# STRATEGIES FOR POLLUTION ABATEMENT: THE RESERVE MINING CASE

Jerrold M. Peterson*

Reserve Mining Corporation processes iron ore for two large integrated steel firms, Armco and Republic Steel Corporation. The process begins when Reserve mines taconite ore in Babbitt, Minnesota, and transports this ore 47 miles to its Silver Bay plant located on the north shore of Lake Superior. Taconite is a hard stubborn rock containing 18 to 25 percent iron. Using large quantities of water, Reserve beneficiates this ore to increase the iron content of the final product. During this beneficiating process, Reserve crushes and then grinds the ore into fine particles. Huge magnets then separate the high iron content particles from the remaining material. These iron particles are agglomerated into marble-sized iron pellets containing 54 to 75 percent iron. These iron pellets are then fired to make them hard enough for shipment down the Great Lakes to the steel mills. It is estimated that Reserve incurs $137,575,000 in total costs to produce an average of 10,640,000 tons of taconite a year and earns an average of $16,598,000 in net profits for its parent companies [18].

During this process, Reserve is also discharging nearly 500 million gallons daily (mgd) of water and 60,000 tons of non-magnetic rock or taconite tailings into Lake Superior daily. The sheer size of this discharge, 21,400,000 tons of tailings annually, has invoked the wrath of nearly every concerned environmentalist and made Reserve's discharge a national issue [26]. Moreover, the Environmental Protection Agency, EPA, has contended that Reserve's current discharge practices present a very serious health hazard to the citizens of the communities utilizing Lake Superior water as a source for their public water supplies. As a result of this contention the EPA and several states have been engaged in a court action to force Reserve Mining to alter its tailings discharge procedure [28].

The remainder of this paper attempts to evaluate the possible abatement strategies which the court action is recommending. This evaluation utilizes cost-benefit techniques to determine the economic feasibility of the suggested abatement plan. The strategies evaluated include land disposal of Reserve's tailings, water filtration and a combination of both techniques. All three strategies are technologically feasible. Unfortunately these strategies are also costly; therefore, both Reserve and society have been reluctant to adopt

*Associate Professor, Department of Economics, University of Minnesota, Duluth.
The author would like to thank Dr. Arthur Wolff for his helpful criticisms of this draft. All errors remain the author's responsibility.

them. Section 1 of this paper reviews the Reserve Mining Trial with particular emphasis on the scientific findings. Section 2 attempts to estimate the social costs of Reserve's discharge utilizing the scientific evidence of Section 1. Section 3 sets up a benefit cost analysis of the alternative abatement strategies. Finally, the paper concludes by suggesting that the court imposed solution seems a relatively costly solution.

## The Trial

In essence the trial of Reserve Mining Corporation has centered on the environmental impact that Reserve's tailings discharge seems to be having on Lake Superior. The plaintiffs have presented evidence during the trial suggesting that significant quantities of these tailings are suspended in the lake's water. These suspended particles include minute asbestos form fibers. The plaintiffs contend that these suspended particles are causing four serious environmental problems for the lake. First, these suspended particles may provide an environment conducive to the growth of algae which accelerates the aging of the lake. Second, the particles and algae seem to cause a serious aesthetic problem called the "green water phenomenon." Green water is a distinct discoloration of the water caused by the defraction of light entering the lake giving the lake water an emerald green appearance. This discoloration occurs periodically along the north shore and connotes water pollution even to the casual observer. Third, these particles may move about the lake while in suspension and then settle to the bottom in locations other than the deep trough. This dispersion of tailings about the lake can cause serious damage to the lake's bottom fauna and aquatic life if it occurs in shallow depths [1, 2, 3, 9, 14].

The fourth and most serious problem is that the tailings seem to be contaminating the lake's water with minute asbestos form fibers. It seems that the asbestos form fibers have followed the lake currents and contaminated the water supplies of several north shore communities including Duluth, Minnesota (population 100,548) [7, 10, 11]. These north shore communities face a very serious health threat from the continued use of this contaminated water since similar asbestos form fibers have been linked to cancer. The exact health hazard that water-borne asbestos particles pose is unknown, but similar particles have been linked to cancer and other severe diseases when air-borne [17]. Numerous studies have shown a very strong correlation between the exposure of amphibole asbestos form fibers and these diseases. Moreover, this statistical evidence has been substantiated by pathological reports of these particles appearing in tumor growth and other tissue of the victims. While the victim's exact exposure time and particle concentration levels are unknown, the longer the exposure continues the more likely the victim may contract the disease. The latent period of the disease seems to be between 20 and 40 years. After this latent period the affected population experiences a serious increase in the incidence of cancer and other diseases. Since the water supplies of several north shore cities, including Duluth, may contain 30 to 1,000 times the asbestos form fibers present in the water supplies of cities not drawing water from the western end of Lake Superior, a reasonable person must conclude that a health hazard may exist for the citizens of these north shore communities [20, 21].

