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WATER QUALITY CONDITIONS IN THE NORTHEAST B.C. COAL AREA

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PREPARED FOR:
ENVIRONMENTAL LAND USE
SUB-COMMITTEE ON N.E. COAL DEVELOPMENT

NOVEMBER, 1977

Inland Waters Directorate
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Vancouver, B.C.

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For:

Department of the Environment
Water Quality Branch
Inland Water Directorate
Vancouver, B.C.

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November 30, 1977

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ACKNOWLEDGMENTS

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I. SCOPE AND PURPOSE OF REPORT

The present report consists essentially of four parts. First, a review of the strip mining literature is given to highlight problems associated with coal development and to determine the most likely effects of strip mining operations on water quality.

Secondly, the environmental conditions dominant in the Northeast B.C. coal area are examined to provide a basis from which water quality impact analysis of strip mining can be made. In this context the interpretations of geology, land use and water quality are based on a partially completed provincial survey and monitoring programs. Sediment composition is determined from a 12 sample data set collected in the field in August, 1977.

The development programs of mining companies, and the Provincial and Federal programs are reviewed in the third section to determine the state and type of development and the effectiveness of monitoring programs.

Finally, development problems and their likely effects on water quality are identified.

At present, the majority of inventories, environmental surveys and monitoring programs by both mining companies and government agencies are incomplete. Furthermore, specifications as to size, type and exact locations of the development operations are currently being written up by the mining companies in the form of a stage two development report. The present analysis is therefore based on incomplete data and consequently some of the conclusions are tentative and general.

II. THE EFFECTS OF COAL STRIP MINING ON WATER QUALITY: A LITERATURE REVIEW

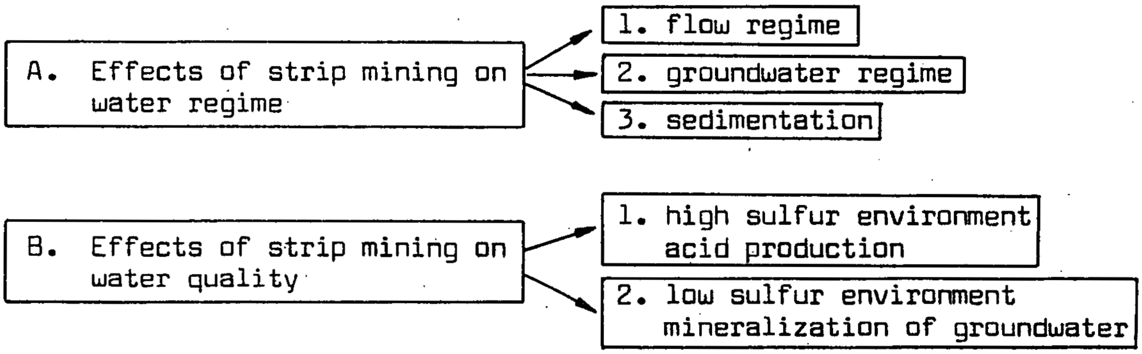
Strip mining has become the most important mining activity in terms of its impact on the environment and the extent of the area affected. Coal usually occurs in thin beds, and to harvest it large quantities of overburden material have to be removed. As a result large areas become unprotected and exposed to climatic, hydrologic, and geologic processes which can ultimately result in water quality deterioration.

In the present chapter an attempt is made to review the literature and to summarize some of the more important effects of coal strip mining on water quality. From the outset it should be noted that it is quite difficult to establish and predict effects on water quality from strip mining since not only are the processes poorly understood but its potential effects are dependent on a large number of factors. Some of the more important of these were identified by the Graduate Center for Public Works Administration (1972) and are listed in Table 1 under the following headings: (a) mining and reclamation process, (b) site conditions, (c) legislation and enforcement.

Table 1. Important factors influencing effects on water quality.

