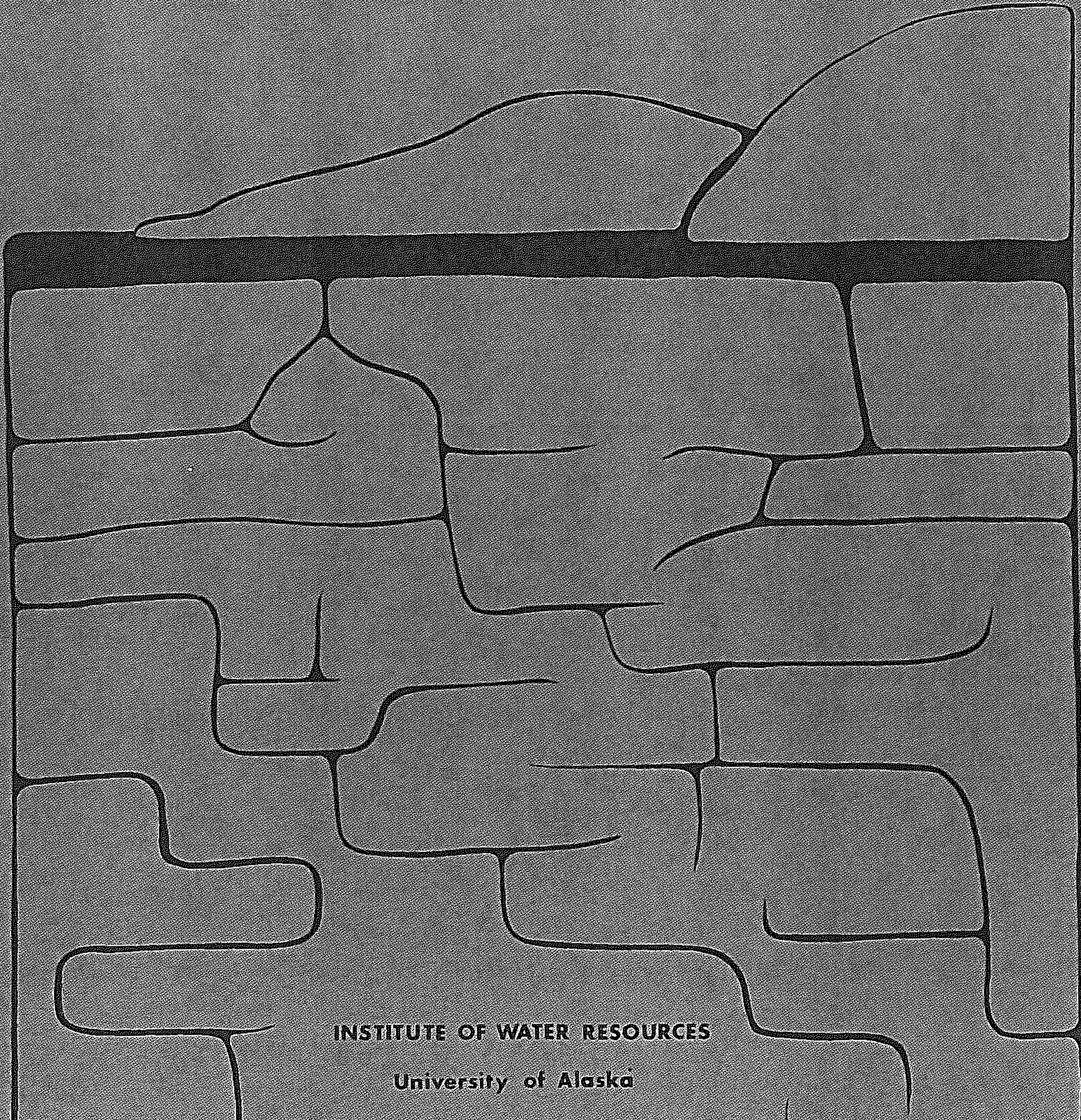
ALASKA MINING AND WATER QUALITY



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Alaska mining and water quality
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Report No. IWR-74 June 1976

The work upon which this report is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Resources Research Act of 1964, Public Law 88-379, as amended (Project A-055-ALAS).

ACKNOWLEDGEMENTS

The assistance and cooperation of miners and government agencies was necessary, and in general was achieved, in the preparation of this report. The reception during on-site visits to mines was uniformly outstanding. Particular appreciation is extended to the following:

Carl Heflinger and Gary Scoretz
Klondike Placer Gold Corporation

Mike O'Carroll
Spruce Creek Mine

"Tex" Gates
Bear Creek Mining Company

John Miscovitch
Otter Dredging Company

Charles Awe and John Bloomquist
Tuluksak Dredging Company

Ed Olson and Joe Fisher
Goodnews Bay Mining Company

Joe Usibelli
Usibelli Coal Mine, Incorporated

Bob Fedeler
Alaska Department of Fish and Game

Jacqueline D. LaPerriere's assistance in technical review of the biological information in this report is also appreciated.

A special thanks is given to Mayo Murray of the Institute of Water Resources for her editing and assistance with the manuscript, given in the finest tradition of the principle that engineers should not be required to know how to spell.

The Institute of Water Resources provided technical and financial assistance for the report preparation.

PREFACE

The Institute of Water Resources has sought financial assistance for some time in an attempt to initiate research relative to the impact of mining on water quality. Attempts were made as early as 1971 by Dr. Timothy Tilsworth and later by Dr. Donald Cook and Dr. Sage Murphy. These investigators anticipated growth in placer gold mining and the development of natural resources in Alaska during a period of national and environmental concern. The subsequent energy "crisis," the major increase in the price of gold on the world market, and dwindling non-renewable resource supplies have resulted in large-scale mineral exploration in Alaska. This exploration, coupled with development of the trans-Alaska oil pipeline, has attracted considerable capital for potential investment and development in Alaska. Expected industrial growth has already started and major new projects are "just around the corner."

Yet, as of 1976, no major research effort has occurred to determine the extent of or potential for water quality impacts from mining operations in Alaska. Recently a series of interdisciplinary research projects have been completed in Canada; however, the application of Canadian data to Alaskan problems is uncertain. Although, state and federal government agencies have been advised and are aware of this potential problem and lack of baseline data they have not sought out new information or rational solutions. Even now, with deadlines of Public Law 92-500 at hand, some regulatory agencies give the impression of attempting to ignore the situation. Interim limitations are proposed and permits are issued with no discernible rationale or basis. Data have not been obtained relative to the Alaskan mining operations and thus are not available for use in seeking solutions compatible with mining and environmental protection. Numbers appear to have been arbitrarily assigned to permits and water quality standards. When permits are issued, self-monitoring requirements are negligible or nonexistent. Nor have regulatory agencies demonstrated the ability or inclination to monitor mining operations or enforce permits and water quality standards.

It was hoped that the project would bring together miners, environmentalists, and regulators in a cooperative effort to identify the problems and seek solutions. The investigators recognized the political sensitivity of the subject matter but proceeded optimistically. Relatively good cooperation, though not total, occurred early in the project. In April 1976, a symposium was held to exchange ideas and determine the state-of-the-art. Although the symposium had good attendance and an exchange of information occurred, the symposium itself was somewhat of a disappointment. With few exceptions, the participants aligned on one side or the other in preconceived fixed positions. Some even chose not to attend and were therefore able to avoid the issues. Little hard data was presented.

Optimistically, some of the miners, environmentalists, and regulators are prepared to resolve their differences. This report, hopefully, will be of benefit to them. It is our experience that miners and environmentalists share a love of the land that is uniquely Alaska. We feel that technology is available for application to this problem for those who care about doing the job right in the "last frontier." Whether or not it will be effectively applied to protect Alaska's water resources is a question which remains unanswered.

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INTRODUCTION

Mining has played a key role in the history of Alaska and, to large degree, can be credited with the opening of the state to settlement, by outsiders. Miners followed the call of gold from California northward through British Columbia, up the southeast Alaska panhandle, across the Chilkoot Pass, and down the Yukon River. The remains of past mining operations can be found throughout the state and it has been estimated that 9,000 acres of dredge tailings alone are still piled along Alaskan streams (Wolff, 1975). Although gold mining continues to be of interest in Alaska, the extraction of other minerals, coal and copper in particular, has been of historical importance and holds considerable potential for the future. Whalers of the 1800's were supplied with coal from the same North Slope fields that later fueled Nome during the gold rush days (Collier, 1905). The deposits of copper near McCarthy, Alaska, and coal from the Bering River fields were the impetus for the financial/industrial syndicate of Morgan and Guggenheim that built the Copper River and Northwestern Railroad.

Mineral resource development in Alaska has been and continues to be of major importance to the state. The potential for mining is high (Ehrenburg, 1976) although production remains low. Today, with approximately 12 per cent of the estimated strippable coal reserves of the United States located within Alaska (Grim and Hill, 1974) and the high priority being given energy resource development, the potential extraction of Alaskan coal is again a subject of national concern. Additionally, much thought has been given recently to mining the copper deposits known to exist within the Kobuk River basin. Although substantial ore remains, cinnabar mining in the Dillingham-Aniak region has declined, perhaps due to the worldwide mercury-poisoning episodes of the early 1970's. Despite extensive deposits of platinum, the only platinum mine in the United States shut down in 1975 after nearly 50 years of production when the depth of the remaining ore exceeded the reach of the operating dredge near Goodnews Bay. Underwater mining of barite is in progress near Petersburg; a tin-tungsten-flourite mine is under development at Lost River; and a proposal is being considered for development of a molybdenum mine near Ketchikan. Considerable mineral exploration has apparently paralleled the implementation of the Alaska Native Claims Settlement Act and development will likely follow. The presence of a haul road north of the Yukon River may be expected to encourage mining activities in that section of the state.

The effect of mining on water quality has long been the subject of debate. This debate continues as does a long-standing lack of relative, quantitative information. Observations about the effects of mining on water quality have been traced back to the European Renaissance. In 1556, Agricola, in his classic treatise on mining, referred to the opinions of environmentalists of his day when he wrote that "when the ores are washed, the water which has been used poisons the brooks and streams, and either destroys fish or drives them away ... it is said, it is clear to all that there is greater detriment from mining than the value of the metals which the mining procures." (quoted by Wolff, 1975)

Information relative to the impact of mining on water quality in Alaska is nearly nonexistent; therefore, it is necessary to utilize information developed outside of Alaska for assessing impacts and alternatives. Given the environmental conditions of Alaska, unique within the United States, the application of technical information from other locales should be applied only with a great deal of circumspection. Water quality is determined, in part, by the natural weathering processes which accompany the movement of water above, on, and under the earth's surface. Mining can affect water quality by changing the rate of natural processes due to alteration of geologic formations during the extraction of minerals. Additional water quality impacts are possible as a result of processing of ores. Wastewaters from processing mills may contain the residue of reagents used during ore concentration as well as the tailings from the processing operation. These water quality impacts can be classified into two broad groupings: physical and chemical/biological.

The physical impact on water quality includes the introduction of those solids which are measurable as settleable matter, suspended solids (technically referred to as nonfilterable residue), and turbidity. Soil erosion contributes to such introduction in several ways related to mining activity. Surface mining operations alter the land's surface and may decrease slope stability so that erosion increases. Erosion can be minimized by using optimum mining techniques such as contour block-out mining on steep terrain, careful disposal of overburden, prompt reclamation (i.e., revegetation binds and stabilizes disturbed soils), and diversion and treatment of surface runoff and subsurface drainage waters. Erosion may also result when waste material from underground mines or processing mills are improperly stacked. Frequently, these waste materials are transported as slurries. Direct discharge of such slurries to surface waters generally results in the introduction of high concentrations of solids. Settling or tailings impoundments may reduce this impact; however, further chemical treatment or filtration may be necessary in some cases.

The primary chemical/biological impact on water quality results from the introduction of dissolved minerals into water. An example is the oxidation of iron pyrites (FeS_2) and subsequent acid mine drainage characterized by low pH levels and high concentrations of dissolved minerals. Another example is drainage water rich in minerals entrained during passage through mined areas or refuse and tailings stacks. An example which has recently received some attention is the potential generation of arsenic-rich drainage resulting from erosion and leaching of placer gold tailings (Hawkins, 1976). Low pH levels may or may not accompany such drainage water. An additional chemical impact on water quality results from the addition of reagents during milling processes. These reagents are then incorporated with the waste slurries. Settling or tailings impoundments have been the primary method of treatment for these wastes. Precipitation aided by lime or other chemicals, coagulation and flocculation, and filtration have also been employed. Treatment of limited flow wastes by demineralization processes such as ion exchange is occasionally practiced.

The principal objective of this project was to seek out basic information relative to the impact of mining on water quality in Alaska through a review of existing regulations, baseline data (of which little was found), and state-of-the-art technology. The latter was assessed, in part, by several on-site visits.

Although the subject of this report is of national concern, most of the material studied was viewed with an Alaskan perspective. Emphasis was placed on the physical impacts confronting miners, regulatory agencies, environmentalists, and others concerned with the placer gold mining industry. In order to gain knowledge of these impacts, the investigators visited several placer gold mines (both dredges and conventional sluicing), Alaska's only operating commercial coal mine, Alaska's single placer platinum mine (which ceased operation in November 1975), and the site of the planned copper mine at Bornite.

This report includes a discussion of proposed federal effluent limitations and state water quality standards so that they may be kept in mind while considering other aspects of the problem. The two major categories of water quality impacts from mining, the physical introduction of solids and the introduction of dissolved minerals with concomitant changes in water chemistry, are discussed in terms of the natural occurrence of the descriptive water quality parameters, their resultant biological effects (with primary emphasis on fishery resources), and the efficiency and availability of control technology. Final emphasis is placed on the particular situation in Alaska where significant coal and placer gold mining is now in progress and is of concern. Conclusions and recommendations are presented as well as a selection of additional applicable reference citations.

EFFLUENT LIMITATIONS AND WATER QUALITY STANDARDS

Federal Effluent Limitations

The Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) provides for the establishment of effluent limitations for specific types of industrial operations, including mining, and water quality standards for natural surface waters into which effluents are discharged. Applicable sections of the law are as follows:

1. Section 301 - places effluent limitations on industrial discharges in accordance with guidelines developed as required by Sections 304 and 306. The guidelines are applicable to specific industries, listed in Section 306, and must be specified in permits issued under the National Pollutant Discharge Elimination System (NPDES) of Section 402
2. Section 302 - requires that effluent limitations (Section 301) be consistent with the attainment and maintenance of water quality (Section 303)
3. Section 303 - requires the setting of federally approved water quality standards, but encourages the setting of such standards by the states rather than the federal government.

Effluent limitations apply to the quality of the wastewater as it is discharged from a point source (ditch, outfall pipe, weir, spillway, etc.) to a surface water such as a stream or lake. The U.S. Environmental Protection Agency (USEPA) published interim effluent limitations and guidelines for the ore mining and dressing industry in November 1975 (USEPA, 1975b). These limitations apply to all types of mining except coal. Regulations pertinent to the coal mining industry are covered by separate limitations which are discussed in the chapter on "Surface Coal Mining in Alaska" later in this report. The effluent limitations and guidelines also specify available control technology. Control technology is to be implemented in three phases as follows:

1. Best Practicable Control Technology Currently Available (BPCTCA) no later than 1 July 1977
2. Best Available Technology Economically Achievable (BATEA) no later than 1 July 1973
3. New source limitations which apply after publication of specific standards for each industry.