After hearing nearly nine months of evidence relating to the impact of Reserve's discharge in Lake Superior, Judge Miles Lord concluded that Reserve Mining Company's discharge was polluting Lake Superior in violation of Federal and State water pollution statutes. The court ordered Reserve to cease discharging its tailings into the lake as of April 21, 1974. In arriving at this decision the judge considered the closing of Reserve's plant necessary because of the serious health threat that the water-borne asbestos form particles poses to the north shore population. The plant has remained open during the appeals process while Reserve and the EPA have considered various land disposal alternatives.

## Social Costs of Reserve's Discharge

The scientific studies presented as evidence during the trial seem to provide conclusive proof that Reserve's discharge is having a detrimental impact on the water quality of Lake Superior. This evidence, unfortunately, has not provided an accurate general index of the severity of the damage to the lake's environment. The severity of this damage may be measured by estimating the social costs that Reserve's current discharge practices are imposing on other segments of society.

Reserve's social costs may be measured as the reduction in economic activity caused by the deterioration of Lake Superior stemming from Reserve's discharge. Reserve's discharge and its impact on Lake Superior seems to be affecting five regional economic activities which are linked to the environmental quality of Lake Superior. These five economic activities are commercial fishing, tourism, retail boating sales, lake shore property values, and the health of the Lake Superior shoreline residents. The environmental linkages between the quality of Lake Superior and these economic activities are complex and subtle. Nevertheless, a significant deterioration in the environment will manifest itself through a change in one or more of these economic activities. Therefore, a reduction in these economic activities as a result of the deterioration of the lake environment measures Reserve's social costs and provides an estimate of the severity of damage Reserve is causing to the water quality of the lake. Naturally, some of the environmental damage caused by Reserve's effluent may not directly influence any economic activity. Under these conditions the social costs measured in this section may underestimate the severity of the environmental changes caused by Reserve's tailings. These environmental changes may include the extermination of some species of animal or plant life or the breaking of some link in the ecological chain. Such events when documented represent serious unmeasurable social costs and may justify pollution abatement by themselves. The scientific studies presented during Reserve's trial seem to have identified all the important environmental damages associated with Reserve's discharge [15].

In addition, Reserve's current discharge practices seem to be imposing substantial social costs directly on the citizens of the north shore by exposing these people to abnormally large quantities of asbestos form fibers, a known carcinogenic material. If the scientific studies reviewed during Reserve's trial accurately predict the health hazards of water-borne asbestos fibers and the current volume of fibers in the water is similar to the exposure level of asbestos workers, the north shore population faces a serious epidemic of asbestos related diseases. This epidemic may culminate in an increase in the area's annual death rate ranging from 91 to 195 deaths (see Table 1). Since the health hazards of water-borne asbestos are still unknown, the predictions in Table 1 are still conjectures. However, water-borne asbestos may be just as hazardous as air-borne asbestos. First, the public may ingest asbestos particles when drinking the contaminated water or eating food prepared with untreated water. If the public ingests these particles while eating or drinking, cancer of the digestive tract of the north shore population may rise to the predictive levels shown in row 3. Second, the north shore public may be directly exposed to air-borne asbestos whenever they use water which is sprayed into the air. The public may be exposed to high concentration of air-borne particles when the water is used for showering or humidifying. In addition, the public may be exposed to these particles when they dry on floors, cabinets, clothes or on dishes cleaned in untreated water. Under these conditions, the north shore population might experience a serious increase in lung cancer as well as digestive tract cancer because of the air-borne particles (see row 2). Third, the population may even face asbestosis from inhaling air-borne asbestos since the air in enclosed areas such as schools, shopping centers, places of employment and the home may be heavily contaminated with air-borne particles particularly in the winter. The north shore population might experience the same health hazard as the asbestos workers studied by Selikoff and others. If this is the case, the annual death rate might be as high as that predicted in row 1.

Although the actual health hazard is unknown, this study assumes that the three victim estimates shown in Table 1 are drawn from a population of death estimates which is normally distributed about an unknown mean. The upper and lower estimates in Table 1 are assumed to be no more than one standard deviation from this population mean. If the area under a normal curve is used to represent the probability that one of these estimates is actually the mean of the population, the victim estimate may be calculated by multiplying these probabilities by the estimated victims and summing the results or (.1587)(195) + (.6826)(185.8) + (.1587)(91.4) = 172. Given the current discharge practice of Reserve, the north shore population may face an increase in its average annual death toll of 172 victims caused by the presence of asbestos in their water supplies.

If Reserve continues to discharge tailings into the lake at its current annual rate, the amount of fibers in the water will increase by approximately 2.18 times their current level before Reserve ceases its operation. Assuming that asbestos related diseases already discussed are linearily related to the quantity of fibers in the water, the death rate will rise from its current projection of 172 to 376 for the last year of the plant's estimated 25 year life. In this event, the death rate will average 274 deaths per year over the remaining 25 years of plant life. After this time the death rate begins to subside because Reserve has ceased operation and will no longer be discharging tailings into the lake. This predicted increase in the area's death rate represents the real social costs of Reserve's current operation.

