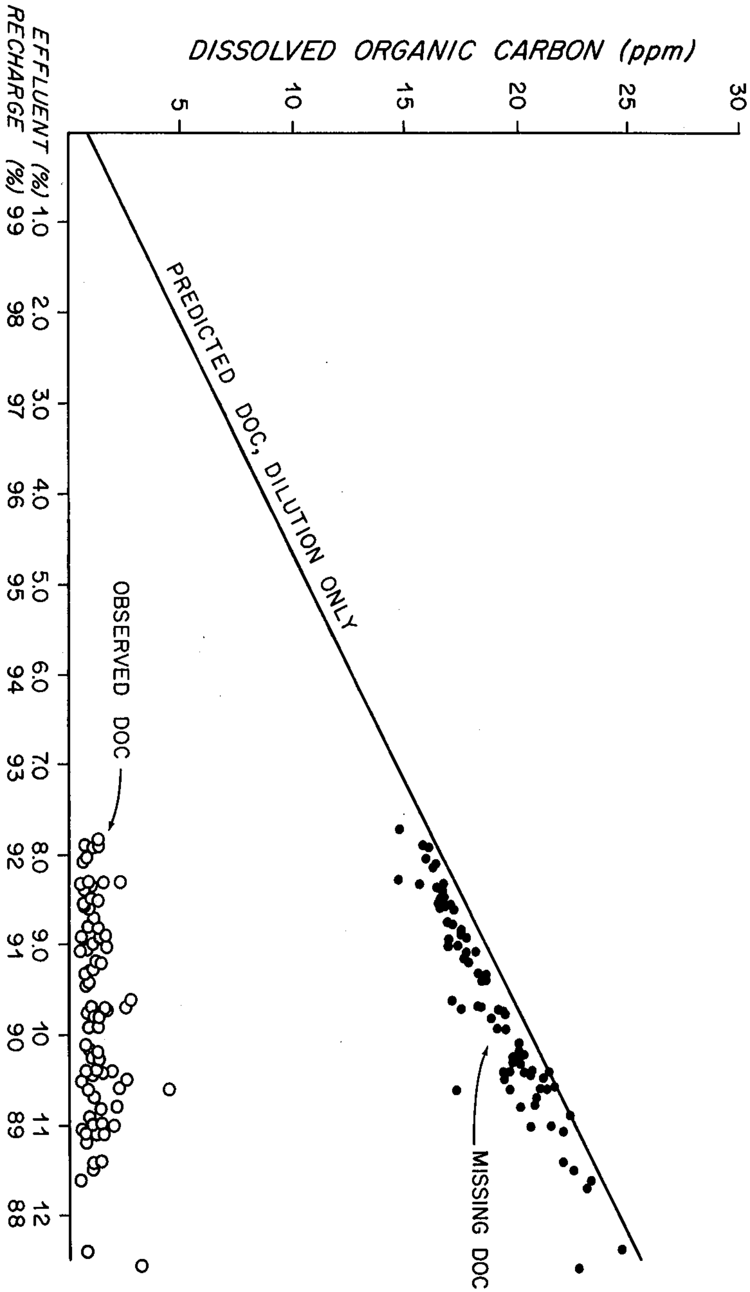

Figure 6. Equivalent concentrations of dissolved organic carbon corresponding to 0-12.5% septic effluent (straight line), the actual concentrations observed (dotted circles) and the amount of attenuation, by difference, beyond that attributable to waste water dilution (open circles).