In many cases there is little difference between the three. Table 1 is a composite summary of the limitations and parameters which will apply for the first phase and a listing of the various control technologies considered for specified ores as BPCTCA. Table 1 requires further explanation. For example, all of the ores have a maximum limitation on total suspended solids (TSS) of 30 mg/l and a pH range requirement of 6.0 to 9.0 units. Specifically, however, the iron ore subcategory has an additional maximum limitation on iron (Fe) of 2.0 mg/l for both mines and mills, whereas the maximum limitation of Fe for a bauxite mine is 1.0 mg/l and additional maximum limitations on aluminum (Al) of 1.2 mg/l and zinc (Zn) of 0.2 mg/l exist. For iron ore mines, BPCTCA is considered to be settling ponds with coagulation-flocculation and lime-neutralization as necessary to meet effluent limitations. For some types of iron ore mills, as opposed to mines, BPCTCA is considered to be settling ponds with coagulation-flocculation systems while at others zero discharge is specified. For bauxite mines, lime precipitation and settling with pH adjustment is listed. Table 1 excludes those mines or mine and mill complexes beneficiating gold, silver, tin, or platinum ores by gravity separation such as placer gold mines. BPCTCA, new source BATEA, and effluent limitations for placer gold mines were

TABLE 1: COMPOSITE SUMMARY OF BPCTCA* INTERIM EFFLUENT LIMITATIONS AND CONTROL TECHNOLOGY

Parameter	Daily Maximum (mg/l)	Maximum Thirty-Day Average (mg/l)
Aluminum	1.2	0.6
Ammonia	60.0	30.0
Arsenic	1.0	0.5
Cadmium	0.1	0.05
Chemical Oxygen Demand	200.0 & 100.0 **	100.0 & 50.0 **
Copper	0.1	0.05
Cyanide	0.1 & 0.02 **	0.05 & 0.01 **
Iron	2.0, 1.0, & 0.2 **	1.0, 0.5, & 0.1 **
Lead	0.4	0.2
Mercury	0.002	0.001
Nickel	0.2	0.1
pH	Within range of 6.0 to 9.0 units	
Radium-226	10.0 pCu/l	3.0 pCu/l
Total Suspended Solids	30.0	20.0
Uranium	4.0	2.0
Zinc	1.0, 0.4, & 0.2 **	0.5, 0.2, & 0.1 **

*BPCTCA: Lime precipitation and settling, pH adjustment, tailings impoundments, reuse of water, alkaline chlorination, zero discharge, filtration through sand and gravel tailings, secondary settling, ammonia stripping, wastewater - stream segregation, ion exchange, barium chloride coprecipitation, and coagulation-flocculation. (USEPA, 1975b)

** Value Dependent on Specific Ore, from USEPA, 1975b.

identical. Maximum TSS was specified to be 50 mg/l with the 30-day average not to exceed 30 mg/l. Additionally, the pH range requirement of 6 to 9 units seen for other ores and types of mines was also specified for placer gold mines. BPCTCA was considered to be settling or tailings ponds and, where necessary, coagulation-flocculation and pH adjustment to meet effluent limitations. The alternative of sand and gravel tailings filtration was also listed. These regulations have now been set aside to be reissued in November of 1976 after further development.

The general procedure followed by the EPA during the development of effluent limitations guidelines and standards of performance has been to visit a selection of operations for the industry involved so that representative conditions of wastewater characteristics and existing control technology may be determined. In the case of placer gold mining, no mines in Alaska were investigated and no special consideration was given to conditions in Alaska (Lamoreaux, 1976).

In the State of Alaska, the EPA administers the NPDES permit program because the state declined to do so. Prior to issuance of interim effluent limitations, the EPA prepared, but did not issue, draft permits for approximately half of the placer gold mines in Alaska which gave the industry a choice of alternative effluent limitations:

1. Settling pond(s) sufficient in capacity to contain the maximum volume of process water used during any one day's operation.
2. Maximum effluent limitation of 1 ml/l of settleable solids (those solids which will settle to the bottom of a one-liter cone in an hour).

After setting aside the interim effluent limitations in May of 1976, the EPA issued the first batch of NPDES permits with few substantive changes from the original draft. The choice of alternative effluent limitations remains the same as in the draft except that the level of settleable solids was decreased from 1.0 to 0.2 ml/l. Additionally, the issued permits specify a mixing zone in the receiving water of 500 feet downstream from the point of discharge and reiterate that the state water quality standard for turbidity, less than 25 JTU increase above natural or upstream conditions, must be complied with (Dickason, 1976 and USEPA, 1976). If the first alternative of settling ponds is chosen, no self-monitoring is required. If the second alternative of a limitation on settleable solids is preferred, samples need only be taken by the miner once per month and reported annually. There is no requirement to measure turbidity in the receiving water. The permit compliance schedule requires submittal of plans and compliance with effluent limitations by 1 August 1976 and annual submittal of operating plans thereafter. The basis for the standards contained in issued permits is unknown. Since reporting is only required at the conclusion of the mining season, there is no mechanism for correction of noncompliance during the same year in which it occurs. Such correction, in order to comply with permit conditions, would require additional field monitoring by the EPA.

ALASKA WATER QUALITY STANDARDS

The Alaska Department of Environmental Conservation (DEC) issued water quality standards in October 1973 as Alaska Administrative Code (AAC) Title 18, Chapter 70. These regulations prescribe standards that must be met in receiving waters (surface streams, lakes, etc.) outside of a defined mixing zone around a point of discharge. Although

At the present time, neither the federal effluent limitations and the NPDES permit program nor the state permit program (which may now consist of acceptance of the NPDES permit) and water quality standards have been well defined as they apply to mining in Alaska. Further changes are probable. Final federal effluent limitations are still under development. Public Law 92-500 also provides for the review of water quality standards and possible revision every three years. Such a review is now in progress. The process will include public input and public hearings; however, the DEC has not yet indicated how the details of this procedure will be carried out.

ALASKA DEPARTMENT OF FISH AND GAME REQUIREMENTS

In addition to the foregoing EPA and DEC considerations, the Alaska Department of Fish and Game (ADF&G) has discretionary authority under Alaska Statute 16.05.870 with regard to operations which might impact anadromous fish waters (anadromous fish include salmon and other species which migrate from the sea to fresh waters for breeding purposes). The ADF&G issued "Title 16" (Alaska Statute 16.05.870) permits during the 1975 mining season and will probably continue to do so on an annual basis. Permits usually require that: 1. the operation will comply with applicable laws administered by the EPA and DEC; 2. fish passage shall not be blocked; 3. spoil material and tailings shall not be placed in the water or in an unstable configuration likely to erode into the water; and 4. explosives will not be used in or near the water without separate approval from the ADF&G.

PHYSICAL PARAMETERS

INTRODUCTION

Settleable matter and TSS is defined by the EPA (National Environmental Research Center, 1974) as those solids which will settle to the bottom of a one-liter cone in an hour. Settleable matter is undesirable in fish-sensitive streams since it may result in sedimentation of streambed gravels (filling up of the interstices with finer material such as silt or fine sand) unless flow is sufficient to flush it downstream. Since data concerning this parameter and its effects are unavailable, it will not be discussed further. However, if the draft permits mentioned in Chapter 2 are issued, this parameter may become a federal effluent limitation. TSS is defined as a direct measure of the solid material suspended in water and is determined by filtering out the solids and weighing them. In this report, the term TSS encompasses the parameters of suspended sediments and nonfilterable residue which are sometimes used interchangeably. *Standard Methods* (APHA, 1971) defines turbidity as an "optical property of a (water) sample which causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. As such, it is an indirect measure of those solids suspended in the water which are responsible for the scattering and absorption.

Particle size is an important consideration in the measurement of both turbidity and TSS. Particle size and nomenclature are shown in Table 2. Decreasing particle size results in an increased specific surface area (area of particle surface per unit volume of suspension) which will result in greater light scattering (Fair, Geyer, and Okun, 1968), thus increasing the turbidity. Finely divided colloidal suspensions

Table 2: Particle Sizes*

Particle Diameter		
0.0000002 mm (0.2 mμ)		
	Atoms	
0.0000003 mm (0.3 mμ)		Solutions
0.000001 mm (1 mμ)	Large Molecules	
		Colloidal Suspensions
0.0001 mm (100 mμ)		Lower Limit Non-Filterable residue
0.001 mm (1 μ)		
	Silt	
0.05 mm (50 μ)		
	Fine Sand	Fines
2.0 mm		
	Coarse Sand	
4.75 mm		
	Fine Gravel	
10.0 mm		Gravel
76.0 mm		
		Rubble
300.0 mm		
		Boulders

mm = millimeters (10^{-3} meters)

μ = microns (10^{-6} meters)

μ = millimicrons (10^{-9} meters)

*Fair, Geyer, and Okun, 1968 and Plotts, 1972.

have a high specific surface area and cause a high degree of light scattering, resulting in what is known as the "Tyndall effect" where light is observed at an angle of 90° to the incident beam of light. The "Tyndall effect" is utilized as the basis for measurement of turbidity in some turbidimeters (nephelometers) (Sawyer and McCarty, 1967).

The arbitrary standard of 1 mg/l of a specified particle size solution of silica (SiO_2) was originally determined to be equal to one unit of turbidity (Sawyer and McCarty, 1967). Current methods specify the use of a formazin polymer standard, measurement by a nephelometer, and the use of nephelometer turbidity units (NTU), which may be comparable to previous measurements of turbidity such as the JTU. Units listed in this report will be as taken from the literature quoted. The older literature generally uses the units of ppm or mg/l for turbidity whereas the newer literature generally uses the units of JTU for turbidity. Presumably, NTU will be used by all the future. The complexity involved with this nomenclature is emphasized and researchers should use caution in the interpretation of turbidity data.

If the solids present are primarily of colloidal size, they will pass through the filter used in a TSS determination; however, they will contribute significantly to a turbidity determination. In many relatively clear streams, the turbidity value (JTU) numerically exceeds the TSS value (mg/l); however for waters carrying significant solids loads, the numerical value of TSS is observed to exceed the turbidity value. The larger particles which increase the TSS value do not cause as much turbidity as do smaller particles and although the relationship is direct, there is no apparent reliable correlation.

more stringent requirements would apply in the case of a receiving water utilized as a drinking water supply (water-use classifications "A" and "B") the standards which generally are of concern with regard to mining are those intended to protect waters used for the propagation of fish and other aquatic life (water use classification "D"). Water quality criteria for Alaska are listed in Table 3. Of these standards, the turbidity requirement (less than 25 JTU increase above natural or upstream conditions) has received the greatest attention; however, all other parameters of the water quality standards would also apply.

Although Alaska Statute 46.04.100 required that industrial operations procure a waste disposal permit prior to discharging, the DEC did not insist upon such permits for mining wastes. In at least one case where the miner attempted to follow legal requirements to obtain a permit, the DEC did not process the application. The State Legislature recently passed Sponsor Substitute for Senate Bill No. 267, amended by the House (effective date added, re-engrossed), and Governor Hammond signed it into law. This legislation amends applicable statutes to allow the DEC to waive previous requirements and accept NPDES permits as satisfying Alaska Statute 46.03.100 (Alaska State Legislature, 1976). This will have the beneficial effect of reducing paperwork requirements.

State certification of NPDES permits has been contingent upon incorporation of the 500-foot downstream mixing zone with the less than 25 JTU increase in turbidity into effluent limitations discussed previously (Scribner, 1976). The basis upon which these requirements have been formulated is unknown.

TABLE 3: Water Quality Criteria for Waters of the State of Alaska[1]

	(1)	(2)	(3)	(4)	(5)	(6)
Water Quality Parameters Water Uses	Organisms of the Coliform Group (see note 1) *	Dissolved Oxygen mg/l or % Saturation	pH	Turbidity, measured in Jackson Turbidity Units (JTU)	Temperature, as measured in degrees Fahrenheit (°F)	Dissolved inorganic substances
A. Water supply, drinking, culinary and food processing without the need for treatment other than simple disinfection and simple removal of naturally present impurities.	Mean of 5 or more samples in any month less than 50 per 100 ml.	Greater than 75% saturation or 5 mg/l.	Between 6.5 and 8.5 (see note 3)	Less than 5 JTU	Below 60°F.	Total dissolved solids from all sources may not exceed 500 mg/l.
B. Water supply, drinking, culinary and food processing with the need for treatment equal to coagulation, sedimentation, filtration, disinfection, and any other treatment processes necessary to remove naturally present impurities.	Mean of 5 or more samples in any month less than 1000 per 100 ml, and not more than 20% of samples during one month may exceed 1000 per 100 ml.	Greater than 60% saturation or 5 mg/l.	Between 6.5 and 8.5 (see note 3)	Less than 5 JTU above natural conditions.	Below 60°F.	Numerical value is inapplicable.
C. Bathing, swimming, recreation.	Same as B-1	Greater than 5 mg/l.	Between 6.5 and 8.5 (see note 3)	Below 25 JTU except when natural conditions exceed this figure effluents may not increase the turbidity.	Numerical value is inapplicable.	Numerical value is inapplicable.
D. Growth and propagation of fish and other aquatic life, including waterfowl and furbearers.	Same as B-1 to protect associated recreational values.	Greater than 6 mg/l in salt water and greater than 7 mg/l in fresh water.	Between 7.5 and 8.5 for salt water. Between 6.5 and 8.5 for fresh water. Max. pH change per hour is 0.5. (see note 3)	Less than 25 JTU when attributable to solids which result from other than natural origin.	May not exceed natural temp. by more than 2°F for salt water. May not exceed natural temp. by more than 4°F for fresh water. No change shall be permitted for temp. over 60°F. Maximum rate of change permitted is 0.5°F per hour.	Within ranges to avoid chronic toxicity or significant ecological change.
E. Shellfish growth and propagation including natural and commercial growing areas.	Not to exceed limits specified in National Shellfish Sanitation Program Manual of Operations, Part 1, USPHS. (see note 2)	Greater than 6 mg/l in the larval stage. Great than 5 mg/l in the adult stage.	Between 7.5 and 8.5 (see note 3)	Less than 25 JTU of mineral origin.	Less than 68°F.	Within ranges to avoid chronic toxicity or significant ecological change.
F. Agricultural water supply, including irrigation, stock watering, and truck farming.	Mean of 5 or more samples less than 1,000 per 100 ml with 20% of samples not to exceed 2,400 per 100 ml for livestock watering, for irrigation of crops for human consumption, and for general farm use.	Greater than 3 mg/l.	Between 6.5 and 8.5 (see note 3)	Numerical values are inapplicable.	Between 60°F and 70°F for optimum growth to prevent physiological shock to plants.	Conductivity less than 1,500 micromhos at 25°C. Sodium adsorption ratio less than 2.5, sodium percentage less than 60%, residual carbonate less than 1.25 me/l, and boron less than 0.3 mg/l.
G. Industrial water supply (other than food processing).	Same as B-1 whenever worker contact is present.	Greater than 5 mg/l for surface water.	Between 6.5 and 8.5 (see note 3)	No imposed turbidity that may interfere with established levels of water supply treatment.	Less than 70°F.	No amounts above natural conditions which may cause undue corrosion, scaling, or process problems.

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[1] Extracted from: Alaska Administrative Code

*See Notes on pages following Table 2.