TABLE 1: Projected Annual Deaths from Asbestos Induced Cancer Duluth-Superior Region

| Assumptions of Impact of Water-Borne Asbestos on Population | Population of Affected Area | Predicted Deaths from Asbestos Induced Disease | Expected Deaths Based on National Statistics | Increased Deaths in North Shore Due to Asbestos |
|---|---|---|---|---|
| 1. Health Hazard same as Air-borne Asbestos | 167,049 | 720.5 | 525.5 | 195.0 |
| 2. Health Hazard same for Cancer as Air-borne Asbestos | 167,049 | 279.1 | 93.3 | 185.8 |
| 3. Health Hazard same for Digestive Cancer as Air-borne Asbestos | 167,049 | 152.6 | 61.2 | 91.4 |

These projections are derived using the reported incidence of diseases observed by Selikoff [20] Table 9. Selikoff's expected and observed incidence of diseases are adjusted for differences in the age, sex, and time of exposure between his study population and the north shore population. This procedure, shown by example below, used the adjusted probabilities to estimate the annual death rate for north shore population.

Example: Row 1 estimates assumes the health hazard to the north shore population is the same as air-borne asbestos in all respects as reported by Selikoff

| Sex | National Ratio Female to Male Cancer Deaths | | Selikoff's Probabilities of Death-Observed/(5) · (Exposed) | | Percent of North Shore Population over 40 | | Percent of North Shore Population by Sex | | Adjusted Annual Probability of Death per Capita |
|---|---|---|---|---|---|---|---|---|---|
| Female | .81 | x | .01224 | x | .4 | x | .5159 | = | .002046 |
| Male | 1.00 | x | .01224 | x | .4 | x | .4884 | = | .002391 |

TABLE 1 - Continued

TOTAL PREDICTED DEATHS PER YEAR

North Shore

| | | | | | |
|---|---|---|---|---|---|
| Female | .002046 | x | 167,049 | = | 341.78 |
| Male | .002391 | x | 167,049 | = | 399.45 |
| | | | TOTAL | | 741.23 |
| Adjusted for Cancer under 40 using national rates | | | | | +2.00 |
| | | | | | 743.23 |
| Less reduction in death from other causes (.00017) (.4) (167,049) | | | | | -22.73 |
| | | | TOTAL | | 720.50 |

The range of predictions shown in Table 1 depends on the health hazard assumed for water-borne asbestos relative to air-borne asbestos. The increased deaths predicted here may begin occurring as early as 1975 since Reserve Mining Corporation began operations in 1955. This author believes that the death rate will probably gradually rise to these predicted levels over the next 10 or 15 years. Not all the deaths predicted here will occur in this region since many people who have been exposed to the asbestos contamination have moved out of this area. Also, many of the current population have not been in the area for the entire period since Reserve commenced operation. These predictions do not attempt to estimate the deaths which may occur from only a brief exposure such as a tourist.

The financial social costs of Reserve's operation may be estimated as the annual present value of the lost productivity society suffers from these victims' premature deaths. This present value calculation is a minimum estimate of each victim's worth to society since it estimates only his intrinsic value and not spiritual value to society. These calculations are based on the area per capita income adjusted for productivity and price changes to 1973 values or $3,370 per capita. Per capita income is used rather than other measures of productivity because of the uncertainty of the individual's participation in the area's labor force. In order to estimate the present value of each victim's per capita income the estimated age at death is required. This age is calculated from the age of known victims dying from air-borne asbestos lung cancer adjusted for earlier exposure to asbestos fibers experienced by the north shore population relative to asbestos workers.[1] If this estimate is accurate the north shore victims will die at an average age of 54 years for the male and 61.8 years for the female victims. Thus, the 274 annual victims will live on the average of 12.8 fewer years than had they not been exposed to water-borne asbestos fibers.

The present value of the remaining life of each victim is calculated by determining the present value of his $3,370 in per capita income discounted over 12.8 years by a 6.3 percent interest rate or $26,511. Since this calculation represents society's lost productivity caused by each individual's premature death, Reserve will be imposing a minimum of $7,264,000 in annual social costs from the lost income of a predicted 274 victims (see Table 2).