(a) Mining and Reclamation Process	(b) Site conditions	(c) Legislation and Enforcement
- Type of mining (trench, auger contour, area) - Pre-planning of operation; - Adequacy of construction design & access roads - Surveillance during operation - Preventive action before, during, after operation - Restoration & reclamation program	- Hydrologic conditions - Proximity to drainage - Groundwater conditions - Topographic conditions - Soil & geological conditions - Climatic setting - Location of water supply and use	- Existence of adequate legislature - Effectiveness of monitoring program (both hydrologic & reclamation) - Effectiveness of enforcement

Theoretically it is possible to conceive of a non-impact mining operation in which all of the factors have been examined prior to mining. In practice, however, it is most likely that because of economic conditions, lack of understanding of processes, and insufficient environmental information some problems will occur which will affect water quality. The most common problems reported in the literature are:



A. Effects of Strip Mining on Water Regime

The disturbance of large surface areas by strip mining usually affects the stream regime. The most important processes have been summarized in Table 2.

1. Extent and frequency of flooding

Alterations in vegetation cover, disturbance of the overburden material, removal of the coal beds, and changes in the surface configuration have a profound influence on the hydrologic cycle. The effect of these changes on the flow regime of the drainage varies undoubtedly according to the physical conditions and operational and regulation practices in the mining area. This point becomes readily apparent in the literature where contradictory observations have been reported.

Collier (1970), Curtis (1972, 1973) and Ahmed (1974) for example noted that mined watersheds tended to have more variable flow conditions than adjacent unmined watersheds. Storm flow rates increased by factors up to

TABLE 2: EFFECTS OF MINING ON WATER REGIME

EFFECTS ON WATER REGIME AS A RESULT OF LARGE SCALE STRIP MINING	INITIATING PROCESS AND REASONS FOR ENVIRONMENTAL EFFECT	AFFECTED WATER PARAMETER	POTENTIAL IMPACT	RELEVANT REFERENCES
1. EXTENT AND FREQUENCY OF FLOODING	INCREASE IN SURFACE RUN-OFF: Decrease in infiltration as a result of vegetation removal & soil cover. Interception and temporary water retention capacity are reduced by changes in topography, porosity & ground cover. This increases overland flow.	Modification of flow Increase in peak flow	Depending on amount and intensity of precipitation and type of surface material, flood run-off rates increased by a factor of 3 to 5 times	Collier, 1966 Curtis, 1972, 1973 Ahmed, 1974 Graduate Center, 1972
	DECREASE IN SURFACE RUN-OFF: Disturbed grounds when properly managed can become aquifers which have the capacity to moderate flow, thus decreasing peak flow and increasing low flow. Type of overburden & management methods (terracing, grading) are of importance.	Modification of flow Moderation of flow; decrease in peak flow; increase in low flow	Increased water storage in spoil pile causing moderation of flow with lower flood peaks and higher run-off during low flow.	Agnew & Corbett, 1973 Cederstrom, 1971 Curtis, 1971 Corbett, 1968
2. GROUNDWATER TABLE	DECREASES IN GROUNDWATER LEVELS OVER EXTENSIVE AREAS Coal beds and associated sedimentary strata often serve as continuous aquifers. Removal of coal and overburden affects water table and groundwater flow.	Decrease in groundwater table; Changes in groundwater flow	Lowering of water table affects wells and vegetation in surrounding area. Direct effect on flow regime.	Ahmed, 1974 Graduate Center, 1972
	CREATION OF NEW AQUIFERS AND GROUNDWATER STORAGE IN SPOILBANKS AND STOCKPILES Stockpiles and spoilbanks retain moisture and can absorb and intercept run-off water.	Increase in groundwater table; Changes in groundwater flow	Moderates flow regime and increases water storage	Van Voast et al, 1976 Corbett, 1968 Anderson & Youngstrom, 1976 Agnew & Corbett, 1973
3. SEDIMENTATION	INCREASE IN EROSION AND MASS MOVEMENT Increased surface wash and availability of sediments cause increased erosion. Exposed spoilbanks as a result of vegetation + soil + overburden removal are more susceptible to erosion. Steep slopes on freshly created spoilbanks become susceptible to sliding and slumping, especially as a result of insufficient drainage. This encourages direct sediment input into the streams. Most common sources of sediments are: spoil slides, haul roads, mining pit.	Affects water carrying capacity; Turbidity; Suspended sediments; D.O.	Sediments clog stream channels causing local flooding, reducing aquatic life; Inert silt suffocates organisms. interferes with fish migration, lowers D.O. which affects biological productivity; Sediments absorb metals and can become toxic; Silt decreases light penetration, thus affecting food production at low level of food chain; Increases in sedimentation by a factor of 1000 X have been reported.	Mills & Clar, 1976 Harrison, 1977 Guthrie & Cherry, 1976 Haynes. 1973 Doyle, 1976 Curtis. 1974 Nowrocki & Virkathurie. 1975 McCarthy, 1973 Boyer & Gleason, 1976