TABLE 3: Water Quality Criteria for Waters of the State of Alaska, continued

(7) Residues, including Oils, Floating Solids Sludge Deposits and Other Wastes	(8) Sediment	(9) Toxic or Other Deleterious Substances, Pesticides, and Related Organic and Inorganic Materials	(10) Color, as measured in color units	(11) Radioactivity	(12) Aesthetic considerations	(13) Water Quality Parameters / Water Uses
Same as B-7	Below normally detectable amounts.	Carbon chloroform extracts less than 0.1 mg/l and other chemical constituents may not exceed USPHS Drinking Water Standards. (see note 4)	True color less than 15 color units.	Conform with USPHS Drinking Water Standards. (see note 4)	May not be impaired by the presence of materials or their effects which are offensive to the sight, smell, taste, or touch.	Water supply, drinking, culinary and food processing without the need for treatment other than simple disinfection and simple removal of naturally present impurities. A.
Residues may not make the receiving water unfit or unsafe for the uses of this classification; nor cause a film or sheen upon, or discoloration of, the surface of the water or adjoining shoreline; nor cause a sludge or emulsion to be deposited beneath or upon the surface of the water, within the water column, on the bottom, or upon adjoining shorelines.	No imposed loads that will interfere with established levels of water supply treatment.	Chemical constituents shall conform to USPHS Drinking Water Standards. (see note 4)	Same as A-10	Conform with USPHS Drinking Water Standards. (see note 4)	Same as A-12	Water supply, drinking, culinary, and food processing with the need for treatment equal to coagulation, sedimentation, filtration, disinfection, and any other treatment processes necessary to remove naturally present impurities. B.
Same as B-7	No visible concentrations of sediment.	Below concentrations found to be of public health significance.	Same as A-10	Conform with USPHS Drinking Water Standards. (see note 4)	Same as A-12	Bathing, swimming, recreation. C.
Same as B-7	No deposition which adversely affects fish and other aquatic life reproduction and habtat.	None affecting public health or the ecological balance, and less than an amount that causes tainting of flesh.	True color less than 50 color units.	Conform to USPHS Drinking Water Standards except where concentration factors of aquatic flora and fauna exceed USPHS reduction factors; then maximum permissible concentrations of radionuclides shall be reduced below acute or chronic problem levels. (see note 4)	Same as A-12	Growth and propagation of fish and other aquatic life, including waterfowl and furbearers. D.
No visible evidence of residues. Less than acute or chronic problem levels as revealed by bioassay or other appropriate methods.	No deposition which adversely affects growth and propagation of shellfish.	Less than acute or chronic problem levels and below concentrations affecting the ecological balance. Less than an amount that causes tainting of flesh. Pesticides may not exceed 0.001 of the median lethal toxicity concentration for the most sensitive organism on 96-hour exposure.	True color less than 50 color units.	Concentrations shall be less than those resulting in radionuclide concentrations in shellfish meats which exceed the recommendations of the National Shellfish Sanitation Program, Manual of Operations, Part 1, USPHS. (see note 2)	Same as A-12	Shellfish growth and propagation including natural and commercial growing areas. E.
None in sufficient quantities to cause soil plugging and reduced yield of crops.	For sprinkler irrigation, water free of particles of 0.074 mm or coarser. For irrigation or water spreading, not to exceed 200 mg/l for an extended period of time.	Less than that shown to be deleterious to livestock or plants or their subsequent consumption by humans.	Inapplicable.	Conform with USPHS Drinking Water Standards.	Same as A-12	Agricultural water supply, including irrigation, stock watering, and truck farming. F.
No visible evidence of residues.	No imposed loads that will interfere with established levels of treatment.	Chemical constituents may not exceed concentrations found to be of public health significance.	True color less than 50 color units.	Conform with USPHS Drinking Water Standards. (see note 4)	Same as A-12	Industrial water supply (other than food processing). G.

Notes to Table 3: Water Quality Criteria for Waters of the State of Alaska

1. Organisms of the coliform group shall be determined by Most Probable Number or equivalent membrane filter technique.

2. Wherever cited in these standards, the National Shellfish Sanitation Program, Manual of Operations, Part 1, means Sanitation of Shellfish Growing Areas, 1965 revision, U.S. Department of Health, Education and Welfare, Public Health Service Publication No. 33, Part 1, obtainable from the Superintendent of Documents, U. S. Government Printing Office, Washington, 20402 (Price 45 cents), or in any regional office of the Department of Environmental Conservation, and which is on file in the office of the lieutenant governor.

3. Induced variation of pH conditions naturally outside this range may not exceed 0.5 pH unit and the pH change shall be only in the direction of this range. pH conditions naturally within this range shall be maintained within 0.5 pH unit of the natural pH.

4. Wherever cited in these standards, USPHS Drinking Water Standards mean the Public Health Service Drinking Water Standards, 1962 revision, U.S. Department of Health, Education and Welfare, Public Health Service Publication No. 956, obtainable from the Superintendent of Documents, U.S. Government Printing Office, Washington D.C. 20402 (Price 30 cents) or from any regional office of the Department of Environmental Conservation, and which is on file in the office of the lieutenant governor.

5. Wherever cited in these standards, National Bureau of Standards Handbook 69 means the handbook entitled "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure", U.S. Department of Commerce, National Bureau of Standards Handbook 69, June 5, 1959, obtainable from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, or in any regional office of the Department of Environmental Conservation, and which is on file in the office of the lieutenant governor.

6. Wherever cited in these standards, Radiation Protection Guides means the guidelines recommended by the former Federal Radiation Council and published in the May 18, 1960 Federal Register, and published in the September 26, 1961 Federal Register, obtainable from any Regional Office of the Department of Environmental Conservation and which are on file in the office of the lieutenant governor.

NATURAL OCCURRENCE

The natural occurrence of TSS and turbidity in Alaskan streams is a function of the various hydrological and geological factors. There are distinct seasonal variations in most Alaskan streams. Generally, low values are seen for both TSS and turbidity under ice cover during the long, cold period after freeze-up and prior to break-up. High values accompany the major flows and erosion at break-up time due to snow and ice-melt and precipitation. Lower values for nonglacially fed streams (approaching winter levels) occur during the summer except after precipitation events. After precipitation, there are temporary peaks for flow, TSS, and turbidity. Surface runoff during the warm period after break-up and prior to freeze-up results in erosion and increased flow, TSS, and turbidity. These values are elevated relative to those normally seen under ice cover or during warm, dry periods when the total flow may be from groundwater.

Figure 1 is a plot of TSS and turbidity measurements for Goldstream Creek at Fox during 1970 and 1971. Although this measurement station is in an old mining area, it is likely that susceptible sediments were washed downstream from the disturbed area and most of what remains is the coarser tailings. Figure 1 illustrates seasonal variation in water quality fairly well. Turbidity readings were about 5 JTU during cold weather periods and warm weather periods without rain. A peak of 35 JTU was measured during break-up time and other high measurements were made during or after periods of precipitation. There is an anomaly in the TSS measurements for the month of March; however, the other TSS measurements are consistent with the turbidity measurements and the expected seasonal variation.

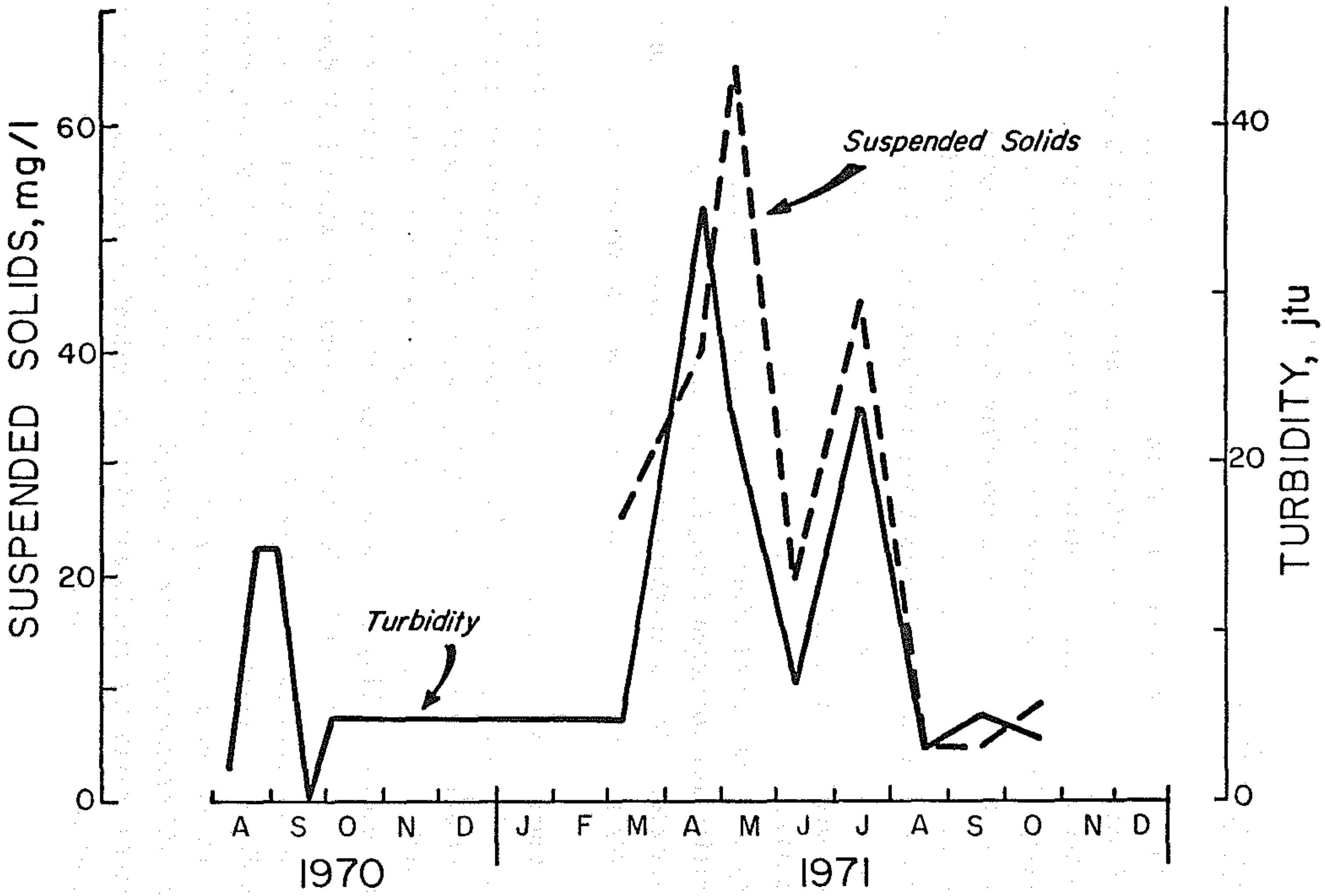

FIGURE 1: TSS and turbidity for Goldstream Creek at Fox during 1970 and 1971.

Data concerning the natural occurrence of TSS and turbidity in Alaska are sparse, and, when available, may only pertain to TSS or turbidity, but not both. Generally, the sample points are widely scattered and the sampling frequency is low. For example, the U.S. Geological Survey routinely samples at a network of stations in Alaska and publishes the results annually. In Water Year 1974 (October 1973 - September 1974) only two stations existed on Alaska's largest and longest river, the Yukon. The tributaries are, however, also measured. The data for the two Yukon River stations are shown in Table 4. Only two measurements, both taken during warm weather, were published for the station at Eagle. Although two cold-weather and four warm-weather measurements were published for the station at Ruby, turbidity was not measured. Additional data presented in Table 4 include measurements on the Tanana River at Nenana, a major tributary of the Yukon River. As with the Yukon River data, the general pattern of low turbidity and TSS values during the low-flow, cold weather period and high values during the high-flow, warm weather period is evident. Overlapping hydrographs from sequential storms, continued snowmelt through the warm-weather period, and glacial melt waters result in the well-known muddy appearance of these two rivers. These rivers run at high stages through the warm weather period and have very large drainage areas. The muddy appearance persists until late in the warm-weather period before freeze-up when melting stops and precipitation is light, consisting of snow which remains frozen.

One major exception to this general rule of seasonal variation in water quality is glacier-fed streams. Research indicates that the large amounts of debris and sediment carried by glaciers result in relatively high TSS and turbidity levels in glacier-fed steams throughout the warm period of glacial melt (Guymon, 1974). TSS concentrations

TABLE 4: YUKON AND TANANA RIVERS WATER QUALITY*

Date	(JTU) Turbidity	(mg/l) Suspended Solids	(CFS) Flow	Suspended Solids Diameter, % Finer Than (mm)								
				.004	.008.	.016	.031	.062	.125	.250	.500	1.00
A. Yukon River at Eagle												
9 Jul. 74	160	305	136,000	40	56	70	79	85	90	97	99	100
16 Aug. 74	120	346	170,000	31	41	52	61	70	85	99	100	-
B. Yukon River at Ruby												
18 Dec. 73	-	3	47,000	-	-	-	-	-	-	-	-	-
18 Mar. 74	-	3	26,900	-	-	-	-	-	-	-	-	-
28 May 74	-	270	412,000	-	-	-	-	-	-	-	-	-
11 Jul. 74	-	400	251,000	-	-	-	-	-	-	-	-	-
20 Aug. 74	-	360	296,000	-	-	-	-	-	-	-	-	-
22 Sep. 74	-	190	178,000	-	-	-	-	-	-	-	-	-
C. Tanana River at Nenana												
29 Nov. 73	1	12	7,800	-	-	-	-	-	-	-	-	-
25 Jan. 74	2	35	4,740	-	-	-	-	-	-	-	-	-
13 Mar. 74	2	12	4,030	-	-	-	-	-	-	-	-	-
11 Apr. 74	3	28	5,330	-	-	-	-	-	-	-	-	-
23 May 74	140	1310	34,300	7	10	17	27	39	60	93	99	100
19 Jun 74	150	924	27,200	14	20	26	31	40	71	98	100	Q
28 Aug. 74	170	-	33,000	-	-	-	-	-	-	-	-	-

*U.S. Geological Survey. (1975)

in glacier-fed streams may run several hundred mg/l during warm weather with peaks an order of magnitude higher during precipitation events (Guymon, 1974; and Ostrem, Ziegler, Ekman, 1973). The characteristic grey-green cast of glacier-fed waters is caused by the suspension of finely ground sediments resulting from the glacial action. The material causing this discoloration and turbidity is referred to as "glacial flour."

BIOLOGICAL EFFECTS

The effects of TSS and turbidity on the aquatic life of streams has long been the subject of controversy and, although it does not appear that any major multidisciplinary research projects were ever undertaken in this area, a significant amount of literature has accrued over the years on this topic. An excellent summary of the earlier literature can be found in Cordone and Kelley (1961). They subdivided the subject into categories related to fishery resources. A summary of those categories is as follows:

1. Direct effects on fishes
2. Effects on reproduction
3. Effects on fish food supply
4. Effects via physical and chemical changes
5. Effects on fish populations

The European Inland Fisheries Advisory Committee (EIFAC)(1965) has also compiled a very good literature survey with an eye towards establishment of appropriate water quality standards.

Direct Effects

One of the first attempts to measure direct effects of TSS on fishes in the laboratory was conducted by Griffin. His work appears as Appendix B to the study by Ward (1938) which was commissioned by the Oregon State Department of Geology and Mineral Industries (OSDGMI). Ward used Griffin's experiments to support his findings that, as OSDGMI Director Nixon summarized, "the placing of muddy water from placer operations in the Rogue River is not inimical (harmful) to fish and fish life." Smith (1940) notes that Ward's interpretation of Griffin's work was highly questionable. The apparently higher initial mortality of fish in clear water over that of fish in water having 300 to 750 ppm TSS most of the time and 2,300 to 6,500 ppm TSS after stirring was attributed by Griffin to problems of acclimatization. After the acclimatization problems of the first few days, the mortality of the trout and salmon fingerlings used in the test was higher in the water containing elevated TSS concentrations. Additionally, the fish in the water containing the high TSS concentrations were noticeably retarded in growth in comparison to the fish held in the clear water.

Wallen (1950) conducted extensive biological laboratory tests using montmorillonite clay to produce turbidity. He exposed 380 fishes of 16 species to turbidities over a wide range and as high as 270,000 ppm. The principle test species was the golden shiner (*Notemigonus crysoleucas)* and exposure times varied from 15 minutes to 39 days. The lowest lethal turbidity found occurred at 16,500 ppm for an exposure time greater than a week. Although examination of gills and opercular cavaties after mortality revealed clogging by the clay, there were no signs of physical damage to the gill filaments or other internal organs. Clogging occurred rapidly as fish movement slowed but could be shed quickly if the fish were transplanted to clear water.