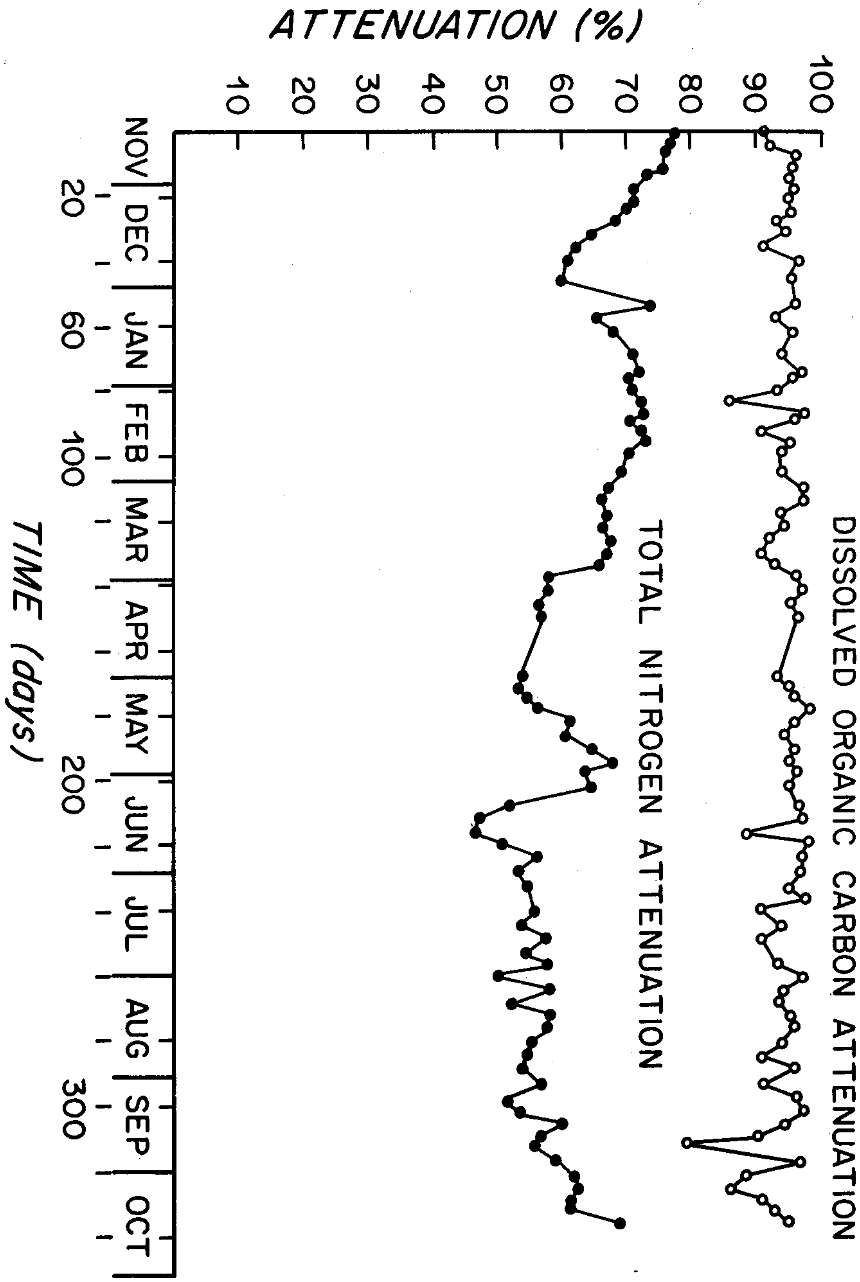

Figure 7. Fractions of dissolved organic carbon and combined nitrogen removed by biological activity in terms of the concentrations anticipated from waste water dilution.

residential and commercial expansion will ultimately lead to unacceptable ground water deterioration and/or surface water eutrophication. Typically, the current strategy and timing of rigorous regulatory decisions affecting residential construction are often strategically tied to ground water quality projections to avoid the expensive alternative of supplying planned homesites with safer water from a more remote source. However, an equitable concern for economic parity among prospective home owners, developers and the local citizenry in general requires that the information which underlies such decisions be of the highest possible relevancy. This study is a plea for extended, empirical field monitoring and points out the possibility of improved ground water assessments for projected residential communities.

Long-term variations in the behavior of conservative vs. non conservative ground water parameters can be used to intercompare the extent of physical as opposed to biological attenuation of residential septic leachates. Information summarized in Table 3 indicates that physical processes (i.e., dilution, solubility, adsorption, volatility, etc.) decisively account for about 90% of the total ground water attenuation observed at Site 34. As for the additional attenuation, beyond that assigned to physical processes, biological activity accounts for over 90% of the non dilutional decomposition of organic carbon. Conversely, the degree of comparable combined nitrogen removal, presumably due to the combined effects of nitrogen assimilation and microbial nitrate reduction by plants and bacteria, respectively is considerably lower, ranging from 46-78%.

In combination our study indicates that the particular ground water source herein evaluated remains reasonably under-stressed with regard to non-exotic waste water carbon infiltration but promises to become highly sensitive to additional nitrate encroachment.

Table 3
Physical vs Biological
Contributions to Waste Water
Attenuation, Site 34 Ground Water

	Range mg/L	Mean mg/L	Mean Attenuation %
Dissolved Organic Carbon			
Primary leachate	150 -250	200	
All impacts	0.50- 4.50	1.26	99.4
Physical attenuation	0.70- 25.4	20.1	90.0
Biological Attenuation	- -	18.8[1]	9.4
Combined Nitrogen			
Primary leachate	35 -90	63	
All impacts	1.12 - 4.34	2.42	96.0
Physical attenuation	5.07 - 8.11	6.33	90.0
Biological attenuation	- -	3.80[2]	6.0