Finally, Reserve's discharge will continue to impose social costs onto

---

[1]The average age of death is estimated from Selikoff [20] Tables 5a and 5b using a weighted average of the 49 victims observed and calculating their average age at exposure and death. These victims' mean age at exposure is 37 and death is 62. Selikoff's study estimated age at death is used as the upper estimate for death of the north shore population. It is believed that the north shore victims may die earlier than the Selikoff study victims because of the earlier exposure to asbestos. Therefore, a second age estimate is obtained by assuming the latent period of the diseases is equivalent and then adding the 25 year average latent period to the mean age of the north shore population. This second estimate is 58.95 years. A third age estimate is derived by assuming that all north shore exposure begins at birth whereas the Selikoff exposure begins at 37. Thus, it is conceivable the north shore mean age at death could be 25 years of age or 37 years earlier than the Selikoff observed age of 62. These three age estimates are assumed to come from a population of normal distribution whose mean is unknown but the upper age estimate and lower age estimate are no more than one standard deviation away from the mean. If the area under a normal curve is used to represent the probabilities that one of these estimates is the actual mean of the population, the mean age of death for the north shore population may be derived by multiplying these probabilities by the estimated ages and summing the results of (.1587)(62) + (.6826)(58.95) + (.1587)(25). The estimated mean age at death of the north shore population is 54 years of age or 12.8 years less than the average life expectancy of a U. S. male of 66.8 years [25] Table No. 78, p. 57.

TABLE 2: Estimated Annual Social Costs of Reserve Mining's Discharge
Reserve's Continued Discharge of 21,000,000 Tons of Tailings

| Ecological Damage | Damage to Economic Activity | | Estimated Social Costs[5] |
|---|---|---|---|
| 1. Aquatic Life | Fishing Industry[1] | | $ 20,000 |
| 2. Aesthetic Algae and Eutrophication | Tourist Trade[2] Recreational Industry Lake Property Values[3] | | 2,920,000 |
| 3. Health Hazard | Economic Loss of Income from 274 Early Deaths Due to Asbestos Related Diseases | | 7,264,000 |
| | | Sub-Total | $10,204,000 |
| 4. Residual | Residual Costs[4] | | 1,475,000 |
| | | Total | $11,679,000 |

[1]Several studies have shown that Reserve's discharge is harming aquatic and fish life in the lake. The severity of this impact seems to be minor as suggested by the social costs being imposed on the fishing industry ranging from $100 to $20,000 annually. See William A. Brungs [4], Henson, et al. [12], R. L. Pycha [16] and J. L. Skrypech, et al. [22] for the scientific studies of the effects of tailings on fish. This estimate is based on $50 per square mile damage and 400 square miles damaged. Currently, the commercial fishing industry in the western end of the lake is doing about $1,000,000 in annual business.

[2]Reserve's discharge may be imposing more substantial social costs on the north shore tourist industry by altering tourist demand for a north shore vacation. Tourist demand for a north shore vacation is probably directly related to a tourist's preconceived idea of the environmental quality of the Lake Superior region. If Reserve's discharge is causing a marked deterioration in the lake's water quality as suggested during the trial, then Reserve may be imposing serious social costs on the tourist industry by reducing tourist trade in the north shore area. These social costs may be as high as $2,200,000 based on the lost tourist trade experience in July 1973. See estimates presented by Peterson [15].

[3]Reserve's discharge may be imposing social costs on other lake related economic activities including retail boating sales, lake property values, and pollution beyond Minnesota boundaries. These social costs may be as high as $720,000. See Peterson [15], Table 1 and discussion pp. 8-9.

[4]Present value calculation made using the average U. S. government bond rate of 6.31 percent Federal Reserve Bulletin, March 1974. Average for 25 years remaining life.

[5]These estimates of social costs are tenuous because they depend on unknown aspects of tourist, consumer and property owner behavior as well as health hazards. Nevertheless, they are presented as estimates of the maximum impact of Reserve's activity on the lake environment. These estimates may understate Reserve's social costs if the environmental impacts move across international boundaries as pointed out by Dr. Kirk Y. K. Kim. To date evidence seems to be that the pollution has not traveled across these borders.

society long after the corporation ceases operation in Minnesota. These residual costs are estimates of the additional expense Reserve should pay to society now to cover the total impact its discharge will ultimately have on the lake's environment. The residual costs are calculated by estimating the present value of Reserve's annual social costs discounted indefinitely into the future and then subtracting the present value of the social costs accounted for during Reserve's remaining life. These residual social costs are then prorated over the estimated 25 years of remaining plant life, adding $1,475,000 in annual costs to fully cover the firm's social obligation. Thus, Reserve's discharge seems to be causing deterioration in Lake Superior's environment and imposing an estimated $11,679,000 in annual social costs to various regional institutions.

## A Benefit Cost Analysis of Alternative Solutions to Reserve's Pollution Problem

As the result of court action pending against the corporation, Reserve Mining is being forced to consider various pollution abatement measures. Since Reserve has been enjoined from further discharge into the lake the company must either close its operation or develop an on-land disposal system for its tailings. At this time the permanent closing of Reserve Mining Company does not seem likely since this measure is far too costly from both society's and the company's points of view. In this section benefit cost analysis will be used to evaluate a land disposal system, a water filtration system and a combination of both systems. This analysis will attempt to determine the economically most efficient pollution abatement measure available. During this analysis society will be defined to include the citizens of the United States and Reserve Mining Corporation. The benefits of any pollution abatement program will be assumed to accrue to all in the society while the costs will be borne initially by Reserve.