In contract with Wallen's findings, there are "many statements in the literature that suspended solids are directly harmful to fishes by interference with normal gill functions." (Cordone and Kelly, 1961) Ellis (1944) refers to the possibility of increasing damage to gill structures with increasing size, hardness, and angularity of particles. Herbert and Merkens (1961) observed thickening of gill epithelium followed by death in rainbow trout exposed to several hundred ppm of TSS for extended periods. Other researchers have made similar observations. More recently, Koski (1972) writes "Heavy concentrations of sediment can kill fish directly by damage to their gills. The lethal concentration is dependent on the characteristics of the sediment and the species and condition of the fish." Barnhard (1975) states "sediment in suspension can be heavy enough to injure fish directly by damaging their gills. Lethal concentrations vary considerably depending on the fish's age, general health, and the type of sediment particles in suspension. The duration of exposure to suspended sediments will also determine the amount of injury to the fish." Unfortunately, neither Koski nor Barnhart define "heavy" or provide supporting data. Some quantitative data was developed by Campbell (1954) when he found 57% mortality of rainbow trout fingerlings in live-boxes one and one-half miles downstream from a placer gold dredge operation in the Powder River, Oregon, during a 20-day experiment. During the study, turbidities ranged from 1,000 to 2,500 ppm in the Powder River as opposed to no detectable turbidity in a nearby tributary used as a control. Mortality in the live-boxes in the control stream was reported to be 9.5%. EIFAC (1965) concluded that "the available evidence suggests that the death rate among fish living in waters which over long periods contain suspended solids in excess of 200 ppm will often be substantially greater than it would have been in clean water." There is some evidence that the nature of the solids is important when considering biological effects and that synergistic effects increase fish mortality when other toxicants are present. According to Huet (1965), "Water turbidity can be harmful to fish...directly if the suspended particles harm or block the gills. It must be pointed out, however, that fish easily tolerate high turbidity for long periods except when the turbidity is accompanied by acids, alkalies, or substances that injure the gills and prevent their functioning normally." Further evidence of the harmful nature of turbidity is implied by the numerous references to fish avoiding turbid waters throughout the literature as, for example, in Sumner and Smith (1940).

The literature indicates that TSS and turbidity cause direct adverse effects on fishes. The effect would be a function of the species of fish, the character and concentration of the solids, the presence of other toxicants, other water quality parameters, natural conditions for the species of fish in question, acclimatization, health and life cycle stage of the fish, and time of exposure. Likely effects are similar to those produced by other toxicants ranging from immediate mortality at high, acute concentrations to more subtle, long-term effects at lower chronic concentrations including gill epethelium changes, susceptibility to such diseases as fin-rot, and delayed mortality. If no other toxicants are present, many species of fish can withstand extremely high suspended solids concentrations for short periods of time and will pass through highly turbid water. However, fish also exhibit avoidance reactions to turbid waters and, as with other toxicants, the introduction of solids may alter species distribution by eliminating sensitive species.

Effects on Reproduction

Extensive research concerning the effects of sedimentation of streambed gravels on fish reproduction has been accomplished. The literature also relates erosion and other sediment transport processes to a streambed sedimentation. Little of this work has attempted to correlate a level of TSS or turbidity in the water column with sedimentation or streambed gravels and resultant effects on fish reproduction. Such a relationship would be most useful from a regulatory standpoint; however, it would likely be complex and dependent on sediment transport variables.

One direct effect of TSS and turbidity on reproduction would be the blocking of migration routes. Such blockage could prevent fish from reaching spawning grounds to commence reproduction (Sumner and Smith, 1940; Cordone and Kelly, 1961; and Huet, 1965).

Salmon and trout require permeable streambed gravels for spawning. The female selects a suitable location, scoops out a depression in the gravel - referred to as a redd - and deposits her eggs into it. Heavy sedimentation may prevent redd excavation and thereby inhibit spawning (Barnhart, 1975). Fertilized eggs or embryo are covered with gravel to incubate. Embryo survival (embryo development and the eventual emergence of fry) is dependent on all environmental factors; however permeability of the streambed gravels appears to be the key element (Vasil'en, 1964). The apparent streambed water velocity and dissolved oxygen (DO) concentration must be sufficient to maintain adequate intergranular DO levels for embryo respiration and to remove carbon dioxide and waste products. Fine particles may clog streambed gravels via sedimentation or filtration, thereby reducing apparent velocity and DO concentrations and resulting in smothering of embryo (Cordone and Kelly, 1961; Phillips and Campbell, 1962; EIFAC, 1965; Huet, 1965; Koski, 1972; Newport and Moyer, 1974; and Barnhart, 1975).

Some researchers have noted that the chorion or outer membrane appears to attract fine silt particles that may eventually suffocate the embryo when a complete coating is formed (EIFAC, 1975, and Koski, 1972). Additional mortality may result from direct physical pressure of shifting gravels during high water (Barnhart, 1975).

In the event of embryo survival, fry emergence may be prevented by the physical barrier of a clogged streambed. Mortality of trapped fry then occurs from starvation (Koski, 1972 and Barnhart, 1975).

Figure 2 illustrates the relationship between particle and distribution and permeability. The coeffecient of permeability, which is indirect proportion to permeability, decreases rapidly as the percentage of streambed material able to pass through a 0.833 mm sieve increases. Particles less than 0.833 mm in diameter would be in the range of fine sand or smaller. Koski (1966) and Hall and Lantz (1969) demonstrate a significant relationship between an increased percentage of streambed material able to pass through a 0.833 mm sieve and decreased embryo durvival. Koski found that a 1% increase in such material decreased survival by 4.5%. Hall and Lantz developed similar information which is graphically presented in Figure 3.

In his Powder River study, Campbell (1954) exposed embryo in hatching baskets to turbidities ranging from 1,000 to 2,500 ppm. Observed mortality was 100% as compared to only 6% for the embryo in a nearby stream with no detectable turbidity. The literature indicates that TSS and turbidity may prevent spawning, that sedimentation of streambed gravels reduces permeability and embryo survival, and that sedimentation of streambed gravels may prevent fry emergence. Data correlating specific levels of TSS or turbidity with harmful sedimentation was not found. Logically, it would be a function of

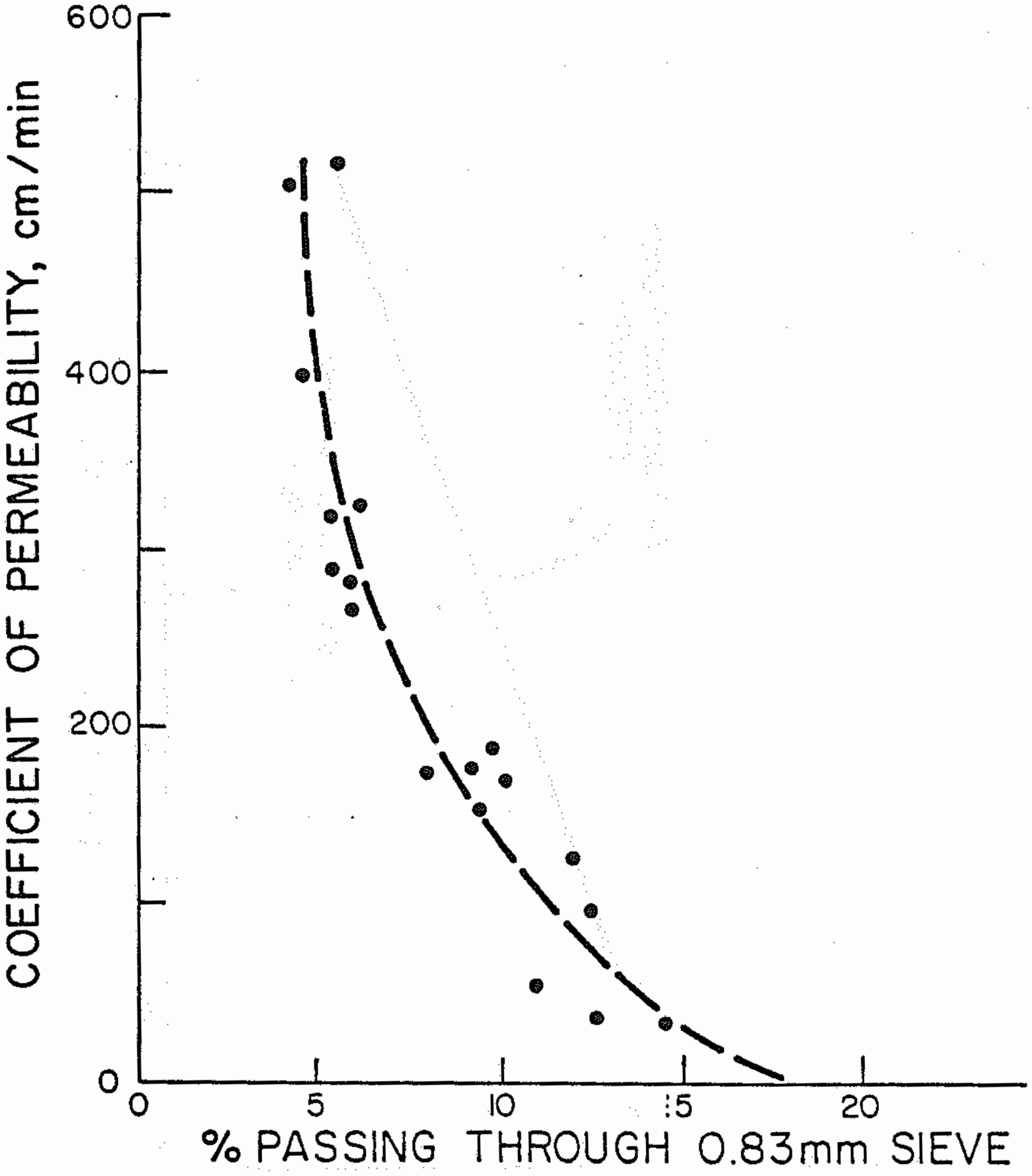

FIGURE 2: Coefficient of permeability and streambed composition.

after McNeil and Ahnell, 1964

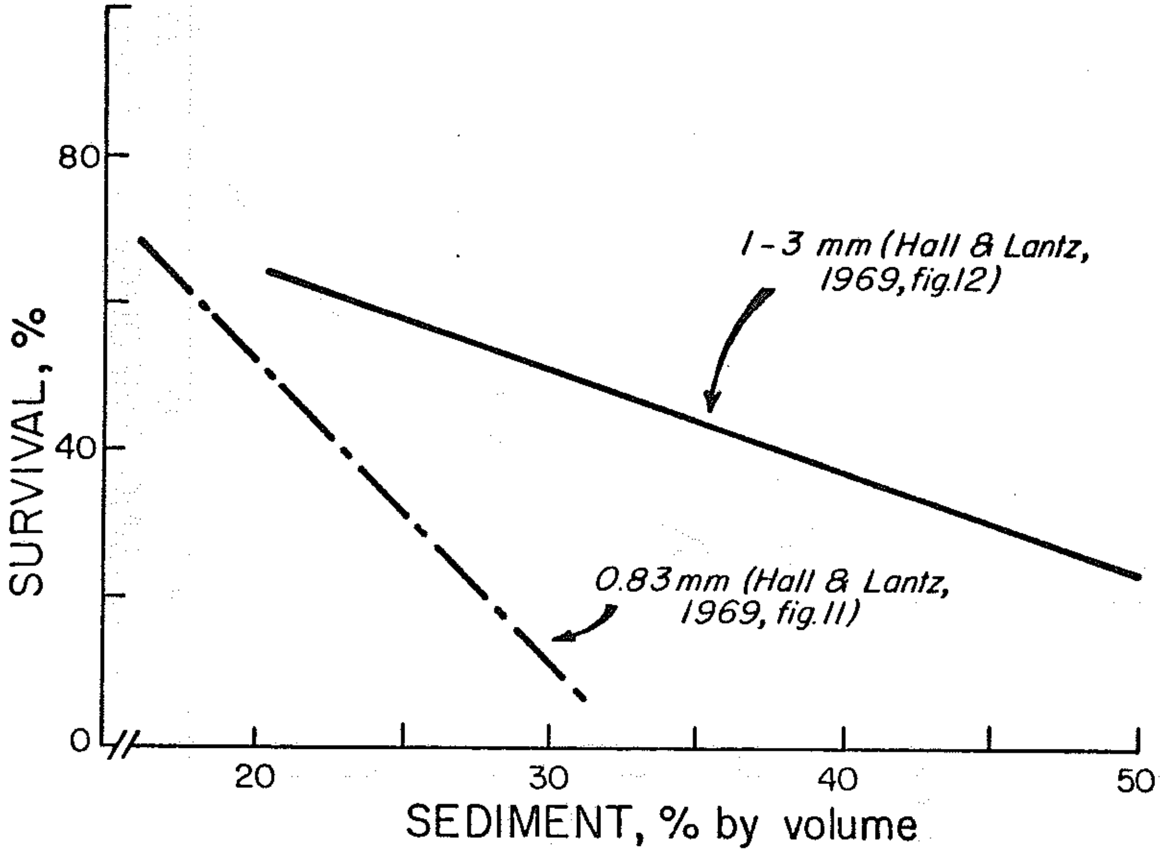

FIGURE 3: Emergent survival and streambed composition. (after Hall and Lantz, 1969)

sediment transport variables

Effects on Fish Food Supply

Effects on fish food supply will be subcategorized into effects on algae, plankton, and macrobenthos.

Of the aquatic plants, algae is of primary concern because of its importance at the base of the food chain. Many of the benthic fauna (variously referred to as macrobenthos, macrofauna, or macroinvertebrates these animals exist on or under stream bottoms) and planktonic fauna (animals drifting in the water column) subsist on algae. Whether benthic or planktonic, algae require illumination for photosynthesis. Ellis (1936) and Corfitzen (1939) found that even small amounts of TSS or turbidity in water-reduced illumination and that the reduction might be preferential in the shorter wavelengths (i.e., less than 0.5 microns) most beneficial to plant growth. Additionally, TSS may "destroy algae by molar action" or physically cover attached algae (Cordone and Kelly, 1961, and Newport and Moyer, 1974). Quantitative information correlating specific levels of TSS or turbidity with harmful effects on algae was not found.

Information related to planktonic organisms is limited. Studies done on Cladocerans and Copepods indicated unspecified "harmful" effects starting TSS concentrations of 300 mg/l (EIFAC, 1965). Clogging of feeding aparatus and digestive organs was hypothesized. Different levels of toxicity are indicated depending on the type of solids. Unspecified "harmful" effects on the *Cladoceran Daphnia magna* were noted at 392 ppm kaolinite and 102 ppm montmorillonite clay. However, a lower concentration of 39 ppm kaolinite appeared to stimulate reproduction. Stimulation of reproduction may be either a compensation resulting from toxicity or a positive effect.

The 'macrobenthos' includes those aquatic organisms that "live in, crawl on, or attach to the bottom substrate of a body of water" and will not pass through a number 30 U.S. standard sieve with openings of 0.59 mm (Cairns and Dickson, 1971). By definition they include insect larvae and nymphs, crustaceans, worms, clams, and a wide assortment of other invertebrates. Macrobenthic organisms are a significant part of the diet of fishes and are widely used as an indicator of water quality. A decrease in macrobenthic diversity is often related to toxicity from water pollution.

There is a substantial body of literature which qualitatively supports the conclusion that sedimentation of streambed gravels results in reduction or elimination of the macrobenthos. This reduction, of course, implies a subsequent reduction of food available to fish. This literature frequently refers to up- and downstream sampling near mining and logging operations where the downstream samples show varying degrees of reduction in abundance and/or diversity (Bartsch, 1959; Cordone and Pennoyer, 1960; Cordone and Kelly, 1961; EIFAC, 1965; Tebo, 1967; Chutter, 1969; Mackenthum 1969; Newport and Moyer, 1974; and Barnhart, 1975). However, the qualitative correlation with specific levels of TSS or turbidity is neither emphasized nor evident and data of this type is limited. Tebo (1967) found a 75% reduction in abundance of macrobenthos in a stream where turbidities of 261 and 390 ppm were measured. EIFAC (1965) mentioned a report indicating that 60 ppm of TSS had not effected macrobenthos in one stream. Additionally, Cordone and Kelly (1961) noted the possibility of increased nutrients from sedimentation by organic soils possibly stimulating macrobenthos abundance. However, this concept is not given much credibility.