five times while base flow was reduced. The changes were attributed to a reduction in the water retention capacity thus increasing the surface run-off rates.

In contrast Corbett (1968), Curtis (1971) Cederstrom (1971), Agnew and Corbett (1973) found apparent increases in base flow and decreases in flood run-off rates in their studies. An increased porocity and storage capacity in the newly created spoil piles which consist of shattered rocks and mixed overburden material, are thought to be responsible for a greater interception of the precipitation and moderation of flow.

The margins between these positive effects of flow moderations and the negative effects of increasing variability and flooding are very small and are heavily dependent on the topographic and climatic setting, the mining operations and reclamation practices, and the material properties. At least initially a negative effect is most likely to take place.

2. Groundwater table fluctuations

Coal beds and their associated sedimentary strata often form continuous aquifers which extend over large areas. They are tapped for local water supply and farming, and are of particular concern in the semi-arid West. As noted by the Graduate Center for Public Works (1972) and Ahmed (1974), changes in topography, disruption and removal of the natural formation can result in lowering the water table over large areas. This again is probably dependent on the geologic setting and the mining practice as shown by Van Voast et al (1976), who found only local water table declines in his study of coal strip mining in Montana. He noted that the rate of decline is dependent on the rate of pit development.

A number of authors, Corbett (1968), Agnew and Corbett (1973), Harrison (1974), Farmer and Richardson (1976), and Van Voast et al (1976) have found strip mining to be beneficial in creating new groundwater aquifers in the overburden spoil piles. This might be accompanied by a deterioration in water quality and will be discussed later in this report. The newly created water storage can partially compensate and reduce changes in groundwater induced by the removal of the coal beds. This does not only minimize water level changes but also has a moderating effect on the stream flow.

3. Sedimentation

Boyer and Gleason (1976) and Doyle (1976) noted that increased sedimentation is by far the most important problem associated with surface mining. Erosion and sedimentation are natural processes but surface mining operations tend to increase and accelerate these processes. Sediment increases by a factor of 1000 have been reported for streams draining mining areas in Kentucky (Graduate Center for Public Works, 1972), and Curtis (1974) noted that increased sedimentation rates persisted for a considerable length of time after the closing of mine operations.

The rate of sedimentation is a function of the amount and intensity of rainfall, flow characteristics determined by the slope, properties and characteristics of the surface soil, and type and density of vegetation cover. As a result of the mining operation, the protective vegetation cover is removed, new steep stockpile and spoil-pile slopes are created, and fresh subsoil is exposed at the surface. Such conditions promote sediment entrainment and erosion especially during heavy storms. Accelerated surface run-off in the mine pit, slope failure, and haul road maintenance are considered the most important sediment sources (Doyle 1975). Slope failure is most common on stockpile and spoil-pile slopes where excessively steep slopes are created. Pile geometry, drainage and type of foundation material are considered the most important factors determining stability (Harrison 1973).

The maintenance of coal haul roads contributes heavily to sedimentation and erosion. Most roads are built as cheaply as possible, ignoring the environmental protection aspects of proper location and good design. They deteriorate rapidly and require continuous maintenance, an activity which is accompanied by continuous surface disturbance. According to Doyle (1976) haul roads contribute as much sediment to the stream as the entire mining operation.