At the present time there seems to be only three general strategies for pollution abatement of Reserve's effluent. First, the effluent may be stopped at its source. This strategy will prevent any further harm from occurring to the lake's environment but does nothing for the harm already caused by Reserve's discharge. If Reserve is forced to adopt a land disposal system, then society will be following this first strategy. Second, the harmful elements of Reserve's effluent may be neutralized before reaching society. This strategy will reduce or eliminate the harm to society caused by the polluted lake but will allow eutrophication of the lake's environment to continue. If society adopts water filtration for public water supplies then society will essentially be adopting this second strategy. Third, society may adopt both the first and second strategies. Society may force Reserve to adopt a land disposal system and adopt water filtration as third pollution abatement strategy.

Each of these three strategies provide society with certain identifiable benefits, and each of these strategies will have certain cost of implementation. Benefit cost analysis tries to compare the benefits of a given strategy with its costs to determine the economically most efficient pollution abatement strategy available.

The first strategy of stopping the effluent at its source may be implemented by forcing Reserve to discharge its tailings on land. Currently both the plaintiffs and the court seem to favor this strategy since they are negotiating with Reserve to develop a land disposal system for Reserve's tailings. A land disposal system is technically feasible since all other existing taconite facilities currently dispose of their tailings in this fashion. However, Reserve is faced with several important technical problems with an on-land-disposal system. The most important problem involves the location of a tailings disposal yard and the transportation of its tailings to this yard. A number of preliminary engineering studies have been carried out for systems which solve these problems and provide for a technically feasible land disposal system. Of all the plans proposed currently, the EPA 1973 plan shown in Table 3 seems to be the least costly from the pollution abatement standpoint. If Reserve were to adopt this plan, Reserve would incur $15,308,000 in additional annual expense for pollution abatement.

If society adopts the second strategy, Reserve Mining may be required to pay the full costs for filtration of all water currently being drawn from Lake Superior to supply the north shore communities. Water filtration is a technologically feasible alternative since known filtration techniques are capable of removing at least 95 percent of the asbestos form fibers by volume now in the north shore water supplies. If all north shore cities adopted some type of effective water filtration to remove the asbestos form fibers currently contaminating their raw water supplies, the water processing industry in this area would incur an estimated $3,157,000 each year in additional costs to filter an estimated 55 million gallons of water daily (55 mgd.) (see Table 3).

Finally, society could adopt both of the above pollution abatement measures and force Reserve to develop a land-disposal system and pay for water filtration. This third strategy is the most costly abatement measure of the three, costing Reserve $18,465,000 annually to implement.

Although each of these pollution abatement measures is costly each strategy provides a unique matrix of social benefits. These social benefits are measurable as the reduction of social costs that Reserve's current operation seems to be imposing on various segments of society. If Reserve continues its current practices unabated then Reserve will continue to impose $13,787,000 in social costs on other segments of society (see Table 4). However, if Reserve adopts one of the three suggested abatement strategies and this strategy is effective, the social costs Reserve is imposing on the fishing industry, tourist industry, north shore citizens and residual costs should begin to subside. This reduction in social costs measures the benefits of a particular pollution abatement measure.

The actual social benefits which a particular abatement strategy yields depends on the rapidity that the reduction of Reserve's pollution manifests itself by improving the lake's or society's environment. If Reserve adopts a land disposal system then the company will cease discharging tailings into the lake and the tailings particles currently in suspension should begin settling out. Studies on the settling rates of these particles suggest that the larger particles will settle out in less than one year [6]. After these particles have settled, the green water phenomenon should subside and the

TABLE 3: Costs of Alternative Pollution Abatement Measures in 1973

| | Land Disposal[1] | Water Filtration[2] | Filtration and Disposal[3] |
|---|---|---|---|
| Capital Expenses | $43,714,000 | $32,476,000 | $76,190,000 |
| Estimated Annual Expense | 15,308,000 | 3,157,000 | 18,465,000 |
| Estimated Annual Profit (Current)[4] | 16,598,000 | 16,598,000 | 16,598,000 |

[1] International Engineering Company [13]. Total cost of the facility is $187,316,716. However, only the costs for floatation cells, thickner tanks, thickner drums, engineering, tailings disposal, water supply and supporting facilities are considered required because of pollution abatement. The annual expense is determined by prorating the total operating expense by the percentage of capital devoted to pollution control. Reserve Mining estimates are higher for land disposal systems. Their estimates range from an annual expense of $16,611,000 to $36,288,000 depending on the technique and disposal site. See "Engineering Task Force Progress Report," [27], pp. 683-688.

[2] Estimates are made by adjusting the costs estimates of the most expensive filtration plan presented by the Corps of Engineers at its October 3, 1974 meeting at Duluth County Court House to include filtration of all affected north shore population's water. This adjustment adds 16,774 people to the total population for which water is filtered. Assuming the same cost of filtration for this population as for the Duluth-Superior population this adds roughly 11 percent to the costs of filtration estimated by the Corps or (1.11). (2,840,000). These estimates are close to those made by Smith, [23], Figure 9, p. 1553 if Smith's estimates are adjusted to 1973 prices.