[1]Taken as 9.4% of 200 ppm
[2]Taken as 6.0% of 63 ppm

CONCLUSIONS

The procedural and analytical techniques adopted for this study underline the advantage of selective and repetitious monitoring for characterizing ground water behavior in geologically defined areas. Also, for exploratory and experimental studies in nature, the selection of a ground water source subject to periodic leachate incursions from neighboring on-lot septic systems offers an obvious tracer advantage. For Site 34 the groundwater range describing detectable residual fractions of unrenovated (tainted) water, presumably of remote septic origin, was 8-12% with minimally contaminated recharge water accounting for the remaining 92-88% of ground water composition. With regard to nitrate-nitrogen, low values were most common during the winter and early spring months; the maximum concentration (4.4 mg/L) appearing in late June. In general, the time-related appearance of dissolved organic carbon resembled that of nitrate and as expected, elevated concentrations of both nitrate and dissolved organic carbon coincided with periods of low summer precipitation, high evapotranspiration and depressed ground water elevations. About 90% of the loss in septic leachate characteristics could be explained in terms of physical as opposed to biologically initiated interventions. However, biological processes, ultimately accounted for the removal of up to 98% of the nonconservative dissolved organic carbon anticipated on the basis of dilution per se. Conversely, biological transformations affecting the persistence of combined nitrogen were notably less efficient than for organic carbon and accounted for only 45-80% of the apparent non biological nitrogen depletion.

These behavioral differences regarding the persistence of organic carbon as opposed to nitrogen suggest that the Mares Pond ground water system is currently more vulnerable to additional nitrate than organic carbon interventions. This conclusion is consistent with the Falmouth Town Meeting decision of 1984 to service the entire Mares Pond community with a remote source of town water due to the impending threat of high nitrate concentrations.

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A STUDY OF MARKETING OF CONSULTING ENGINEERING SERVICES TO INDUSTRIAL FIRMS

Robert J. Carey and James A. Brunner[1]

INTRODUCTION

This paper addresses the methods used and the factors considered by industrial firms to select consulting engineering firms. It is intended to provide a basis for formulation of guidelines leading to effective marketing of consulting engineering services to industrial firms.

The authors designed a marketing research study to identify and evaluate the following aspects of consulting engineering services marketing: the dimensions of the industrial market, including the types of services needed and the frequency of need; perceptions of attributes and reputation which distinguish and differentiate consulting firms; marketing tools which can be effectively utilized to increase the client base; and the processes used by industrial firms to select a consultant.

The instrument for the research is a questionnaire which was sent to industrial firms in the heavy industrial Great Lakes region. It was targeted toward industrial categories which are, or will be, subject to Federal Pretreatment Standards.

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BACKGROUND OF THEORY AND RESEARCH

The marketing of services in general, and consulting engineering services in particular, is a field of study in its infancy stage of development. Consulting firms that are embarking on marketing efforts have little guidance on how to plan and control the marketing program. With very few exceptions, service marketing is not taught at the university level of academia and is not the subject of published research. Two or three books regarding architectural/engineering services marketing are available, and authored by marketing consultants. Also, a handfull of articles and papers have been published in various industrial trade journals which present the advice and opinions of persons with experience in this area.

While the value of this available literature is not being questioned, it is believed that the field of study can be, and needs to be, improved through empirical research. Only in this way can a viable basis be established upon which marketing guidelines can be formulated. Therefore, many of the questions which are addressed in this study are based on factors which the authors of the available literature have considered to be important.

The reason for this lack of development of the field of service marketing is uncertain. With regard to engineering services marketing, it can be postulated that the following two factors have contributed to the present situation.

First, the market for consulting engineering services has been growing rapidly for the past twenty years as a result of increased government regulations and funding of civil engineering/public works projects. Therefore, ample opportunities have existed for new consulting firms to enter the market and be successful; the pie has been growing. The need to aggressively compete against other firms in order to grow and survive was not crucial to the success of a firm.

Second, professional engineering ethics have included the generally accepted principle that an engineering firm should be able to generate a sufficient amount of demand for its services on the basis of goodwill and performance.

Therefore, marketing has been considered to be at best, unnecessary and unproductive, and at worst, deceptive and unethical.

Recent environmental (in the broad sense) changes have occured, however, which are causing consulting engineering firms to reconsider marketing and the importance of it. The first such change is a significant decline in funding programs for municipal civil engineering/public works projects. Therefore, municipalities are reducing, postponing, or eliminating many projects due to lack of funds. As a result, consulting engineering firms are competing for market shares of a smaller pie. Some firms are being shaken out of the market; others are becoming more austere. Survival is a key strategic concern today - marketing might represent the difference between success and failure.