A wide range of effects related to increased sedimentation has been reported. Amongst the more important are: clogging of streams, waterways and reservoirs, increased flooding, reduction of water use for irrigation and domestic purposes (Doyle 1976) and destruction of habitat, fish and aquatic life (Hynes 1973).

Numerous preventive measures have been proposed to ameliorate the sediment problem. Settling ponds and reservoirs away from natural drainage have only been partially successful (Nawrocki and Virkathuria 1975), McCarthy (1973) noted that colloidal particles often do not settle because they contain repellent negative charges. The analysis of overburden and soil properties and selection of the most appropriate surface material are considered essential in enhancing conditions for revegetation (Harrison 1973a & b, 1974, Farmer and Richardson 1976, Capp et al 1975, Lyle et al 1976). The use of vegetative filters has been suggested by Kao et al (1976). A combination of measures have been proposed by Mills and Clar (1976) and Doyle (1976). Doyle noted that the primary rule for effective erosion and sedimentation control is: "to plan earth moving activities in such a way that the minimum amount of disturbed area will be exposed for the minimum amount of time."

B. Effects of Strip Mining on Water Quality

The subject of water quality deterioration as a result of coal strip mining has received considerable attention in the literature. The most important processes and effects from such activities have been summarized in Table 3.

1. High sulfur environment: acid production

Next to sedimentation, water pollution by acid mine drainage is considered the most serious environmental problem. Coal seams and overburden strata which originated in brackish marine paleo-environments often contain significant amounts of pyrite. Once exposed to the atmosphere pyrite and its amorphous form, marcasite, is readily oxidized to a soluble hydrated iron sulfate. When the hydrated sulfate is dissolved sulfuric acid is formed. The acidity arises both from the oxygenation of ferrous ions and sulfide. The rate of pyrite oxidation is, according to Lorenz and Stephan (1967), dependent on oxygen concentration, particle size, temperature, moisture, pH, and bacterial catalysts. The ultimate level of acidity in the stream is determined by the rate of pyrite oxidation, the presence of Fe-bacteria, and the neutralizing capacity of both the geologic formation and the existing groundwater (Caruccio 1973, 1976). As a result of sulfuric acid release the pH of the water decreases and the solubility of a number of metals increases. Amongst the more abundant ones are: Fe, Al, Mn, Mg, Ca, Na, Zn, Pb, Cu, Cr. Increased dissolution may result in toxic concentrations of some metals. The acid mine drainage has been a particularly widespread problem in Appalachia where Biesecker and George (1966), for example, found 194 out of 318 sites affected by acid drainage.

The measurement of pH is not considered adequate in determining mine drainage pollution (Striffler 1973) since it does not account for neutralizing processes initiated by groundwater and geological formations. Fe, Mn, Al and SO_4 concentrations were found to be good indicators of acid mine drainage by Biesecker and George (1966), Stiffler (1973). All these parameters have been used to illustrate mine pollution in reservoirs (Brezina et al 1970), in groundwater (Emrich and Merrit 1969), and streams (Curtis 1973). Mn and sulfate are particularly sensitive and sulfate values of $>$ 20 mg/l have been suggested as indicators for mine drainage pollution (Biesecker and George 1966, 1972). Fe and Al concentrations are related to pH and as such are less useful. Extremely high concentrations of Fe (93,000 mg/l) and sulfate (22,000 mg/l), as well as Mn, have been observed in coal pile leachate by Anderson et al (1976) and Anderson and Youngstrom (1976). They noted that during periods of little precipitation these elements are dissolved by the moisture in the pile and are usually flushed out during high precipitation periods (see also Agnew and Corbett 1973).