The evidence clearly supports the conclusion that clean, coarse streambed gravels will support a more diverse and abundant microbenthos and thereby provide greater food supply to fish (Cordone and Kelly, 1961, and Brusven and Prather, 1974) than one which has become embedded with sediments. Gammon (1970) studied macrobenthos populations downstream from a quarry on Deer Creek where natural TSS concentrations ranged from about 15 to 40 mg/l during the period of quarry operation. Wastewater from the quarry was treated during the first year of the study, in two settling basin arranged in series. During the next year only one of the basins was used and average effluent quality increased from about 47 mg/l to about 75 mg/l TSS. It was found that an increase in TSS of about 40 mg/l above normal stream conditions would increase the drift rate of macrobenthos about 25%. Further, when TSS reached a level of 120 mg/l, the drift rate was increased to 90%. The net result of increased TSS as measured by Surber samplers was a significant decrease in macrobenthos populations despite the absence of visible accumulations of bottom sediments.

Effects Via Physical and Chemical Changes

Very little was found concerning this subcategory. Besides the decrease in light penetration which accompanies increased turbidity and which has been mentioned with regard to photosynthesis of algae, Ellis (1936) found that solids interfer with heat transmission, because they act as insulation. The possibility exists that decomposition or organic material carried with the solids could cause DO and pH changes, particularly if they are deposited on the bottom and then resuspended at some time in the future after undergoing some degree of anaerobic decomposition, Ellis (1936) found some indication of this; however, others measuring DO and pH up- and downstream from mining operations have not found significant changes (Cordone and Kelly, 1961).

The limited data indicates that large changes in temperature, DO, and pH would probably not result from turbidity caused by mining operations. It is noted, however, that even minor changes in these parameters can materially affect aquatic organisms.

Effects on Fish Populations

There are numerous comments in the literature concerning the overall effects of TSS and turbidity on fish populations leading to the conclusion that these factors inhibit the growth of fish and lead to reduction of fish populations. Despite the numerous references to population changes, little information relates such changes to specific TSS and turbidity levels. In several studies, it is implied that turbidity inhibits sport fish and thus inhibits reduction in fish populations (Ward, 1938). Although Puckett (1975), in surveys of the Eel River in California, found that few sport fisherman attempted fishing when turbidities exceeded 30 JTU, he attributes the decrease in the sport catch on the Eel River since 1950 to a decrease in the river's production of steelhead and salmon caused by excessive erosion and turbidity.

Gammon (1970) found that the changes in fish populations were species related. He concludes that increases in TSS concentrations of 40 mg/l or more above natural conditions depressed populations of warmwater fishes. Newport and Moyer (1974) list data for a study in which four species of fish were raised for two growing seasons in ponds of three different levels of turbidity; less than 25 ppm, 44086 ppm, and 116-214 ppm. The study demonstrated inhibition caused by turbidity of both growth and reproduction. The total weight of fish in the clear ponds was 1.7 times that in the intermediate-turbidity-level ponds and

5.5 times that in the most turbid ponds. Additional indication of TSS and/or turbidity-caused reduction in fish population and/or growth rates is contained in numerous references (Rees, 1959; Cordone and Pennoyer, 1960; Cordone and Kelly, 1961; EIFAC, 1965; Branson and Batch, 1974; Bjornn, et. al., 1974; and Barnhart, 1975).

Several authors have suggested effluent limitations or water quality standards to protect fishery resources. Cooper (1956), after studying a placer mining operation, recommended that sediment in the effluent be less than 0.1 mm in diameter and that effluent turbidity be less than 25 ppm. EIFAC (1965) concludes that "there is no evidence that concentrations of suspended solids less than 25 ppm have any harmful effects on fisheries" and that "it should usually be possible to maintain good or moderate fisheries in waters which contain 25 to 80 ppm suspended solids" at a somewhat lower yield of fish. These values compare fairly closely with Newport and Moyers' (1974) conclusion that "... the literature reviewed to date indicates that a precise minimum concentration of inorganic solids detrimental to maintaining good fisheries has not been unequivocally established. There is sound evidence, based on numerous research projects completed in this area, however, that the suspended solids concentrations listed below are meaningful approximations: 0-25 ppm, no harmful effects on fisheries; 25-100 ppm, good to moderate fisheries; 100-400 ppm, unlikely to support good fisheries; and over 400 ppm, poor fisheries."

Water Quality Control Technology

Solid/liquid phase separation can be accomplished in a variety of ways. The most common method is plain sedimentation in settling or tailings ponds. Such ponds have long been used by the mining industry.

Whether by accident or design, the use of sand and gravel tailings as filtration media has been practiced to some degree. More recently, chemical coagulation and flocculation is not in use at some operations where plain sedimentation was inadequate in removing fine particles to levels required by regulatory agencies. Removal of suspended solids also reduces turbidity.

Settling and Tailings Ponds

Settling and tailings ponds provide a relatively large, quiescent volume where gravity sedimentation occurs. The time required for sedimentation is a function of two combinations of factors: particle size/mass/density and fluid density/viscosity/flow velocity. The larger and denser particles settle out rapidly while the smaller and less dense particles settle slowly, if at all. In colloidal suspensions, negligible settling occurs with time because the forces of buoyancy and drag are equivalent to gravitational force. Generally, a settling pond would be thought of in terms of short-term wastewater containment on the order of several days or less. Settling ponds should be built in pairs or with plans for intermittent operation so that periodic shutdown and removal of sediments is possible. A variety of shapes, sizes, and combinations is acceptable depending upon the specific settling characteristics of the wastewater being treated. Caution should be exercised, however, since the design of efficient settling ponds requires considerably more than merely digging a "hole in the ground." (Additional information relating to settling pond design is contained in Appendix A.) Mine drainage and mill process waters are often discharged to settling ponds in the form of slurries, similar in nature to the washwaters discharged from sluices at placer gold mines. Settling curves are necessary to identify the settleability of the slurry, an important requirement in settling pond design. These curves are plots of either the solid-liquid interface or residual turbidity above the interface versus time. Examples of such curves are presented as Figures 4 and 5.

Settling ponds are capable of achieving a high degree of removal of TSS. Williams (1973) indicates that a shallow settling pond near Hunker Creek, Yukon Territory, Canada, was able to remove 73% of the sediment load of that stream and reduced the TSS to 30 mg/l in the effluent. A situation more nearly approaching that which might be considered more typical of mining operations is outlined by McCarthy (1973) where drainage from a surface mine was directed to settling ponds having a theoretical detention time of 8 to 23 hours, depending on precipitation duration and intensity. A reduction of 99% TSS was achieved; however, effluent TSS was still approximately 125 mg/l and effluent turbidity was approximately 100 JTU.

Tailings ponds are normally sized more for long-term storage of tailings than for water detention time; however, a nominal detention time of 30 days is often specified (Bell, 1974). Theoretical detention times may run quite long and even approach zero-discharge in arid regions. As a result, tailings ponds can be expected to discharge effluents low in TSS unless the discharge is the result of heavy surface runoff, in which case large amounts of solids might be washed downstream. Sceva (1973) listed effluent analyses for eight tailings ponds receiving only mine drainage or mill process wastewaters. TSS concentrations ranged from 10 to 52 mg/l and averaged 22 mg/l. Design and other pertinent operational data for the ponds is not presented.

Tailings Filtration

Many old mining operations are marked by a relatively coarse material called tailings. The efficiency of filtration through such tailings can

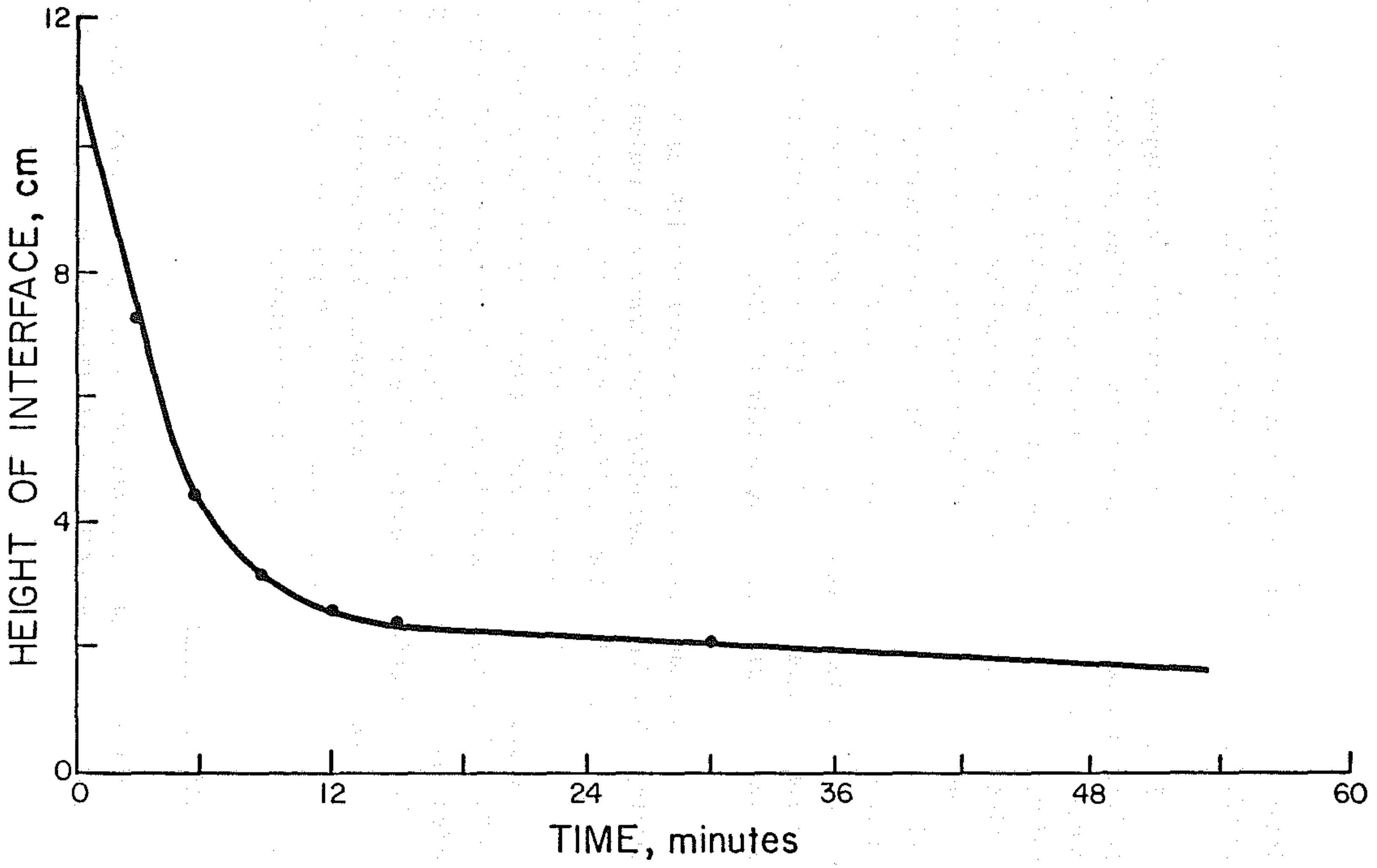

FIGURE 4: Tailings settling curve - interface. (after Bérubé, et al., 1973)

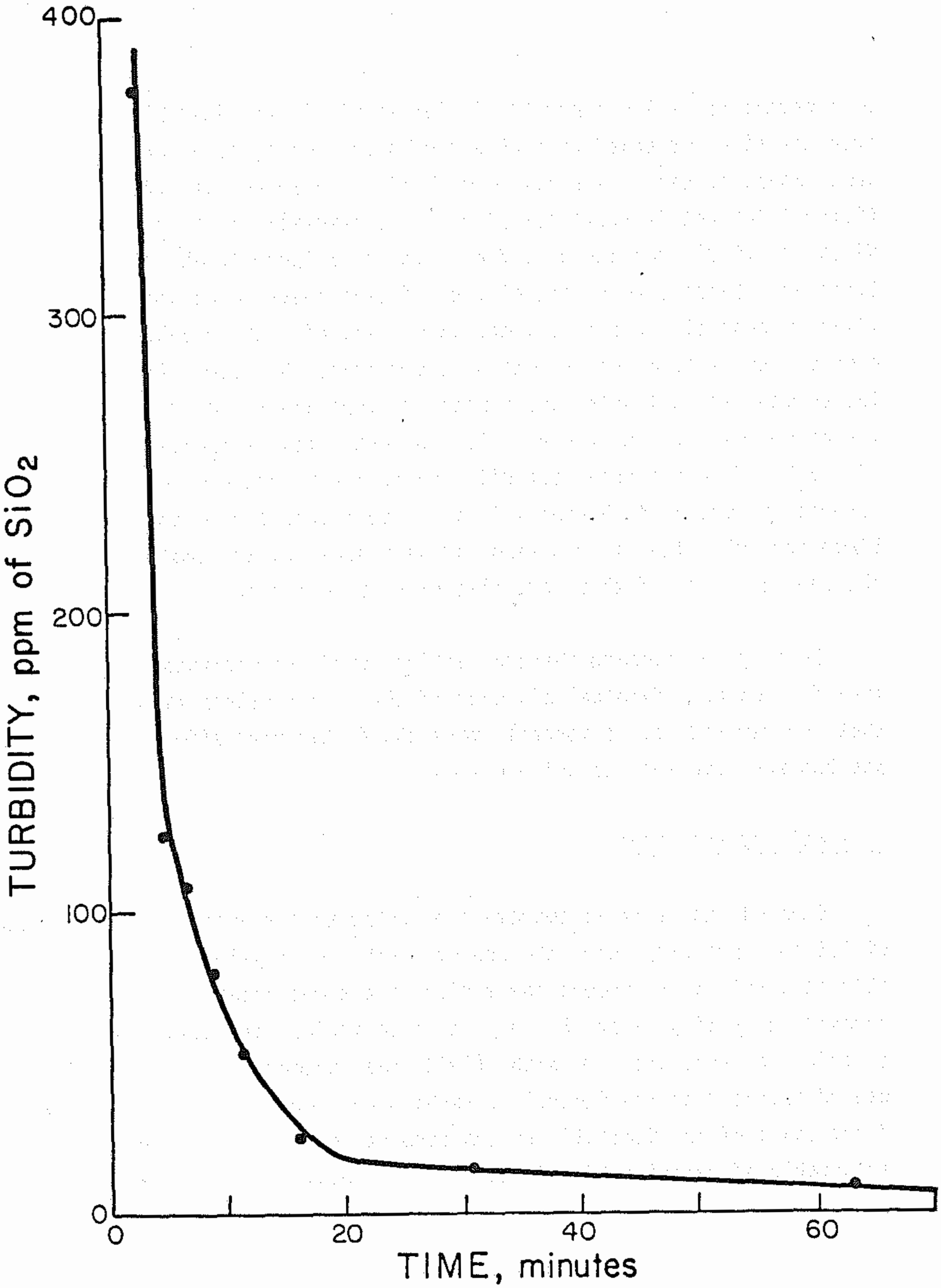

FIGURE 5: Tailings settling curve - residual turbidity. (after Bérubé, et al., 1973)

be expected to be low since the filter matrix is considerably larger than the fine suspended particles for which removal is desired. In some cases, particle size may be colloidal. However, if sufficient filter thickness is available, significant removals may be obtained. Williams (1973) presents data for a mine on Sulpher Creek, Yukon Territory, Canada, where the sluice effluent seeps approximately two miles through old dredge tailings before entering the creek. In the process, there is a 96% reduction in sediment. However, since the TSS concentration leaving the sluice is approximately 4,080 mg/l, the discharge will still have a TSS concentration of approximately 180 mg/l. Unless substantial dilution occurs in the receiving waters, adverse effects on fisheries will still be probable from this discharge Since particle size distribution and settleability were not discussed, the applicability of this data elsewhere is uncertain.