The second key change is that industrial firms are facing increasing pressure to improve their pollution control procedures. The Clean Water Act, The Clean Air Act, The Toxic Substances Control Act, RCRA, and the Federal Categorical Pretreatment Standards are placing requirements on industrial firms to assume responsibility for their emmissions, effluents, and solid waste. Therefore, the need for engineering services is increasing.

Finally, most, if not all, professional fields are changing their ethics standards to allow the use of promotional activity. This includes the consulting engineering profession.

Numerous seminars have been held recently regarding marketing. The engineering magazines and journals are including more and more articles and papers on marketing. Consulting firms are expanding their staff capabilty for marketing matters. Clearly, marketing of consulting engineering services is no longer taboo.

As a management science, crucial to the development of marketing is empirical research. This paper presents the results of one research study. Much more work needs to be done to increase the understanding of marketing and the benefits it can provide to consulting firms.

PROCEDURES USED IN THE STUDY

A close- ended five page questionnaire was sent to 400 industrial firms. The questionnaire included five sections, with the first section being a screening section to identify the firms. The firms are identified on the basis of size, industrial category, and need for consulting engineering services. Responses to later sections of the questionnaire may correlate with responses to this section.

Section 1 of the actual questionnaire asks the respondents to identify the attributes and reputation factors of a consulting firm that are considered to be important. Section 2 concerns the consulting firm's promotional program. Section 3 concerns the types of services which are needed by industrial firms. Finally, Section 4 concerns the methods used to select consulting firms.

The responses to the questionnaire were analyzed with the assistance of a statistical software package developed by McGraw-Hill called SPSS (Statistical Package for the Social Sciences). The frequencies, mean, and median of all responses were analyzed. Also, where appropriate, cross classification analysis, including Chi-square analysis of independence and Pearson Correlation Coefficient determination of linear relationship, was used to analyze and evaluate the responses.

POPULATION AND SAMPLE

The population for this research was industrial firms within a 100 mile radius of Toledo, Ohio, in the middle of the heavy industrial Midwest. The firms employed at least 50 persons, and were in categories with SIC (Standard Industrial Classifications) Codes which would make them subject to the Federal Categorical Pretreatment Standards.

Cluster Sampling was used to select most of the firms for inclusion in the study. The clusters consisted of industrial firms in selected counties. Within the clusters, all industrial firms in the population were included. In addition, some firms were included in the sample based on their notification to the U.S. EPA, through the RCRA Manifest program, that they are involved in either the generation, treatment, or disposal of hazardous materials.

ANALYSIS OF RESULTS

Nature of Respondents

Seventy questionnaires, representing roughly a 17% response rate, were completed and returned for analysis. This is not unusually low for this type of survey, particularly since a follow up letter or other means to increase the response rate was not practical due to time and cost constraints.

The size of the firms ranged from 9 employees to 7000 employees, with a mean of 610 and a median of 150. The median is more useful in this case because a few very large firms created a sharply skewed distribution of the number of employees which distorts the results. In fact, 23% employed between 150 and 200 persons. Of those firms which intend to use consulting engineering services in the future, the median was 200 employees. Therefore, for purposes of this study, "small" firms employ 200 or less, and "large" firms employ more than 200 persons.

The largest single categorical group of respondents was Fabricated Metals (24%). The next largest group was Rubber and Plastics (10%), followed closely by Paper (9%) and Miscellaneous Manufacturing (9%). The other groups were relatively evenly represented. Table 1 summarizes the groups of respondents.

Table 1

Industrial Groups and Frequencies

Group	All Respondents	Future Users
1. Fabricated Metals	24 %	32 %
2. Rubber and Plastics	10	7
3. Paper	9	4
4. Miscellaneous Mfg.	9	7
5. Food and Kindred Products	7	4
6. Stone, Clay, Concrete, Glass	7	11
7. Chemical	6	7
8. Primary Metals	6	4
9. Transportation Equipment	4	7
10. Lumber	3	0
11. Industrial Equipment	3	0
12. Electrical/Electronics	3	0
13. Petroleum	1	4
14. Instruments	1	0
15. Other	7	14
	100 %	100 %

Roughly 41% of the respondents have used consulting engineering services in the past. Coincidentally, 41% also will need to use a consulting firm in the future, but not the same firms which have used these services in the past. Eighty-nine (89%) percent of the firms which used consulting services in the past intend to use them in the future as well. A surprisingly large number of firms, 57%, have not, and will not require consulting services. This is surprising because the questionnaire was targeted at firms which are potentially in need of engineering services. A possible reason for the high percentage of "non-needers" is that it was relatively easy for them to indicate this by simply completing the first page of the questionnaire. Therefore, the "non-needers" may have responded in greater relative numbers than those in need of consulting services. In any case, 30 firms have indicated that they have or will be in need of consulting engineering services, and have provided valuable information concerning the marketing of these services.