Acid run-off water can attack clay sediments (Boyer and Gleason 1975) and in the process release Al, Fe, K and Si. This causes exchange reactions

TABLE 3: EFFECTS OF STRIP MINING ON WATER QUALITY

EFFECTS ON WATER QUALITY	INITIATING PROCESS AND REASONS FOR ENVIRONMENTAL EFFECT	AFFECTED WATER QUALITY PARAMETER	POTENTIAL IMPACT	RELEVANT REFERENCES
1. HIGH SULFUR ENVIRONMENT: ACID PRODUCTION	ACID MINE DRAINAGE: Coal and overburden strata often contain a significant amount of pyrite (formed in a brackish marine Paleo-environment). Once exposed pyrite is oxidized and mineral acid (H_2SO_4) is produced. The pyrite oxidation rate is dependent on oxygen concentrations, particle size, temperature, moisture, pH, and Fe & S bacteria which operate as catalysts. Acid generation is partly a function of sulfur content, the crystallinity of the pyrite, the presence of Fe bacteria, and the buffering or neutralizing capacity of the groundwater. Continuous acid production reduces buffering capacity causing an increase in acidity and decrease in pH. At low pH the solubility of some metals increases. Mn, Fe, Al, and Sulfate are considered the prime indicators of acid drainage.	Decrease in pH; Increase in acidity; Increase in Sulfate; " " Mn " " Fe " " Al Other possible increases: total dissolved solids; soluble salts, Mn Ca, Na, Mg, As, Pb, Zn, Cu, Cr REDUCTION IN OXYGEN; DECREASE IN BUFFERING CAPACITY.	MAJOR PROBLEM: Acid drainage at pH below 4.5 is lethal to fish and will reduce aquatic life and vegetation growth. Decrease in oxygen (used in pyrite oxidation), metal toxicity (Mn, Al), and $Fe_2(SO_4)_3$. Accumulation in stream will reduce fish reproduction, stream productivity and water use. MINOR ADVANTAGE: Acid drainage interaction with sediments cause exchange reaction in which higher exchange capacity clays are reproduced. This increases cation exchange capacity.	ACID MINE DRAINAGE PROCESS: Caruccio, 1973, 1976 Striffler, 1973 Biesecker & George, 1966, 1972 Boyer & Gleason, 1975, 1977 Lorenz & Stephan, 1967 Brezina et al, 1970 Ahmed, 1974 Emrich & Merritt, 1969 Foster & Wittmann, 1976 ACID EFFECT ON STREAM ECOLOGY: Warner, 1973 Parson, 1968 Katz, 1969 Radford & Graveland, 1973 Spauling & Ogden, 1968 Jensen & Snekvik, 1972 Beamish et al, 1975 Kwain, 1975 Berg & Vogel, 1968 Crouse & Rose, 1976
2. LOW SULFUR ENVIRONMENT: SOLUBLE SALT PROBLEMS	MINERALIZATION OF GROUNDWATER: Water from inorganic aquifers is usually more mineralized than groundwater from coal bed aquifers. The removal of the coal and the creation of new aquifers in storage and spoil piles are accompanied by an increase in mineral content of the groundwater. MINERALIZATION OF STREAM WATER: Some materials in the overburden contain more available salts and when exposed and used as pit-cover are leached. During periods of low precipitation moisture in coal pile dissolves minerals which will be flushed out during storms.	Increase in: Specific conductance total dissolved solids; sulfate Ca, Mg, Na, Fe, Mn bicarbonate minor metals salts	MINOR PROBLEM: Increase in: Soluble salts, dissolved solids and metals in groundwater can limit its use; Salts can be toxic to benthic environments; Greater seasonal, monthly and well quality variations are usually associated with strip mining.	Van Voast et al, 1976 Pietz et al, 1974 Minera & Tschantz, 1976 Boyer & Gleason, 1976 Dettmann & Olson, 1977 Farmer & Richardson, 1976 Struthers, 1964 Curtis, 1973 Hallam et al, 1975 McWhorter et al, 1975

in which higher exchange capacity clays are produced (Crouse and Rose 1976). The greater cation exchange capacity can be beneficial provided that the effects of acid pollution and metal toxicity do not dominate.