Drainage or seepage through tailings ponds enbankments also undergoes filtration. Eventual clogging of the filter matrix with fines that are removed may temporarily make the filter more effective with age but may also lead to self-sealing.

Chemical Sedimentation

Chemical addition to improve sedimentation for purposes of reduction of TSS and turbidity means the use of synthetic polyelectrolytes (polymers). This is a relatively recent innovation that shows great promise for removing turbidity caused by very small particles, including those in colloidal suspensions. McCarthy (1973) has documented the successful use of polymers at the Centralia, Washington, surface coal mine. The first stage of the Centralia system consists of a settling pond that is capable of removing 99% of the TSS. Effluent from this pond had a turbidity ranging from 85 to 120 JTU. The turbidity was apparently caused by particles of near colloidal size that were negatively charged. Addition of a cationic polymer, mixing via a vaned weir, and secondary settling produced an effluent quality ranging from 4 to 15 JTU. This degree of treatment was necessary to comply with a waste discharge requirement which prohibited effluent quality of greater than 5 JTU above the turbidity of the receiving water.

One note of caution should be mentioned with regard to polymers. Whereas the normal dosage rate should be low (on the order of 10 mg/l was used at Centralia) and most of the polymer should be removed in the sedimentation process, recent bioassay data has shown that some cationic polymers may be toxic at relatively low concentrations. (Biesinger, et. al., 1976) One polymer had an LC50 (the concentration which is lethal to half of the test fish in a 96-hour bioassay) of 2.12 mg/l to rainbow trout. Chronic toxicity would be expected at lower concentrations. Concentrations of polymers which might occur in the effluent are unknown.

Operation Mode Changes

Additional control technology consists of operational mode changes which may result in less usage of water, less erosion, or more optimum usage of terrain. Replacement of hydraulic stripping of overburden techniques by mechanical removal possesses whenever possible will reduce water usage and wastewater treatment requirements. However, it may necessitate timing of overburden removal to coincide with break-up or freeze-up conditions if material that is unstable when thawed is to be removed. Proceeding upstream so that old workings may be used for construction of tailings filters and settling ponds would also be desirable. Diversion of runoff or natural streams around mine works and reclamation, including revegetation, can reduce erosion and may also be appropriate. Finally, it may be possible in some cases to store wastewater until an appropriate discharge time when stream flow and turbidity from natural causes is high. Although such a procedure might enable some operations to comply with water quality standards, effluent standard compliance would still be a concern from a regulatory standpoint.

CHEMICAL/BIOLOGICAL PARAMETERS

Introduction

Mining breaks up and exposes mineral deposits which may then undergo chemical and/or biological reactions leading to solution or suspension of the minerals in water. The degree to which this may occur and the resultant water quality is dependent on a number of factors including the specific mineralization of the ore, the method of mining, and environmental factors such as precipitation, presence or absence of permafrost, and soil permeability.

The effects of mining operations on water quality resulting from chemical or biological processes are discussed in this chapter in summary fashion because of the limited available information and the scope of this report. Extensive information is available on the subject of acid mine drainage (AMD); however, this topic is not reviewed in detail since its application to Alaska is considered marginal.

Considerable work has been done in Canada relative to mining wastewaters in a northern environment including mine drainage, milling effluents, and containment or tailings ponds effluent. Much of this work should be pertinent to future similar operations in Alaska. Some related work has also been done with regard to the engineering aspects of tailings pond embankment dikes.

Acid Mine Drainage

There is no literature specific to Alaska concerning AMD; however, there is considerable information on the topic with regard to other states.

In the past, the emphasis has centered on the problems of AMD from coal mines in the eastern United States. Some work has been done in Canada with regard to AMD from base metal mines. It is not important to this project to duplicate the work done concerning AMD with a detailed discussion or compilation of references; however, the reader is referred to the publication Water Resources Scientific Information Center (1975), an extensive annotated bibliography on the subject. Additionally, the following references, not listed in that publication, may be of interest: Bell (1974); California Regional Water Quality Control Board, Lahontan Region (1975); Mink, Williams, and Wallace (1972); Montreal Engineering Company Limited (1973); and Sceva (1973).

AMD results from the oxidation of sulfide minerals. Although iron sulfide or pyrite is the most common mineral involved, copper, zinc, lead, and other sulfides may also undergo acid forming oxidation (Herricks and Cairns, 1973). The overall chemical reaction for iron sulfide is as follows:

$$4\ FeS_2 + 15\ O_2 + 14\ H_2O \qquad\qquad 8\ H_2SO_4 + 4\ Fe(OH)_3$$

Since iron-oxidizing bacteria may be involved in the reaction, it is both chemical and biological in nature. Mining operations disturb the equilibrium and accelerate the natural processes. Sulfide ores are exposed to oxygen from the atmosphere and water from precipitation or altered drainage patterns. The resulting drainage may be acidic (note the production of sulfuric acid in the above equation) and have high concentrations of a variety of trace metals as well as iron.

Mine Drainage

Little information concerning mine drainage wastewater was located. If temperatures in an underground mine in a permafrost region can be kept below freezing, mine drainage wastewater may be minimal. In discontinuous permafrost or outside the permafrost zone, drainage problems are probable (Berube, et. al., 1973, and Johansen, 1975). Berube, et. al. (1973) measured the water quality of drainage at one Canadian gold mine in a discontinuous permafrost zone. The results, listed in Table 5, should be considered with caution since they are only the average of two samples taken on one day. However, they are presented in this report as an indication of a mine drainage wastewater that might be encountered. The presence of sulfates and various trace metals was attributed to the dissolution of sulfide-bearing rocks, high arsenic levels to the oxidation of arsenopyrite, and the basic pH to the dominance of carbonaceous rocks. The wastewater characterized in Table 5 is untreated. Some form of treatment and dilution would be necessary prior to discharge in order to meet water quality standards.

Milling Effluents (Tailings)

Mills are used to concentrate ores and a variety of processes are possible depending on the metal being processed, the quality of the ore, and other factors. In some of these processes reagents may be added to facilitate the operation. In one Canadian gold mill investigated by Berube, et. al. (1973), the ore was beneficiated by crushing, flotation, roasting, and hydrometallurgical processing including calcine cyanidation. The flotation process involved the addition of copper sulfate, polypropylene glycol, potassium amyl zanthate, and sodium isopropyl xanthate. Sodium cyanide and calcium oxide were added during the leaching operation

Table 5: Mine Drainage Wastewater Characteristics*

pH	8.3	Units
Suspended Solids	1	Percent by Weight
White Discoloration		
Hardness	937	mg/l
Sulfates	298	
Antimony	2.4	
Arsenic	3.8	
Calcium	312	
Copper	1.63	
Iron	0.21	
Lead	0.46	
Zinc	0.318	

Average of two samples taken on one day at a Canadian gold mine.

*Berube, et. al., 1973.

and carbon and soda ash during quenching. Finally, zinc, alchem, dicalite, and lead nitrate were added during the precipitation process and hydrochloric acid was used for cleaning. While it may be unusual for so many reagents to be utilized in one mill, this example illustrates the wide range that is possible. Additionally, crushing and grinding of the ore results in the introduction of iron as the result of machine wear.

The wastewater discharged from this mill was in the form of a slurry with a solids content ranging from about 10 to 15 percent by weight (Berube, et. al., 1973). This slurry is referred to as tailings and consists of gangue minerals and the residue of reagents and water added in the mill. Average analysis of the solid portion of the tailings at this mill on one day is listed in Table 6. Other water quality information such as pH and color was not presented; however, settled effluent characteristics are available in the original test and some of those characteristics are listed in the section of this chapter on water quality control technology.

Natural Occurrence

Other than some of the reagents which might be added during the milling operation, constituents of mine drainage and tailings occur naturally in the environment and in water. Mine wastewaters, however, commonly have pH's that are either extremely basic or extremely acidic and concentrations of trace metals which far exceed those normally occurring.

The pH of most productive fresh waters is in the range of 6.5 to 8.5 and is a function of carbon dioxide and mineral content (Committee on Water Quality Criteria, 1972). pH data specific to Alaska indicates

Table 6: <u>Milling Effluent Characteristics*</u>

SiO_2	55.6%	Copper	41 ppm
AL_2O_3	13.6%	Lead	700 ppm
Fe	13.5%	Zinc	810 ppm
CaO	8.6%	Manganese	1,075 ppm
MgO	4.0%	Arsenic	4,000 ppm
Sulfur	0.64%		

Average analysis of solid portion of milling effluent on one day at a Canadian gold mine.

*Bérubé, et. al., 1973.

little deviation from the above range. Limited studies conducted along the trans-Alaska pipeline corridor from the Lowe River near Valdez to the Sagavanirktok River near Prudhoe Bay included pH values ranging from 6.56 to 8.60 (Alaska Operations Office, 1971) and may be representative of naturally occurring waters in Alaska. Although a minor reduction in pH is sometimes observed in streams and lakes in tundra regions, available data does not indicate a low pH situation as might otherwise be expected. A pH near, or slightly below, neutral appears to be the general case (Barsdate, 1976; Brown and West, 1970; and Hobbie, 1976).

With the exception of iron, the natural occurrence of trace metals in Alaskan waters appears to be in the low range generally found in other parts of the United States. Table 7 is a comparison of mean concentrations reported for five metals in surface waters of the United States with levels measured in lakes of northern Alaska. The occurrence of iron may reach unusually high levels in Alaskan surface waters and particularly high levels are found in some turbid rivers. Barsdate, et. al. (1970) reported an average iron concentration of 4 mg/l above an eroding section of a small tundra stream. Upstream turbidity averaged 9 JTU. In the Yukon River on 16 August, 1974, a value of 8.9 mg/l of iron was measured when the turbidity was 120 JTU.

Biological Effects

A significant body of literature exists concerning the biological effects of pH and trace metals; however, less information is available concerning the effects of some of the milling reagents. pH deviations higher or lower than the natural range tend to produce toxic effects proportionate to the amount of change and final pH reached. Synergism

Table 7: Natural Occurrence of Trace Metals in Surface Waters

Metal	Average Total United States Concentration (mg/l)	Average Total Northern Alaska Concentration (mg/l)
Copper	0.015[1]	0.0054
Iron	0.052[1]	0.224
Lead	0.0056[2]	0.0006*
Manganese	0.058[1]	0.0910
Zinc	0.159[2]	0.0051

*Dissolved fraction only.

1. Kopp, 1969.
2. Durham, Hem and Heidel, 1972.
3. Barsdate, 1976.

between pH changes and the effects of some toxicants has also been established. For example, an increase in pH would result in less dissociation of ammonia and a corresponding increase in toxicity. Most species of fish cannot survive if the pH is reduced below 4.0 or raised above 9.5. The buffering capacity or resistance to change in pH is a further factor of importance since low alkalinity or a major reduction in alkalinity would allow greater pH changes (Committee on Water Quality Criteria, 1972).

Many metals are micronutrients. That is, they are required in small concentrations for proper nutrition and their absence is detrimental to metabolism of many organisms. At higher concentrations, they exert a toxic effect. The toxicity of a metal is dependent on a variety of factors including other water quality parameters (pH, temperature, hardness, DO, turbidity, the presence of other metals or toxicants) and the species and condition of the organism. Acute toxicity may result from exposure to relatively high concentrations of some metals while lower concentrations produce chronic toxicity of a more subtle nature. For example, Mount (1968) found an LC_{50} for copper to fathead minnows of 0.47 mg/l in hard water (hardness of approximately 200 mg/l as $CaCO_3$) whereas an application factor of 0.03 was recommended to avoid adverse effects on reproduction (0.014 mg/l or copper). An excellent summary of metal toxicity information is provided by the Committee on Water Quality Criteria (1972).

Milling reagents such as copper sulfate, sodium cyanide, zinc, and lead nitrate are known toxicants. Bioassay testing has also demonstrated the toxicity of xanthates used in flotation (Leduc, Ruber, and Webb, 1973). Others such as calcium oxide and soda ash produce pH changes and carbon adds to turbidity and the suspended solids load.

Information pertinent to chemical feed rates, wastewater flow rates, dilution, and residual chemicals in the effluents from tailings ponds was unavailable.

Water Quality Control Technology

The primary control technology currently in use is the tailings pond. Other control technology available includes chemical sedimentation, pH neutralization, and the more advanced and expensive processes such as filtration, ion exchange, and reverse osmosis. Due to the limited scope of this paper and the predominant technological use of tailings ponds, the effectiveness of that technology is discussed herein. Other processes are in use; however, outside of the coal mining industry of the eastern United States their use is not widespread. Advanced treatment technology is expensive to implement and is therefore not used, even when necessary to mitigate adverse water quality impacts, due to nonenforcement of water quality standards.

Mine drainage and milling wastewaters are normally discharged to tailings ponds for treatment (settling) after reuse possibilities have been fully exploited. By that time the wastewater characteristics may be similar to those listed in Tables 5 and 6. Suspended solids concentrations are very high and significant levels of trace metals are probable.

The design of tailings ponds in the past has centered around the objective of storage of solids during the operational lifetime of the mine (Roy, LaRochelle, and Anctil, 1973; and Shields, 1975). The large ponds have provided relatively long retention times which has been fortuitous from a water quality standpoint. With new emphasis on environmental protection and safety during and after the operational lifetime of mines, greater attention to the prevention of seepage and the minimization of abandonment costs is being paid. (Roy, et. al., 1974, and Shields, 1975). Many states now require approved mining plans for new developments which specify reclamation of the land and prescribe measures for water quality control after mine shutdown. Such control measures are more effective and economical when integrated into planning from the start. For example, if natural drainage can be routed around tailings ponds in the design phase, a washout is less likely during operation and leachate generation is reduced after abandonment.

Despite the high proportion of fines in the tailings slurries (at one Canadian gold mine 60% of the solids were less than 15 microns in diameter and 9% were less than 2 microns) sedimentation tests have demonstrated that extensive coagulation and rapid clarification is likely. At two Canadian mines, residual turbidities of approximately 20 ppm (SiO_2) were observed to occur in less than 20 minutes of settling, after which little change was seen (Berube, et. al., 1973). Examples of the typical settling curves observed at these mines are shown in Figures 4 and 5. At two other mines, rapid initial settling was observed; however, the sedimentation tests indicated slightly longer times were necessary (30 minutes of settling) to achieve slightly higher residuals (60 to 70 ppm)(Roy and Vezina, 1973).

The effectiveness of tailings ponds is also a function of whether or not natural drainage is excluded from them or must pass through them. In dry climates and where drainage is routed around tailings ponds, it may be possible to achieve zero discharge. Where natural drainage transits the ponds, a steady discharge may occur and it will increase with stream flow. Problems involving ice-jamming of spillways or exit structures, washouts of solids, and breaching of dike embankments are probable during breakup in the spring. Washouts are frequently seen during precipitation events.

Tailings ponds also provide a degree of natural oxidation which Berube, et. al. (1973) found to be effective in reducing COD. Reductions as large as 90% were observed. A related increase in sulfate concentrations and oxidation of cyanides and trace metals was noted. Despite this oxidation and the presence of basic pH levels, several trace metals (copper at 14 mg/l, nickel at 1.6 mg/l, and arsenic at 14 mg/l) and cyanide (at 13 mg/l) were still found in excessive concentrations in the tailings pond effluents.

Wallace, Hardin, and Weir (1975) reported the results of bioassays conducted on the seepages and effluents from six tailings ponds in Canada. Acute toxicity to rainbow trout was demonstrated in four of the six cases and elevated concentrations of cyanide, arsenic, copper, iron, and zinc were detected.