"Non-needers"

The primary reason for an industrial firm not to need consulting engineering services is that they are able to receive similar services from other sources, such as corporate headquarters or equipment vendors. Thirty-six (36%) cited this reason, followed by 26% and 21% who cited no wastes and no improvements planned, respectively.

A strong correlation was found between the size of the industrial firm and the responses to this question. A review of Table 2 shows that 81% of the large firms need engineering services but are obtaining them from staff engineers or other sources. On the other hand, 57% of the small non-needers have no need for engineering services at all (no wastes and no improvements planned).

Table 2

Reasons Cited for Not Needing
Consulting Engineering Services

Reason Cited	Total	Large	Small
1. Corporate/Vendor Assist.	36 %	62 %	30 %
2. No Wastes	26	0	32
3. No Improvements Planned	21	0	25
4. Staff Engineers	8	19	6
5. Unfamiliar With Consulting	3	9	2
6. Waiting For Regulations	1	9	0
7. Other	5	0	6
Totals (rounded-off)	100 %	99 %	101 %

Attributes and Reputation

Consulting firms are evaluated on the basis of tangible attributes, which are verifiable through either documentation or observation, and reputation, which, on the other hand, is intangible and subjective in nature.

According to the respondents, the most important attribute of a consulting firm is the completenesss and quality of a proposal. The proposal demonstrates that the firm understands the requirements of the project in question, and has invested a significant amount of resources and interest in obtaining the work. Closely following in importance are the relevant experience of the consultant, and a working relationship with the consultant. This indicates that industrial firms tend to have a strong loyalty to a consultant, particularly if they are satisfied with the quality of the services being provided.

The overwhelming least important attribute was the promotional efforts of the consultant. This is not surprising in light of the importance accorded quality and loyalty. Also, it may be that the industrial firms are not familiar with promotional efforts of consulting firms. Obviously, the proposal was not considered to be a promotional effort. This will be commented on later.

Other attributes which were considered to be very important were cost of services, recommendations/referrals, scheduling, and geographic location.

Generally, the size of the firm did not significantly affect the responses. A possible exception would be cost of services, which was considered to be more important to the smaller firms than the larger firms.

Table 3 summarizes the rank and relative importance of the attributes of a consulting firm. It would seem, based on a review of these responses, that entry into the industrial market for a consulting firm does not necessarily favor the large established, full service firms. In fact, a small firm which specializes in a particular area might be in a very competitive position.

A reputation for providing "State of the Art Know-how" and maintaining confidentiality rank as the most important factors. The large firms considered confidentiality as most important. The small firms cited state of the art know how as most important. Adherence to schedules and budget and respect for client's input were also considered to be very important. Large firms considered cost adherence to be more important than meeting scheduling, probably reflecting the impacts of bureacracy on reduced budgeting flexibility.

Two of the least important reputation factors are low cost and standardized designs. This finding, combined with earlier discussed findings regarding the importance of quality and experience, clearly shows that the industrial firm is looking for a consultant that is technically proficient in the service area in question. Also, because past use of the consultant and confidentiality are so important, it is very likely that an industrial firm will stay with a consultant that they are satisfied with, and are not likely to change consultants without good reason to do so.

Table 4 summarizes the relative importance of the factors influencing a consulting firm's reputation.

Table 3

Attributes of a Consulting Engineering Firm

Attribute	Rank	Importance
1. Completeness/Qual. of Proposal	1	Extreme/Very
2. Relevant Experience	2	"
3. Past Use of Consultant	3	"
4. Cost of Services	4	Very
5. Recommendations/Referrals	5	"
6. Scheduling/Begin Immediately	6	"
7. Geographic Location	7	"
8. Range of Services	8	Moderate
9. Staff Tenure	9	"
10. Years in Operation	10	"
11. Size, Facilities, Resources	11	"
12. Promotional Efforts	12	Slight

Table 4

Reputation Factors of a Consulting Firm

Reputation Factor	Rank	Importance
1. State of Art Know-How	1	Extreme/Very
2. Confidentiality	2	"
3. Adherence to Schedule	3	Very
4. Adherence to Budget	4	"
5. Respect for Client Input	5	"
6. % of Repeat Business	6	Moderate
7. Standardized Designs	7	"
8. Low Cost	8	"
9. Contract Flexibility	9	"

An analysis of whether the relative importance of the attributes and reputation will change in the future indicated that any changes would be minor and insignificant.