High acid and metal concentrations have serious effects on stream ecology, water use and vegetation growth. The effect of acidity on fish has received considerable attention in the literature, but acid problems in the form of acid precipitation from industrial sources have been observed worldwide (U.N. Conference on Human Environment 1972, Jensen and Snekvik 1972, Almer et al 1974, Likens 1976, Beamish 1974, Beamish et al 1975, Hendry et al 1976, and Schofield 1976). Acid precipitation in streams, lakes, and reservoirs seems to provoke effects similar to those identified by acid mine drainage, namely low pH, high Al, Mn, and sulfate values, (Wright and Gjessing 1976). Water with pH values below 4.5 was found to be lethal to fish (Kwain 1975) in the laboratory, and a reduction in all benthic invertebrates was reported at the same level by Warner (1973) for streams influenced by acid drainage. A reduction in productivity and species diversity as well as damage to aquatic life were found by Katz (1969) and Spauling and Ogden (1968). The latter also noted deleterious effects of acid drainage on terrestrial animals.

High metal concentration was found to be detrimental to both the aquatic environment and vegetation growth. Increases in metals by a factor of up to 10,000 times were reported from acid metal mine operations by Forstner and Wittmann (1976). Metal toxicity at these levels was found to inhibit plant growth, a problem which is most serious in mine reclamation. Berg (1965), Berg and Vogel (1968), Wali and Freeman (1973) and Peterson and Nielson (1973) found that high concentrations in Cu, Al and Mn inhibit vegetation growth on spoil piles. Toxic spoil piles were characterized by Struthers (1964) as having high acidity, very high salt content, high levels of soluble Al, Fe and Mn, and low amounts of Ca and Mg.

The role and importance of trace metals in U.S. coals have been reviewed by O'Gorman and Walker (1972). Lead isotopes were found to be more radiogenic in coal than in other natural environments (Chow and Earl 1972). Many of the trace metals find their way into the stream but the control mechanisms, variability and incidences are at present still poorly understood (Alderman 1973).

Acid and metal pollution can be reduced by proper analysis of the coal and overburden material prior to mining (Grube et al 1973, Sobek et al 1976). On the basis of such analysis the least offensive material which is suitable for vegetation growth is selected as surface cover in reclamation (McCormack 1974). Many other methods which can ameliorate acid and metal pollution have been proposed. They range from neutralization with lime (Lovell 1973, Ross 1973) to hydrolytic absorption of metals (Miller 1972), precipitation of metals (Pugsley et al 1970), chelation with agents (Lee and Howard 1973), and revegetation (Kosowski 1973). None of these methods are very successful in isolation as demonstrated in the example by Up de Graft and Sykora (1976). They noted that salmon avoid acid water when it has been neutralized with lime. A combination of activities placing emphasis on reducing acid production at the mine source during the mine operation is probably the most effective. This is more logical than trying to restore polluted streams and lakes, a process which is complex and time consuming (Campbell and Lind 1969).

In some cases natural acid lake recovery has been observed. The processes involved were analyzed by King et al (1974) who found that the accumulation of organic matter can produce anaerobic conditions which favour bacterial induced reduction of sulfate to sulfide. These processes are generally slow and such factors as acid production potential, temperature variations, oxygen conditions, turbidity etc. all seem to influence the rate of recovery.

2. Low sulfur environment: soluble salt problems

In low sulfur environments acid formation has not been observed; instead mineralization of ground and stream water is of some concern in a number of strip mine operations. Such problems are of lesser importance than sedimentation and acid mine drainage but are of local importance in western North America where coal and overburden materials usually have low sulfur concentrations (less than 1%) and where water is used for irrigation.

Waters from inorganic aquifers are usually more mineralized than groundwater from the coal bed aquifers. The removal of coal and the creation of new aquifers in the storage and spoil piles is usually accompanied by an increase in the mineral content of the groundwater. Moisture in the new storage piles usually dissolves salts which are flushed into the groundwater reservoir and streams during heavy storms (Anderson and Youngstrom 1976, and Agnew and Corbett 1973). Van Voast et al (1976) found only slight increases in the mineral content of groundwater from non-acid mine drainage in Montana. Pietz et al (1974) on the other hand found significant increases in electrical conductance, soluble salts, and selective metals in his study in Illinois. Fe, Mn, Zn, NH_3-N were found to be above public water supply standards and Cd, Cr, Pb and Zn values increased by 2-5 times over those from undisturbed areas. They also noted a greater seasonal, monthly and well variation after mining and attributed this to the more heterogeneous surface conditions created by the mining operation.