[3] The costs of land disposal and water filtration are combined.

[4] This estimate is Reserve's estimate derived from a document made for public disclosure. The author feels this figure may substantially underestimate Reserve's actual profits.

TABLE 4: Annual Benefits of Pollution Abatement

| Abatement Plan | Remaining Social Costs: Fishing and Tourist | Health | Residual | Annual Total Social Costs | Annual[1] Social Benefits |
|---|---|---|---|---|---|
| No Change | $2,940,000 | $7,264,000 | $1,475,000 | $11,679,000 | $ -0- |
| Land Disposal[2] | -0- | 3,287,000 | 475,000 | 3,762,000 | 7,917,000 |
| Filtration[3] | 2,940,000 | 371,000 | 479,000 | 3,790,000 | 7,889,000 |
| Land Disposal[4] and Filtration | -0- | 106,000 | 15,000 | 121,000 | 11,558,000 |

[1]Social benefits are calculated by subtracting total social costs of the pollution abatement plan from total social costs of no change.

[2]The reduction in social cost is based on an estimated reduction of volume of asbestos material in the raw water from 3,900,000 to 1,685,000 tons or 43.2 percent reduction over 25 years. This reduction in fibers in the water may help reduce the predicted annual death rates by 49. In addition, the land disposal method will prevent any new introduction of fibers into the lake thus eliminating the risk of an additional 101 annual deaths which might be induced by an increased volume of asbestos fibers in the lake water. The $3,977,000 present value of the 150 lives is estimated by suggesting the people will live an additional 12.8 years and produce $3,370 or a present value of $26,511 per each life saved.

[3]Assumes that the north shore water processing plants adopt filtration at least 95 percent effective in removing asbestos form fibers from raw water. Further, assumes that Reserve's continued discharge into the lake increases the volume of fibers in the raw water by 4.72 percent per year based on the estimated differences between the settling rate and discharge rate of asbestos form fibers. These increases in fibers would cause the average annual death rates associated with asbestos to rise to 274 if the water were untreated over the remaining life of the plant. However, filtration would reduce this death toll by 260 to 14 again assuming the asbestos related disease is directly related to the volume of fibers in the water.

[4]Assumes the combination of land disposal and filtration saves 4 additional lives annually over simple filtration because of the reduced volume of fibers in the raw water.

bottom fauna and other aquatic life may improve. As the green water phenomenon subsides, the social costs imposed on the tourist, fishing and other economic activities may fall by as much as $2,940,000 (see Table 4).

Of more importance, this pollution abatement strategy should also reduce the health hazard currently being imposed on the north shore. By adopting land disposal for its tailings, Reserve will cease discharging a total of 21,000,000 tons of tailings into the lake annually including 184,000 tons of tailings one micron in diameter or less (estimates based on [30] Table 20, p. 53). These fine tailings are potentially the most dangerous since they possess the largest number of asbestos form fibers. In addition, the asbestos fibers now in suspension in the lake water should begin settling out. The settling rate for these minute fibers seem quite slow ranging from one year for the largest particles to over 63 years for the fine fibers [6]. In fact, there is some question whether the most harmful fibers in the water would ever settle or dissipate from the western end of the lake. In addition the tailings already deposited on the bottom of the lake may periodically be resuspended by lake storms and currents. Nevertheless, nearly 88,600 tons of material should settle each year based on weighted average settling rate for all fibers of 22 years and that there are currently 3,900,000 tons of material one micron in diameter or smaller in suspension ([30, Table 20, p. 53). Assuming that the occurrence of the asbestos related diseases is directly related to the volume of tailings in the lake water, Reserve's adoption of a land disposal system may reduce the estimated death toll by an average of 150 per year over the remaining life of the plant. In economic terms this pollution abatement measure would generate $3,977,000 in annual social benefits based on the present value of the predicted lives saved each year.

Therefore, if Reserve adopts a land disposal system, society will receive an estimated $7,917,000 in annual economic benefits. These benefits will accrue primarily to the tourist industry, fishing industry, and sundry industries in the form of increased economic activity and to the citizens of the area in the form of increased life expectancy. However, the region will still face a serious health hazard if this is the only pollution measure adopted since an estimated 124 persons will die each year prematurely as the result of the previous asbestos pollution of the lake. This health hazard will continue to impose at least $3,762,000 in social costs to the region each year.

A land disposal system attempts to eliminate Reserve's effluent at its source. An alterntive abatement strategy is to eliminate or reduce the effluent prior to reuse of the water. Since water filtration is technologically feasible, this strategy provides society a different matrix of benefits in comparison to land disposal. Naturally, filtration will not affect the tailings already in the lake or the amount of tailings being discharged into the lake. Thus, water filtration will not reduce the social costs Reserve is imposing on the fishing industry, tourist or other activities depending on the environmental quality of the lake. However, water filtration will drastically reduce the quantity of asbestos fibers in the north shore's public water supplies. The reduction of fibers may be 95 percent or more depending on the filtration techniques finally adopted by these communities. Assuming that the asbestos related diseases are directly related to the volume of fibers in the processed water, filtration ought to drastically reduce the projected annual death rate. If filtration is 95 percent efficient, the projected annual death rate should fall from 274 to 14. This pollution abatement measure could generate $7,889,000 in social benefits by reducing Reserve's health hazard and saving 260 lives annually (see Table 4).