WATER QUALITY EFFECTS OF ALASKA MINING

Introduction

Although mining activities in Alaska are not limited to gold and coal, this research project and associated literature review is focused on those two important commodities. Gold mining has historically been of great importance in Alaska and recent increases in the price of gold have resulted in a resurgence of activity in Alaska. Recent interest has also been shown in developing Alaskan coal reserves to supply national energy needs. Those reserves are substantial and largely untapped.

Placer Gold Mining

Research concerning the effects of placer gold mining in Alaska on water quality is extremely limited. The early placer gold mining literature discussed water only in terms of supply requirements (Hilchey, 1947). Not until recently has there been sufficient interest in the impact of mining on water quality to attract a research effort. The major published work in this subject area is the Alaska Water Laboratory's controversial 1969 publication "Effects of Placer Mining on Water Quality in Alaska." Field work for that publication was conducted during the summer and early fall of 1968 and was originally intended as preliminary groundwork for further investigations (Mitchell, 1975). Other work completed during that same summer was published by the Institute of Water Resources (Morrow, 1971). Both of these studies attempted for the first time to measure the direct effects of placer gold mining in Alaska on water quality and the aquatic environment.

The Alaska Water Laboratory (1969) study consisted of water quality and biological sampling in six different mining districts and involved ten mines. The study conclusions were as follows:

1. Water quality downstream from placer mining operations showed increased turbidity, decreased dissolved oxygen, and decreased populations of fish and fish-food organisms when compared to upstream conditions

2. The major impact of placer mining operations results from hydraulic stripping; actual ore washing (sluicing) generally has a smaller effect

3. Water quality control technology is available but is generally not in use

4. Water quality effects may continue after the termination of mining operations due to accelerated erosion.

Turbidity increases far in excess of present water quality standards were noted during the study. The highest levels were measured during hydraulic stripping operations and were accompanied by DO reductions and decreased populations of fish and fish-food organisms. In the worst case, a turbidity of 111,000 JTU's and a DO concentration of 0.0 mg/l were seen just below a mine where stripping operations were in progress. What might be considered a more typical situation, resulting only from sluicing, would be a turbidity of 3,600 JTU's and a DO concentration of 7.4 mg/l (the DO was reduced approximately 2 mg/l from upstream conditions and the turbidity was essentially all a result of the sluicing) measured just below a mine where mechanical stripping methods were employed.

In a sharply worded paper, the Alaska Division of Mines and Geology criticized (Williams, 1969) the conclusions of the Alaska Water Laboratory study. It was noted that the data base was small and that the work may have occurred during an atypically dry summer. There were unanswered questions concerning the impact of placer mining on dissolved oxygen concentrations and the duration and magnitude of biological effects. Furthermore, although Williams didn't discuss this point, the Alaska Water Laboratory report did not deal with the efficiency or economic feasibility of available treatment technology.

Morrow (1971) concluded from his work that placer gold mining operations might have limited adverse effects on streams where overburden is thin and has a low organic content. He detected elevated turbidity, decreased faunal populations, and siltation of streambed gravels downstream from a small intermittently operated placer mine. However, he hypothesized that high water flows might flush the silt downstream and allow recovery to natural conditions in a relatively short time frame. Morrow's findings were consistent with those of the Alaska Water Laboratory, but are open to the same criticism - they are only supported by a small data base.

Arsenic

Another aspect of the impact of placer gold mining on water quality that has recently received attention is introduction of trace metals, particularly arsenic. Wilson (1975) sampled surface streams, springs, and wells in the Pedro Dome-Cleary Summit area north of Fairbanks, Alaska. He found relatively high concentrations of arsenic which he postulated were the result of past and present mining operations. Arsenic is known to occur primarily as arsenopyrite which can be associated with gold mineralization such as that in the Pedro Dome-Cleary Summit area. As previously mentioned, mining accelerates natural weathering processes by exposing minerals to air and water and by reducing average particle size. Tailings from past mining operations have, on occasion, been dumped into streams and water percolating through the tailings, in or out of streams, may leach out arsenic and other minerals. Wilson (1975) found high arsenic concentrations in sediments downstram from old tailings deposits. He also found elevated arsenic concentrations downstream of present-day placer mining operations where sluicing is practiced. Sluicing may result in the suspension (solid form) and particle solution (dissolved form) of arsenic.

The literature indicates that naturally occurring arsenic concentrations in surface waters are on the order of 0.01 mg/l or less (Taylor, 1962, and Smith and Hayes, 1975). Interim federal and state drinking water standards contain a maximum contaminant concentration limit for arsenic of 0.05 mg/l. Wilson (1975) found concentrations of arsenic as high as 15.0 mg/l in Cleary Creek downstream of past and present mining operations. Very high arsenic concentrations were associated with stream sediments and suspended solids in the water column (600 and 200 ppm respectively). Wilcox (1976) found significant concentrations of arsenic in surface waters and wells in the Ester Dome area west of Fairbanks, Alaska, downstream from past and present mining operations. In several cases, however, high concentrations were measured which were thought to be removed from the influence of mining activities. The majority of the arsenic in surface waters was in the solid form whereas the arsenic found in well waters was primarily in the dissolved form. The maximum concentration found was 3.0 mg/l in a well supplying drinking water to a private residence.

Regulatory Data

Although no other research has apparently been done in Alaska directly involved with the effects of placer gold mining on water quality, field work by personnel of the Alaska Departments of Environmental

Conservation and Fish and Game during the 1975 mining season produced some related information. The only case where water quality measurements were taken involved the Klondike Placer Gold Corporation mine near Livengood, Alaska. Measurements were taken in the late spring and early summer when turbidity increases resulted from hydraulic stripping of a ditch in ice-rich permafrost. The ditch was meant to replace an old water supply tunnel which had collapsed. Although sluicing occurred later that summer, no measurements were taken at that time. Turbidity was in excess of 1,000 JTU's on Livengood Creek at a point several mines downstream from the settling ponds. Readings as high as 400 JTU's were measured several mines further downstream after dilution by the Tolovana River, a larger stream. Discoloration of the Tolovana River due to the turbidity was traced 25 to 30 miles downstream by airborne observers (Fedeler, 1975, and Mach, 1975). Reportedly, settling ponds and filtration through coarse tailings were ineffective in noticeably reducing turbidity (Mach, 1975). Although more detailed information and data concerning these operations was requested from both the miners and regulatory agencies, it was not received.

Related Stream Disturbances

Some closely related work of the effects of sedimentation has been done or is in progress in Alaska. McVey (1959) discusses the impact of gravel removal from streams on Kodiak Island on the salmon fishery there; however, he presents no quantitative data other than declining salmon packing plant production figures following large scale gravel removal operations. Shapley and Bishop (1965) investigated the artificial intentional sedimentation of a portion of Maybeso Creek near Ketchikan, Alaska. Sediment was introduced via hydraulic mining. It was found that suspended solids concentrations of less than 50 mg/l produced a significant increase in percentage of streambed material 0.833 mm or less in diameter, even after partial flushing by high water flows following a precipitation event. However, no decrease in intergranular DO was measured and high water flows following additional precipitation events flushed the streambed clean within two months. Lack of oxygen demand due to low organic content of the sediments or sparse benthic biota could account for the lack of decrease in intergranular DO following streambed sedimentation. The U.S. Fish and Wildlife Service is sponsoring research in Alaska which commenced in late 1975 to determine the water quality effects of stream gravel mining in Alaska. The first phase of this work is a literature search and the results will not be available for some time. Although there have been observations of turbidity increases resulting from construction of the trans-Alaska oil pipeline, these are frequently qualitative in nature (i.e., muddy water) rather than quantitative (Rockwell, 1975). Quantitative work conducted by the U.S. Geological Survey has not been made available by that organization. The EPA's Arctic Environmental Research Laboratory has conducted portions of a study of the Chatanika River underground pipeline crossing which involved biological, physical, and chemical sampling up-and downstream of the crossing. This investigation is continuing into the after-construction phase and the results will not be available for some time.

Canadian Placer Gold Mining

There has been some relevant work done in Canada over the past several years regarding placer gold mining and water quality. Some of the work by the Canadian Department of Indian Affairs and Northern Development has already been mentioned in this report. Williams (1973) presented monitoring data and a state-of-the-art summary of practices in the Klondike Gold Fields of the Yukon Territory. Further information exists in other reports including those of Brandon (1974), Williams (1974a and 1974b), and Boyd (1975). The Canadian Fisheries and Marine Service is in the process of publishing the results of two years of studies concerning water quality and biological impacts of placer gold mining in the Yukon Territory. This work is not yet available.

Mercury

A further potential problem about which there is no information available is the possibility of discharge of mercury from those washing plants where mercury may still be employed in the sluices to aid in the removal of gold by amalgamation. It is unknown to what extent these practices may still be employed, or, when they are, how much mercury may be discharged; however, mention of its use during the 1975 season was made at several mines in Alaska.

Surface Coal Mining

It is estimated that twelve per cent of the United States' strippable coal reserves are located in Alaska, primarily in deposits found on the arctic North Slope (Grim and Hill, 1974). Nevertheless, the major use of other fuels in Alaska, the manifold problems of cold region development, and adverse economics of transportation have resulted in limited coal mining activity to date. Usibelli Coal Mines, Inc., is currently operating Alaska's only commercial surface coal mine in the Nenana Field near Healy, Alaska.

There is virtually no specific information available on the observed impact of surface coal mining in Alaska on water quality. Jirik (1973) speculated on potential problems related to permafrost degradation and subsequent erosion. Zemansky, Tilsworth, and Cook (1975) attempted to consider potential impacts based primarily on information from sources outside of Alaska. Neither of these papers presented quantitative Alaskan data. There is, however, reason to believe that past mining activities utilizing hydraulic stripping of overburden did introduce large quantities of solids into some streams in the past (Usibelli, 1975).

Due to the relatively low sulfur content of most Alaskan coal, it is generally considered that acid mine drainage is not a significant potential problem. It is reasonable to expect that mine drainage would be alkaline in nature rather than acidic; however, little quantitative data is available. Acid-forming minerals might be concentrated in washing-plant effluents; however, this potential problem has not been investigated either.

Interim federal effluent limitations for the coal mining industry were published in October of 1975 (USEPA, 1975b) and are listed in Table 8. The coal industry has been categorized into mining drainage and mining services. Mining drainage is subcategorized into acid or ferruginous and alkaline and mining services are subcategorized into coal preparation plants and coal preparation plant ancillary areas, refuse storage, and coal storage. BPCTCA, new source, and BATEA limitations are the same for all parameters in all subcategories and become more stringent moving from BPCTCA to BATEA. Zero discharge via water reuse is specified for the coal preparation subcategory.

Treatment technology is also similar in all cases and consists of variations of lime neutralization, aeration, sedimentation, chemical sedimentation (utilizing polymers or lime), and possibly filtration. The use of reverse osmosis to remove dissolved solids was considered in the development of the BATEA limitations; however, it was decided that reverse osmosis technology was not sufficiently advanced to be

Table 8: Interim Federal Effluent Limitations for Coal Mining

	All Categories					
	30 Day Average			Daily Maximum		
Parameter	BPCTCA	New	BATEA	BPCTCA	New	BATEA
Total Iron	3.5	3.0	3.0	7.0	3.5	3.5
Dissolved Iron	0.3	0.3	0.3	0.6	0.6	0.6
Total Aluminum	2.0	2.0	2.0	4.0	4.0	4.0
Total Manganese	2.0	2.0	2.0	4.0	4.0	4.0
Total Nickel	0.2	0.2	0.2	0.4	0.4	0.4
Total Zinc	0.2	0.2	0.2	0.4	0.4	0.4
Acid or Ferruginous Mine Drainage TSS	35	35	20	70	70	40
Alkaline Mine Drainage	25	25	20	50	50	40
Coal Storage, Refuse Storage, and Coal Preparation Plant Ancillary Area TSS	35	35	20	70	70	40

*All values are in mg/l. Additionally, there is a pH limitation for each sub-category of from 6 to 9. The effluent limitations for the sub-category coal preparation plants is zero discharge. (USEPA, 1975a) considered operational in this application. Solid-liquid phase separation for slurries discharged from coal preparation plants is to be accomplished by the use of settling ponds, thickeners, and filters. Centrifuges were not specified; however, they would also be available for this purpose.

EVALUATION OF DATA AND INVESTIGATORS' CONCLUSIONS

Summary and Conclusions

1. Information concerning the impact of mining on water quality is limited. Information specific to placer mining and mining in Alaska is particularly lacking. However, there is a relatively large body of information available concerning acid mine drainage.

2. A comprehensive study of the effects of placer mining on water quality has apparently not been conducted; however, a number of studies attempting to define the biological effects of streambed sedimentation have been completed through the years in other states and a report of the findings of a recently completed two-year Canadian study is now in publication.

3. The available evidence indicates the following potential water quality problems associated with placer mining:

a. Changes in physical parameters - primarily, increased turbidity and suspended solids; and chemical parameters - primarily, decreased DO and increased trace metals concentrations such as arsenic and mercury.

b. Water quality deterioration resulting in changes to the aquatic environment including effects on fish and fish food organisms

c. Water quality changes resulting in an adverse effect on human uses of the stream including degradation of esthetic quality and introduction of toxic trace metals.

4. The very limited body of information specific to Alaska tends to support the aforementioned conclusions. Although some of the potential problems could be expected to be relatively minor and short-lived, others might be of major consequence and long-lasting. The

lack of information precludes a thorough evaluation.

5. The development of Federal effluent limitations for placer mines is still in progress. In the meantime, NPDES permits have been issued with effluent limitations. The rationale behind these effluent limitations is unknown and is questionable.

6. Alaska water quality standards are applicable to waters impacted by mining discharges. As with the Federal limitations, the rationale for the State standards is unknown and is questionable.

7. There is an apparent lack of monitoring of mining operations as well as a lack of water quality standards enforcement.

8. Technology is available to provide treatment sufficient to meet effluent limitations and water quality standards; however, it is apparent that such technology is generally not in use. The economic feasibility of technology implementation is questionable.

9. There is a lack of understanding of water quality problems related to mining on the part of both miners and government regulatory agencies. Some miners are unwilling to acknowledge environmental concerns while some government regulatory agencies lack the necessary knowledge about mining operations. A tendency to ignore the problem when possible and to maintain the status quo has been the evident result.

10. There is a little ongoing research related to mining in Alaska and water quality and none is of the necessary scope.

11. It is probable that Alaska will continue to develop and that mining activity will increase in response to national demand for non-renewable minerals. In the process, there will be conflicts in land and water use which will likely aggravate problems that are unsolved today. The burden is on government, with industry and public participation, to develop and implement plans and standards which are responsive to public needs. Public needs include the extraction of minerals in an environmentally compatible manner, where that is the primary beneficial use, and absolute environmental protection in some other areas.

12. Optimum solutions are not likely without sound planning supported by well founded research data. After rational standards are determined they must be enforced if they are to be effective.

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APPENDIX

APPENDIX A

SETTLING PONDS

Introduction

The state-of-the-art for the control of sediment discharge from placer mining operations is not well advanced. Although the technology exists to fully control these discharges so as to reduce or eliminate water quality impacts, the technology available is not being utilized. Nonutilization is occuring for several reasons, including: (technology is too complex and requires skilled personnel, 2) economics are prohibitive, 3) nonenforcement of regulations occurs - thus advanced technology is not required, 4) technology is not applicable/adaptable to small and/or remote operations, and 5) other.

One particular facet of existing technology that is being used for sediment control is "settling ponds." These ponds are part of the control strategy proposed by the federal government as part of their interim regulations. Unfortunately many of these ponds are no more than "holes in the ground" having little or no engineering basis.