Promotional Tools

The quality of documents such as reports and contract plans and specifications are considered to be the most important promotional tool. This is surprising because there was some apprehension, in designing the questionnaire, to listing quality of documents as a promotional tool. However, documents are a tangible result of a firm's services, and are often used internally by clients to promote a project. The selection of this as the most important promotional tool lends further support to the finding that industrial firms are primarily interested in firms that exhibit high quality services.

Indirect, or passive, promotional tools such as high quality documents, goodwill, and trade memberships, are considered to be more important than direct promotional tools such as telephone calls, visits, and brochures/promotional literature. Therefore, the consulting firm which effectively uses these indirect promotional tools may be positioning itself very competitively without pursuing an advertising or direct promotional program.

The only significant differences in the responses on the basis of size was goodwill. The larger firms considered goodwill to be the most important promotional tool; slightly more important than the quality of documents.

Clearly, by the time that documents are used by an industrial firm to review a consulting firm, the industrial firm is already familiar with the consulting firm, and the project is being defined. Goodwill and trade memberships/participation are the best ways to promote the consulting firm to prospects with projects which have not been defined or identified. Consulting firms tend to compete for projects against firms which have relatively similar levels of goodwill and trade memberships. Therefore, a distinct advantage is not necessarily present to a particular firm; a prospective client may still seek a competitor's services. Since direct promotional tools are the only way to actively plan and control a program to identify prospective clients, they may still be important to the consulting firm, while not being important to the prospective client.

Of the direct promotional tools, letters and literature/brochures appear to be the most effective. Perhaps this is because the prospective client can review the material at their convenience, as opposed to visits and telephone calls. Advertising is the least effective means of promotion.

Industrial firms are contacted by one or two consulting firms per year by visits and/or telephone calls, and three to five firms by letters and literature. Therefore, very little direct contact is engaged by consulting firms. While the cause and effect is uncertain, it may be that the low contact is why the industrial firms do not consider direct promotional tools to be important.

Table 5 summarizes the relative importance of promotional tools.

Table 5

Promotional Tools Used By Consulting Firms

Tool	Rank	Importance
1. Quality of Documents	1	Very
2. Goodwill	2	"
3. Trade Membership	3	Moderately
4. Letters, Literature	4	"
5. Personal Visits	5	"
6. Telephone Calls	6	Slightly
7. Trade Advertising	7	"
8. Yellow-Pages	8	"

Status of Marketing Representative

The respondents indicated that it is relatively important that the consulting firm's marketing representative be a Registered Professional Engineer and also manage the project. They want the marketing representative to demonstrate an awareness of the technical nature of the client's problem. Also, if the marketing representative also manages the project, the client is assured of attention to the client's project, and a working relationship with the leader of the project team. What the client does not want is, to quote a cliche, a "dog and pony show".

Larger firms considered it to be more important than the smaller firms did for the marketing representative to be a P.E.. The smaller firms tend to have a less formal technical/engineering staff, and therefore, do not require that the marketing representative be prepared to discuss technical matters concerning the project in question.

Cross classification analysis indicated that the industrial firms which consider years in operation of a consulting firm to be important, also considered it important that the marketing representative be a P.E. Also, firms that consider low cost and standardized designs to be important, also felt that the marketing representative should manage the project. A strong correlation was found between the importance of the marketing representative to be a P.E. and the size, promotional efforts, and range of services. Finally, there appears to be a strong correlation betwwen the reputational factors of low cost, repeat clients, standardized designs, and opportunity for client input with the P.E. status.

Table 6 summarizes the importance of the status of the marketing representative.

Table 6

Importance of Status of
Marketing Representative

Importance	P.E.	Manager
Extremely	14%	7%
Very	28	31
Moderately	38	41
Slightly	3	10
Not Important	17	10
	----	----
	100%	99%

Methods Used To Select Consultants

The respondents indicated that the most commonly used method of selecting a consulting firm is to use the same firm they used the last time they needed consulting services. However, this was not a majority method, because only 31% of the resondents indicated that they used this method. Twenty one percent of the firms indicated that they checked their files for literature on firms who have previously expressed an interest in assisting them on engineering matters. Referrals from business associates is another commonly used method to select consultants, used by 19% of the respondents. Interviewing of prospective consulting firms is used by 19% of the firms.

Responses to this question lend further support to the finding that a past relationship with an industrial firm, and goodwill, are two of the key success factors for a consulting firm to obtain work with an industrial firm. However, there tends to be a discrepancy between an industrial firm tending to check their files for information on consultants, and their indication that direct promotional efforts are not important. Perhaps this implies that if an industrial firm has prior knowledge of a consulting firm through promotional literature, it will consider the firm for selection. However, if the industrial firm has the opportunity to consider more than one consulting firm, the promotional material may not be a key success factor in the final selection process. In other words, the promotional material may serve to get the consulting engineering firm " in the door".