Finally, society may force Reserve to develop a land disposal system and pay for water filtration. This pollution abatement strategy would eliminate all social costs to the fishing and tourist industries and reduce the health hazard so that the predicted deaths in the north shore area drop to 10 from the 14 predicted for filtration alone. The annual social benefits of this strategy rises to $11,558,000 shown in Table 4.

The benefit cost analysis shown in Table 5 indicates that filtration is the only economically efficient abatement measure considered. The strategy meets the first criterion by projecting an estimated $4,732,000 in annual net benefits. Society, therefore, saves $4,732,000 annually in resources over the costs of implementation of the project. The other two strategies considered project negative net benefits suggesting the projects cost more than they yield back in benefits to society. Second, the strategy is more efficient than land disposal since filtration's marginal benefits exceed its marginal costs by $12,123,000. Both the other strategies project marginal benefits which are less than their marginal costs. Finally, filtration has an estimated benefit cost ratio of 2.50 as opposed to a ratio of .52 for land disposal and .63 for filtration coupled with land disposal. Thus, water filtration meets all three benefit cost criteria necessary to suggest that this abatement measure is the most efficient of the three considered.

## Conclusions

Although Reserve Mining's discharge into Lake Superior is causing serious pollution problems, society should not impose a land disposal system on the company without comparing the benefit of this pollution strategy with its costs. The benefit-cost analysis carried out in this paper suggests that this strategy is not the best pollution abatement measure available for correcting the Reserve problem. Water filtration, the second strategy evaluated, seems far more appropriate both from a benefit cost and a health criteria. The benefit cost analysis of this strategy shows that this pollution measure will yield sizable positive net benefits, and meets all of the other benefit cost criteria necessary for its acceptance. Furthermore, the water filtration measure will save an estimated 260 lives annually if the health hazard of Reserve's discharge has been accurately projected. Finally, society may consider using both land disposal and filtration to further improve the environment. While this pollution abatement measure does not meet the benefit cost criterion necessary for its adoption, the four additional lives that it is estimated to save each year and reduced pollution to the lake may be worth the $15,308,000 in additional annual costs. However, before adopting this strategy society ought to consider whether that $15,308,000 in annual costs might save more lives or improve the environment more if it were utilized in other health or environmental programs.

TABLE 5: Benefit Cost Analysis of Alternative Abatement Plans[1]

| Population Abatement Plan | Annual Social Benefits | Marginal Benefits | Annual Cost of Abatement | Marginal Costs | Annual Net Benefits | Benefit Cost Ratio |
|---|---|---|---|---|---|---|
| No Change | $ -0- | | $ -0- | | $ -0- | 0 |
| | | $7,917,000 | | $15,308,000 | | |
| Land Disposal | 7,917,000 | | 15,308,000 | | (7,391,000) | .52 |
| | | (28,000) | | (12,151,000) | | |
| Filtration | 7,889,000 | | 3,157,000 | | 4,732,000 | 2.50 |
| | | 3,669,000 | | 15,308,000 | | |
| Filtration and Land Disposal | 11,558,000 | | 18,465,000 | | (6,907,000) | 63 |
| | | | | (negative numbers) | | |

[1]Before society adopts any of the three abatement strategies being considered, a benefit cost analysis should be conducted to ensure that the chosen strategy is economically efficient as well as technologically feasible. This benefit cost analysis compares the benefits generated by each strategy with the costs incurred with implementation. If this analysis shows that a strategy meets three criteria outlined above, the abatement strategy is economically efficient. First, the abatement measure must be shown to yield positive net social benefits. The social benefits of the project must exceed the costs of the project's implementation. The net benefits of the three strategies being considered are shown in column 6 of Table 5. Second, the project should be shown to have marginal benefits (column 3 of Table 5) which are equal to or greater than the marginal costs of implementations (column 5 of Table 5). This criterion ensures that the project is more efficient than the project preceding it. Finally, the project should have a benefit cost ratio equal to or greater than one. This criterion if it is met ensures that society will receive at least one dollar in benefits for every dollar expended on the project (see column 7).

## REFERENCES


1. Andrew, R. W. and G. E. Glass. "Effect of Taconite Tailings on Algae Growth." Proceedings: Conference in the Matter of Pollution of Lake Superior and Tributary Basins. Washington: U. S. Department of the Interior, Federal Water Quality Administration (1970), 295-303.

2. Andrew, R. W. and G. E. Glass. "Physical Characteristics of Green Water Along the Minnesota Shore of Lake Superior." Proceedings, op. cit. 226-250.