Theory

Settling ponds should provide a relatively large and quiescent volume where solid particles suspended in water may settle to the bottom. The process is called sedimentation and occurs when sufficient time is provided for gravity to overcome the opposing forces of bouyancy and induced drag on the solid particle and when hydraulic conditions are suitable. The efficiency of sedimentation is theoretically dependent on a complex range of variables which describes the nature of the solid particles and the water they are suspended in. Particle size, shape, mass, and density and water density, viscosity, and hydraulic factors are some of the more important variables. When the concentration of solids is high, particle interactions may also be important. All of these variables would be considered in an engineering approach to optimum settling pond design. If particle size is very fine and specific gravity of the particles is low, settling will be slow or even negligible. For example, a colloidal suspension (particles ranging from 0.0001-0.000001 mm) would remain nearly unchanged with long settling times. Very fine silts or clay suspensions might require weeks of settling to achieve a clear supernatant. Theoretically, there are four distinct types of sedimentation which are dependent on the suspension concentration and the flocculating properties of the particles (Weber, 1972). They are:

Type 1 - Dilute suspension, non-flocculating discrete particles.
Type 2 - Dilute suspension, flocculating particles.
Zone Settling - Intermediate suspension, flocculating particles.
Compression Settling - Concentrated suspension in compression, discrete and flocculating particles.

Analytical Determinations

An approximation of the settleability of a wastewater can be obtained by collecting a sample in a glass jar and observing how long it takes for the majority of solids to settle to the bottom. The jar should be cylindrical in shape and calibrated so that vertical height can be measured in the water column. Where initial solids concentrations are high and settleability is good, a relatively clear water supernatant will form above a sludge layer. The line of separation between the supernatant and sludge is called the "mud-line" (interface of zone settling) and a graphical plot of mud-line" height versus time is called a settling curve. In more dilute wastewater the "mud-line" may not be distinct and a plot of supernatant solids concentrations or turbidity versus time would describe the settling curve. A sample curve is shown as Figure 4. In some cases detailed analyses are required in order to achieve optimum sedimentation results through engineering design. This is particularly true when dealing with colloidal type materials. It would be necessary to perform soil type analyses as well as a settling column analyses (Weber, 1972, and APHA, et al., 1971). Engineering analysis of the problem may determine that gravity sedimentation is ineffective and a nonviable solution and thus some alternative, such as coagulation/flocculation or chemical precipitation may be necessary.

Application

The general lack of information for placer gold mining operations precludes a thorough design analysis of settling ponds (Berube, et.al, 1973). It is surmised, however, that soil encountered in placer gold mining operations may range from large gravel to clay and thus theoretical design consideration would be directed at suspensions that include all four categories of "ideal" sedimentation theory. This means, for example, that soil encountered would include gravel, sand, silt, clay and mixtures thereof, and the suspensions would range from dilute to concentrated and flocculant to discrete nonflocculant It is hypothesized that turbidity could be removed through natural coagulation processes but it is highly doubtful that existing State water quality standards for turbidity could be achieved.

As mentioned previously, the EPA has considered a permit requirement of settling pond(s) sufficient in capacity to contain the maximum volume of process water used during any one day's operations. The minimum one-day detention time would theoretically allow for settling of fine silt suspensions; however, settling pond design should be based on settling-velocity experiments rather than arbitrary parameters which may or may not be adequate (Weber, 1972).

The volume of process water used in any one day's operation may vary widely from mine to mine and would be dependent on the material being worked, continuity of operation, and the grade, size, and type of sluice. Hilchey (1947) quoted the "duty" of water in Alaskan sluices as varying from 0.32 to 1.60 cubic yards of material per miner's inch/day. In other words, a miner's inch (one fortieth of a cubic foot per second of water) flow of water could be used to sluice from 0.32 to 1.60 cubic yards of material. A miner's inch would equal 16,200 gpd. Hilchey (1947) also quoted sluice water flow rates ranging from 300 miner's inches (7.5 cfs or 4,840,000 gpd) for a 24-inch wide sluice 20 inches deep to 2,600 miner's inches (65 cfs or 42,000,000 pgd) for a 52-inch wide sluice 36 inches deep when both were on the same grade (6 inches per 12 feet).

If maximum daily flow is known, the volume required for the settling pond may be readily calculated using the equation $V = Q\ t$ where V is the volume, Q is the flow rate in units of volume per time, and t is the time of one day. For examples purposes, total water use of 300,000 gallons in one day has been arbitrarily chosen. Such a flow rate might be seen at a small placer gold mine and would amount to 0.46 cfs or 208 gpm if a 24-hour working day is assumed. Actual washing rates would likely be higher since the water would probably be used over less than a 12-hour period; e.g., 300,000 gpd over a 12-hour period equals 417 gpm or 0.93 cfs. Since there are approximately 7.485 gallons of water per cubic foot at about 50°F and atmospheric pressure, 300,000 gallons would occupy a space of 40,080 cubic feet. As sedimentation occurs a volume of the pond must be provided for sludge storage. Allowing 50% (arbitrary value) additional volume for sludge accumulation and assuming intermittent operation with drain down and sludge removal when the pond is one-third full of sludge, total pond volume required would be about 60,000 cubic feet. The percent additional volume provided for sludge storage is dependent on the characteristics of the soil and the suspension as well as the mode/manner of sludge removal. The pond must be of sufficient depth to prevent hydraulic scouring from inhibiting settling; however, settling is more efficient when pond surface area is maximized. Theoretically, all particles which settle at a velocity (N_s) greater than the overflow rate (v_o) will be removed in the settling pond. "v_o" can be calculated by dividing the volumetric flow rate by the surface area ($v_o = \frac{Q}{A}$). When A is maximized, v_o becomes small and particle settling velocities will be more likely to exceed v_o. If we arbitrarily pick a depth of 4 feet (2.67 feet effective settling depth plus 1.33 feet for sludge storage) for our example pond and for east of calculation assume a rectangular shape, "A" would equal 15,000 square feet and pond dimensions ot 75 by 200 feet might be suitable. "v_o" would then equal $\frac{40{,}000 \text{ cubic feet/day}}{15{,}000 \text{ square feet}}$ or 2.67 feet per day or $3.09\text{X}10^{-5}$ feet/second. The theoretical particle size with a settling velocity of $3.09\text{X}10^{-5}$ feet/second would have a diameter of 3.7 microns, the size of fine silt (assuming a water temperature of 50°F and a spherical particle of 2.65 specific gravity). Smaller particles with slower settling velocities would also be removed to some degree, but not completely.

Other design considerations should include hydraulic evaluations for the inlet/outlet areas of the settling pond, prevention of short circuiting, and the depth, length and width relative to the pond configuration. Alternatives for sludge removal must also be studies.

EXAMPLE CALCULATION - SETTLING POND

Measured Flow = 300,000 gallons/day GPD) = Q

Q = 300,000 GPD = 208 GPM = 0.46 CFS

Actual Water Use Rate is 300,000 over 12-hour period = 600,000 GPD

= 25,000 GPH = 417 GPM = 0.93 cfs.

Regulatory Requirements = Detention Time (D.T.) = 24 hours.

Design Assumptions:

(1) Pond Settling Capacity = 24 hr. = 300,000 Gallons = $\frac{300{,}000 \text{ Gal}}{7.485 \text{ Gal/ft}^3}$ = 40,080 ft^3.

(2) Sludge Storage Capacity = 50% of Pond Settling Capacity = 0.5 x 40,080 = 20,040 ft^3.

(3) Total Pond Volume = Settling Capacity + Sludge Storage = 40,080 + 20,040 = 60,120 ft^3.

(4) Assume the practical depth to be 4' of which 2.67 feet is for effective settling and 1.33 feet is for sludge storage. Total depth = 4 feet.

(5) A_s (surface area) = $\frac{60{,}120}{4} = \frac{40{,}080}{2.67}$ = 15,030 ft^2.

(6) Assume Length to Width Ratio = 2:1

$L = 2W$

$2W^2 = 15{,}030$

$W^2 = 7{,}515$ ft.

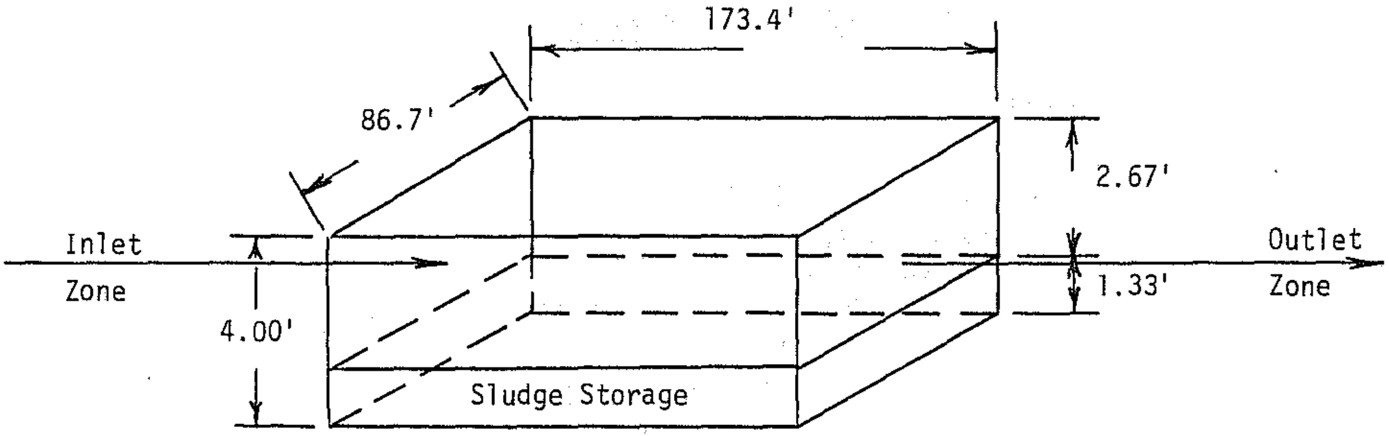
$W = 86.7$ ft. width

L = 173.4 ft. width

d = 2.67 ft. effective settling depth

d_s = 1.33 ft. storage capacity

d_t = 4.00 ft. total depth



Calculations:

(1) Overflow Rate = O.R. = vo

$$O.R. = Q/A_s = \frac{0.46\ ft.^3/sec}{15,030} = 3.06 \times 10^{-5}\ ft./sec$$

$$= 9.33 \times 10^{-6}\ m/sec$$

(2) Use the following soil classification (Hough, B.K., 1958*):

size classification:

sand - 0.05 to 2.0 mm
silt - 0.005 to 0.05 mm
clay - less than 0.005 mm
colloids - 0.000001 to 0.0001 mm

terminology:

s.g. = specific gravity
H_2O, S.G. = 1.000

δ = specific weight, $\#/\text{ft.}^3$
H_2O, $\delta = 62.4\ \#/\text{ft.}^3$

ρ = mass weight density, $\frac{\#\text{-sec}^2}{\text{ft. } 4}$
H_2O, $\rho = 1.94\ \frac{\#\text{-sec}}{\text{ft } 4}$

specific weights (wet):

sand - δ = 77 to 93
silt - δ = 81 to 87
clay - δ = 81 to 94
colloidal clay - δ = 71
gravel, sand, silt, clay mixture - δ = 125

$$\begin{aligned} s.g &= \delta/\delta \text{ water} \\ \rho &= \delta/g \end{aligned}$$

(3) Calculate smallest particle removed -

Assume v_s (settling velocity) = v_o = O.R.

Assume Temperature = 50°F = 10°C

Assume Sand Particles, $\rho_s = 2.64$, $\delta = 85$, S.G. = 1.36

v_s (discrete particles) $= \frac{g}{18} \left(\frac{\rho_s - \rho}{\mu}\right) d^2$

μ (dynamic viscosity) $= 0.273 \times 10^{-4}\ \frac{\#\text{-sec}}{\text{ft } 2}$

*Hough, B.K., Basic Soils Engineering: The Ronald Press Co., 1957, pp. 30-31.

$$v_s = \frac{g}{18} \frac{(s.g._s - 1)}{v_k} d^2$$

v_k (kinematic viscosity) = 1.41×10^{-5} ft^2/sec

$$V_s = \frac{32.2}{18} \frac{(2.64-1.94)d^2}{0.273 \times 10^{-4}} = 3.06 \times 10^{-5} \text{ ft./sec.}$$

$$d^2 = \frac{(3.06 \times 10^{-5})(0.273 \times 10^{-4})\ 18}{32.2\ (0.70)} = \frac{15.04 \times 10^{-9}}{22.54}$$

$$d^2 = 0.67 \times 10^{-9}$$

$$d = 2.59 \times 10^{-5} \text{ ft.} = 0.79 \times 10^{-5} \text{ m}$$

$$= 7.9 \times 10^{-6} \text{ m}$$

$$= 7.9 \times 10^{-3} \text{mm}$$

$$= 0.0079 \text{ mm}$$

$$= 7.9\ \mu$$

Therefore, smallest particle removed has diameter of 0.0079 mm which is in the silt range.

Check:

$$v_s = \frac{32.2}{18} \frac{(1.36 - 1)}{1.41 \times 10^{-5}} d^2 = 3.06 \times 10^{-5}$$

$$d^2 = \frac{(3.06 \times 10^{-5})(1.41 \times 10^{-5})\ 18}{32.2(0.36)}$$

$$= \frac{(4.31 \times 10^{-10})\ 18}{11.59} = \frac{77.58}{11.59} = 6.69 \times 10^{-10}$$

$$d = 2.59 \times 10^{-5} \text{ ft} = 0.79 \times 10^{-5} \text{ meters}$$

$$= 7.9 \times 10^{-6} \text{ m}$$

$$= 7.9 \times 10^{-3} \text{ millimeters}$$

$$= 0.0079 \text{ mm}$$

$$= 7.9\ \mu$$

(4) Show the effect of increased surface area by decreasing depth by one half and holding volume constant.

d_t = 2.0 ft. Vol_t = 60,120 ft^3

As = 30,060

$$O.R. = \frac{0.46 \text{ ft}^3/\text{sec}}{30{,}060} = 1.53 \times 10^{-5} \text{ ft/sec.}$$

Note: With these conditions, v_s is now one half the original v_s

$$v_s = 1.53 \times 10^{-5} = \frac{32.2}{18} \left(\frac{2.64 - 1.94}{0.273 \times 10^{-4}}\right) d^2$$

$$d^2 = \frac{7.52 \times 10^{-9}}{22.54} = 0.33 \times 10^{-9} = 3.3 \times 10^{-10}$$

$$d = 1.82 \times 10^{-5} \text{ ft} =$$

$$d = 0.55 \times 10^{-5} \text{ meters} = 5.5 \times 10^{-6} \text{ meters}$$

$$d = 0.0055 \text{ mm}$$

In this case, the smallest particle removed has a diameter of 0.0055 mm which is the lower range for silt and the upper range for clay. Thus more particles were removed by increasing the surface area. Caution must be exerted, however, as the depth should be reduced only within practicable limits where short circuiting will not occur. Additionally, the area available and terrain conditions may not permit adjustment for controlling the overflow rate.

EXAMPLE SUMMARY

	(1)	(2)	(3)	(4)
Q, GPD	30,000	300,000	300,000	300,000
D.T., HRS	24	24	24	24
D_t, Ft	4.00	2.00	4.00	2.00
D_e, Ft	2.67	1.33	2.67	1.33
D_s, Ft	1.33	0.67	1.33	0.67
Vol_t., Ft^3	60,120	60,120	60,120	60,120
$Vol._\rho$, Ft^3	40,080	40,080	40,080	40,080
A_s, ft^2	15,030	30,060	15,030	30,060
v_s=O.R.=Ft/sec	3.06×10^{-5}	1.53×10^{-5}	3.06×10^{-5}	1.53×10^{-5}
Soil, type	sand	sane	gravel, sand, silt, clay mixture	
δ, #/ft^3	85	85	125	125
T,°C	10°C	10°C	10°C	10°C
dia., mm	0.0079	0.0055	0.0047	0.0033
dia., μ	7.9	5.5	4.7	3.3
Particle Removed	silt	silt/clay	silt/clay	clay