Requests for Proposals (RFP) are not commonly used. This indicates that industrial firms are not likely to advertise the fact that they need engineering assistance, particularly if the services in question are of a sensitive nature. It is not surprising when it is recalled that confidentiality is considered to be so important.

Yellow pages advertising is rarely used by industrial firms to select consulting firms. This supports the finding that advertising is not an effective method of promoting a consulting firm to the industrial market.

Large industrial firms are significantly more likely to select a consultant that has been used in the past than are the small firms. Perhaps the reason is that they are more likely to need the engineering services on a more frequent basis, and develop a satisfactory working relationship with the consultant.

Also, it is less risky, more confidential, and convenient to do so.

Table 7 summarizes the usage of the various methods to select consultants. The percentages do not sum to 100% because more than one method may be used.

Table 7

Methods Used To Select Consulting Firms

Method	%
1. Select Firm Used The Last Time	31%
2. Check Files For Literature	21
3. Business Associates Referrals	19
4. Interviews	17
5. Professional Org'zation Referrals	10
6. Visit Consultant's Offices	7
7. Requests for Proposals (RFP)	4
8. Yellow Pages	1
9. Other	1

Demand for Types of Engineering Services

The respondents were asked to indicate which types of services they need, and the frequency of need. Environmental services were the most commonly cited services. Because the survey primarily comprised firms that may have environmental concerns, this was expected. Water/wastewater treatment, environmental monitoring, and toxic waste management are all used by over 60% of the firms. Also, the demand for these services is expected to increase significantly in the near future.

The large firms had a greater tendency than the small firms to need environmental monitoring services. The small firms had a greater tendency than the large firms to use toxic waste management services.

Air pollution control is also needed by a large percentage of the firms. While the respondents indicated that the need will no increase in the future, recent regulatory changes may tend to increase the need.

Structural engineering, water supply, drainage, and solid waste management services are needed by less than half of the respondents. However, they expect that the need will increase slightly in the future.

Site engineering, transportation/roadways, and landscaping are all aspects of site development. These have not been needed very much in the recent past, and are expected to be needed less in the future. This response is not surprising considering that the survey was conducted a few years ago, in 1982, when the economy was in recession, particularly in the Midwest, and industrial capacity was very underutilized. It may be that if the same question was asked today, the responses would be significantly different.

A secret to success in any business is to provide a service or product in need. However, needs change with time and events. Therefore, long range success depends on a firm's ability to sense need levels and changes in these levels so that it can position itself to respond accordingly. Demand analysis is one of the primary purposes of market research and should be conducted on a frequent basis. In fact, the responses to this section of the survey may already be outdated, and should not be assumed to be reliable for purposes of future services planning.

Table 8 summarizes the past demand or need for services, and anticipated changes in the demand level. The past demand is based on frequency of need during the last five years (prior to the survey).

Table 8

Demand for Consulting Services

	Past Demand		Future Demand
	5 Times or Less	6 Times or More	
1. Env'mental Monitoring	62%	10%	Incr. Significant
2. Water/Waste-water Treat.	65%	3%	Incr. Significant
3. Toxic/Haz. Waste	62%	6%	Incr. Significant
4. Air Pol'tion	52%	3%	No Change
5. Structural	41%	6%	Incr. Slight
6. Water Supply & Drainage	38%	0%	Incr. Slight
7. Const. Mgmt	31%	0%	No Change
8. Solid Waste	28%	0%	Incr. Slight
9. Site Engr.	21%	3%	No Change
10. Trans/Roads	10%	0%	Decr. Slight
11. Landscaping	7%	0%	Decr. Slight

Persons Responsible for Selecting Consulting Firms

Various stages of decision making are involved between an industrial firm and a consulting firm, and can be summarized as follows:

1. Determination of Need
2. Identification of Prospective Consultants
3. Evaluation
4. Selection
5. Post Selection Liaison

These stages will not be discussed in detail, but are listed to make the point that different tasks and responsibilities are required, and may involve various levels and segments of the industrial firm's organizational staff. The consulting firm must recognize this and be prepared to design their marketing program to relect it. Various aspects of the marketing program must be directed towards the appropriate decision makers.

According to the survey results, the plant manager, plant engineer, and general manager are generally responsible for consulting engineering matters. The plant engineer tends to be involved throughout the decision making process. The plant manager is primarily involved in the preliminary stage of need determination, and the final selection process. The general manager is involved in the later stages of final selection and post selection liaison.