3. Arthur, John W., et al. "Periphyton Growth on Artificial Substrates in Lake Superior." Studies Regarding the Effect of the Reserve Mining Company Discharge on Lake Superior. Washington: U. S. Environmental Protection Agency, May 1973, 69-143.

4. Brungs, William A. "Transfer of Elements Associated with Taconite Tailings to the Liver Kidney of Rainbow Trout." Unpublished paper, 1973.

5. Burrel, Stephen. "Amphiboles in Taconite from the Peter Mitchell Mine, Reserve Mining Company, Babbitt, Minnesota." University of Wisconsin-River Falls Report to the Environmental Protection Agency (1973), 7-10.

6. Cohen, Jesse M. and Sidney A. Hannah. "Coagulation and Floatation" in Water Quality and Treatment a Handbook of Public Water Supplies, New York: McGraw Hill (1971), 70.

7. Cook, Phillip. "Distribution of Taconite Tailings in Lake Superior Water and Public Supplies." Studies, op. cit., 755-782.

8. Dixon, J. R., et al. "The Role of Trace Metals in Chemical Carcinogensis; Asbestos Cancers," Cancer Research, Vol. 30, April 1970, 1068-1074.

9. Dybdahl, A. W., et al. "Remote Sensing Study: Green Water in Lake Superior," Studies, op. cit., 782-824.

10. Glass, Gary E. "Analysis and Laboratory Experiments with Taconite Tailings Data Report," Studies, op. cit., 991-1014.

11. Glass, Gary E. "A Study of Western Lake Superior Sediments Interstitial Water and Exchange of Dissolved Components Across the Water Sediments Interface," Studies, op. cit., 1034-1127.

12. Henson, et al. The Ecological Effects of Taconite Tailings Disposal on the Benthic Population of Northern Lake Superior. Washington: Environmental Protection Agency, 1973.

13. International Engineering Company. Cost Study for New Iron Ore Concentration Facility - Reserve Mining Company. Washington: Environmental Protection Agency, 1973.

14. Mount, Donald I. "A Summary of the Studies Regarding the Effect of Reserve Mining Discharge on Lake Superior." Studies, op. cit., 1-21.

15. Peterson, Jerrold M. "Reserve Mining Pollution Abatement: A Cost Benefit Analysis of Alternative Abatement Proposals," A paper presented at the Second National Sumposium on Societal Problems of Water Resources, April 1973

16. Pycha, R. L. Effects of Dumping Taconite Tailings in Lake Superior on Commercial Fisheries. Washington: Department of Interior, unpublished, (1968) 4.

17. Rall, David, et al. "Biological Effects of Asbestos." Environmental Science Laboratory, Mount Sinai School of Medicine, 1973.

18. Reserve Mining Corporation. A Plan to Modify Tailings Discharge System. 1971.

19. Royal, H. J. "The Health of the Public and Asbestos Usage." Journal of Royal Institute of Public Health. Vol. 51 (1968), 126-146.

20. Selikoff, Irving J., et al. "Cancer Risk of Insulation Workers in the United States." A paper presented at a meeting of the Working Group to Assess Biological Effects of Asbestos International Agency for Research on Cancer. Lyon, France, October 1972.

21. Selikoff, Irving J., et al. "Carcinogenicity of Amosite Asbestos." Arch Environ Health, Vol. 25, September 1972, 183-186.

22. Skrypech, J. L., et al. "Bottom Fauna Off the Minnesota North Shore of Lake Superior as Related to Deposition of Taconite Tailings and Fish Production." Minnesota Department of Conservation, Division of Game and Fish. Special Publication No. 57, 1968.

23. Smith, Robert. "Cost of Conventional and Advanced Treatment of Waste Water." Journal of Water Pollution Control Federation. Vol. 40, September 1968, 1546-1574.

24. Stanton, Mearl F. and Constance Wrench. "Mechanisms of Mesothelioma Induction with Asbestos and Fibrous Glass." Journal of the National Cancer Institute, Vol. 48, No. 3, March 1972.

25. Statistical Abstract of the United States, 94th ed. (1973), Table No. 73, 57.

26. Ulrich, Stanley, et al. "Superior Pollutors," Save Lake Superior Association, Duluth, 1972.

27. United States Department of the Interior. Proceedings: Conference in the Matter of Pollution of Lake Superior and its Tributary Basin Minnesota-Wisconsin-Michigan. Washington: FWQA, Vol. 2, 1970.

28. United States District Court. "United States of America, et al., Plaintiffs vs. Reserve Mining Company, et al., Civil Action." District of Minnesota, No. 5-72, Div. 19.

29. Wagner, J. C., et al. "Epidemiology of Asbestos Cancers," British Medical Bulletin, Vol. 27, No. 1 (1971), 71-76.

30. Weston, Roy F. "Concept Evaluation Report Taconite Tailings Disposal," Reserve Mining Company, Washington: Environmental Protection Agency, 1971.