The involvement of the industrial firm's technical personnel in the preliminary stages of selection indicate that the industrial firm is probably prepared to discuss technical details regarding the project with the consulting firm's marketing representative who makes the initial contact with the industrial firm. Therefore, the representative must be prepared to address these technical matters. In the later stages which involve the general manager as decision maker, it may also be advantageous for the marketing representative to also be a good communicator, particularly if a formal presentation is involved.

CONCLUSION

Industrial firms typically select consulting engineering firms that can demonstrate technical proficiency. Confidentiality is also very important. The industrial firms tend to be very loyal to the consulting firm, particularly if the past relationship is favorable or satisfactory.

The consulting firm that has little or no experience with industrial clients faces some barriers that must be overcome. However, opportunities do arise from time to time. If an industrial firm becomes dissatisfied with the services they are receiving, then they may decide to change consulting firms. Also, if their needs change, or they are seeking engineering services for the first time, then the barriers are minimal if the consulting firm can demonstrate competence. Further, the size of the consulting firm, and the range of services it provides are very minimal factors in the selection process. Therefore, the opportunity does exist for a small consulting firm to compete effectively against larger firms on the basis of quality.

The consulting firm that seeks to take advantage of these opportunities must position themselves such that they are considered for selection. The best ways to do this are:

1. Provide the needed services
2. Generate Goodwill
3. Actively participate in professional organizations
4. Distribute promotional literature

The goodwill is typically generated by favorable recommendations and referrals. Professional memberships are effective because they allow the consulting firm to be aware of current trends in the profession, demonstrate an involvement in advancing the quality of engineering services, and are an effective means of socializing with the prospective clients. The promotional literature, while not necessarily important to the industrial firm, do allow the consulting firm to demonstrate an interest in assisting the industrial firm, describe the available services, and are available to the industrial firm to review when they are in need of services and looking for qualified consultants which provide the services.

The consulting firm must exhibit technical competence in a direct manner. The quality and completeness of a proposal, and documents such as technical reports and contract plans and specifications, are tangible indicators of a consulting firm's ability. Another method of exhibiting competence is to provide a Registered Professional Engineer as a marketing representative for discussions with the industrial firm.

Finally, the industrial firms that responded indicated that the following services are demanded frequently, and the demand is likely to increase significantly in the future: environmental monitoring, water and wastewater treatment, toxic/hazardous waste management, and structural engineering.

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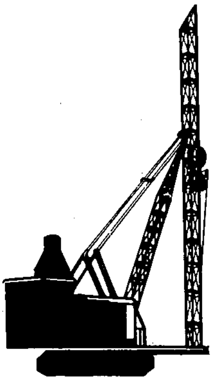

A NOTE FROM BSCES

The Boston Society of Civil Engineers Section/ASCE has recently reevaluated its 70-year-old journal and is committing new resources to the production of a new and different journal designed to attract a broad, national readership.

The new journal, Civil Engineering Practice: Journal of the Boston Society of Civil Engineers Section ASCE, will attempt to capture the spirit and substance of contemporary Civil Engineering in a careful selection of articles comprehensive in scope, yet clear to the non-specialist. Key emphasis will be placed on techniques now being applied successfully in the analysis, justification, design, construction, operation and maintenance of Civil Engineering works. It will cover the various technical and professional divisions of Civil Engineering with discrimination, understandability and balance.

The new journal will appear twice yearly, in Winter/Spring and Summer/Fall issues. Volume 71, Nos. 1 & 2 (a combined issue), 1985, of The Journal of the Boston Society of Civil Engineers represents the last issue of that publication. The first issue of Civil Engineering Practice will be the Winter/Spring 1986 issue. Please contact the Editor, BSCE Journal, 236 Huntington Ave., Boston, MA 02115-4701, for subscription and advertising rates for Civil Engineering Practice. BSCE members will receive the new journal as part of their membership fees.

Civil Engineering Practice welcomes article submissions. For guidelines see the following page.

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Articles on subjects related to civil engineering, either technical or professional, are welcomed and will be considered for publication. Unless you have already prepared the article, please submit an outline of what you propose to do/cover for our review and comments. Each article must be the original work of the author(s). If published or offered for publication elsewhere, this should be mentioned in a cover letter. Earlier oral presentation, or membership in BSCES or ASCE, are not prerequisites for publication. After review, authors will be notified either that the article has been accepted, accepted with changes suggested by reviewers, or not considered suitable for publication. Please send three copies of an outline or article to the Editor, BSCE Journal, 236 Huntington Ave., Boston, MA 02115-4701.

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All artwork (photos, figures, charts, graphs, tables, etc.) should accompany the final manuscript. Photos should be black and white glossy prints. If you need the artwork returned to you, please note so on the reverse side of each piece.

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