Similar results were reported in studies of non-acid streams. Total dissolved solids, Ca, Mg, Mn, Fe and sulfate were found to differ significantly between disturbed and non-disturbed watersheds (Minera and Tschantz 1976, Harrison 1977). Curtis (1972) noted that some of these elements increased for up to two years after the mining operation ceased, while others peaked very rapidly and returned to normal levels. Significant increases in soluble salts but not heavy metals were observed in studies by McWhorter (1975) and Boyer and Gleason (1976). Radical fluctuations in sulfate and possible metal problems were indicated by Hallam et al (1975). In contrast to these observations, Dettmann and Olson (1977) and Van Voast et al (1976) found few and insignificant changes in water quality in their studies in Montana.

The diversity in these observations can probably be attributed to differences in the geological formations, site conditions and type of mining operation. Because of this variability it is difficult to determine the overall effects of increases in soluble salts and selective metals on stream ecology and water use. Some authors, such as Tomkievicz and Dunson (1977), observed decreases in stream biomass in marginally polluted acid mine drainage. Radford and Graveland (1973) found that Pb and Zn concentrations from some coal mine drainage could be toxic to benthos and trout populations.

Problems relating to high salt content are more serious for water use in irrigated agriculture and reclamation work where vegetation growth can be inhibited (Ries et al 1976). In these cases, however, it is more likely that climatic factors such as lack of moisture (May 1967, Root 1976), a problem most common in the arid west, and higher ground termperature in the summer are the causes for inhibiting plant growth. The latter condition disturbs germination and is induced by darker surface configurations resulting from mixing coal residues with the overburden (Deeley and Borden 1973).

SUMMARY

Sedimentation and acid mine drainage were found to be the most widespread problems related to coal strip mining. The former is of concern in all strip-mine operations, while the latter is restricted to geological strata which contain high amounts of pyrite (> 1%). In low sulfur environments water quality problems were found to be more variable; the more important concerns range from increased soluble salts to greater mineralization of groundwater.

No long term solutions have been found to cope with all the problems resulting from coal strip mining, and greater or lesser effects on water quality are expected to take place in all mining operations. Proper planning and analysis of the mine site, careful control during operation, efficient reclamation programs and an effort to minimize the size of the exposed surface area at all times during and after the operation are the key to minimizing the effects of coal strip mining on water quality.

III. DESCRIPTION OF ENVIRONMENTAL CONDITIONS IN THE NORTHEAST B.C. COAL AREA

Extensive coal deposits have been found in the eastern foothills of Northeastern British Columbia. Many of the coal seams are near the surface and those with the greatest economic recovery potential are located in the upper part of the watersheds of the Murray and Sukunka Rivers, with additional sites to the north (Carbon Creek) and to the south (Red Deer and Narraway Rivers).

For the purpose of this study emphasis will be placed on the Sukunka-Murray area where future development activities will be centered. The rivers in question are tributaries of the Pine River forming part of the Peace River drainage system. An overview of the area is provided below in an annotated Landsat image (Plate 1).

Since the present report is concerned with water quality, only those environmental conditions relevant to this subject will be highlighted. The analysis is primarily based on information provided by the Environmental Land Use Committee Secretariate (ELUCS) and the Resource Analysis Branch in Victoria (contacts: T. Boydell, N. Carter, R. Crook, L. Regan). Additional information on water quality of the Pine River was obtained from S. Sheehan (Water Quality Branch, Vancouver), and data on sediments were obtained by field sampling and laboratory analysis.

A. Geology of the Murray and Sukunka Watersheds and Rock Composition of Mining Areas

The two rivers have cut through the eastern foothills of the Rocky Mountains and the basic geological structure consists of a series of cretaceous sedimentary rocks ranging from coal to sandstones, siltstones, shales, mudstones and claystones. (The analysis of drill core data was provided by Denison Coal Ltd.) The regional geology is currently being mapped by the Mines and Reclamation Branch in Victoria (contact: N. Carter) and the area can be divided into three distinct regions: the rolling upland,

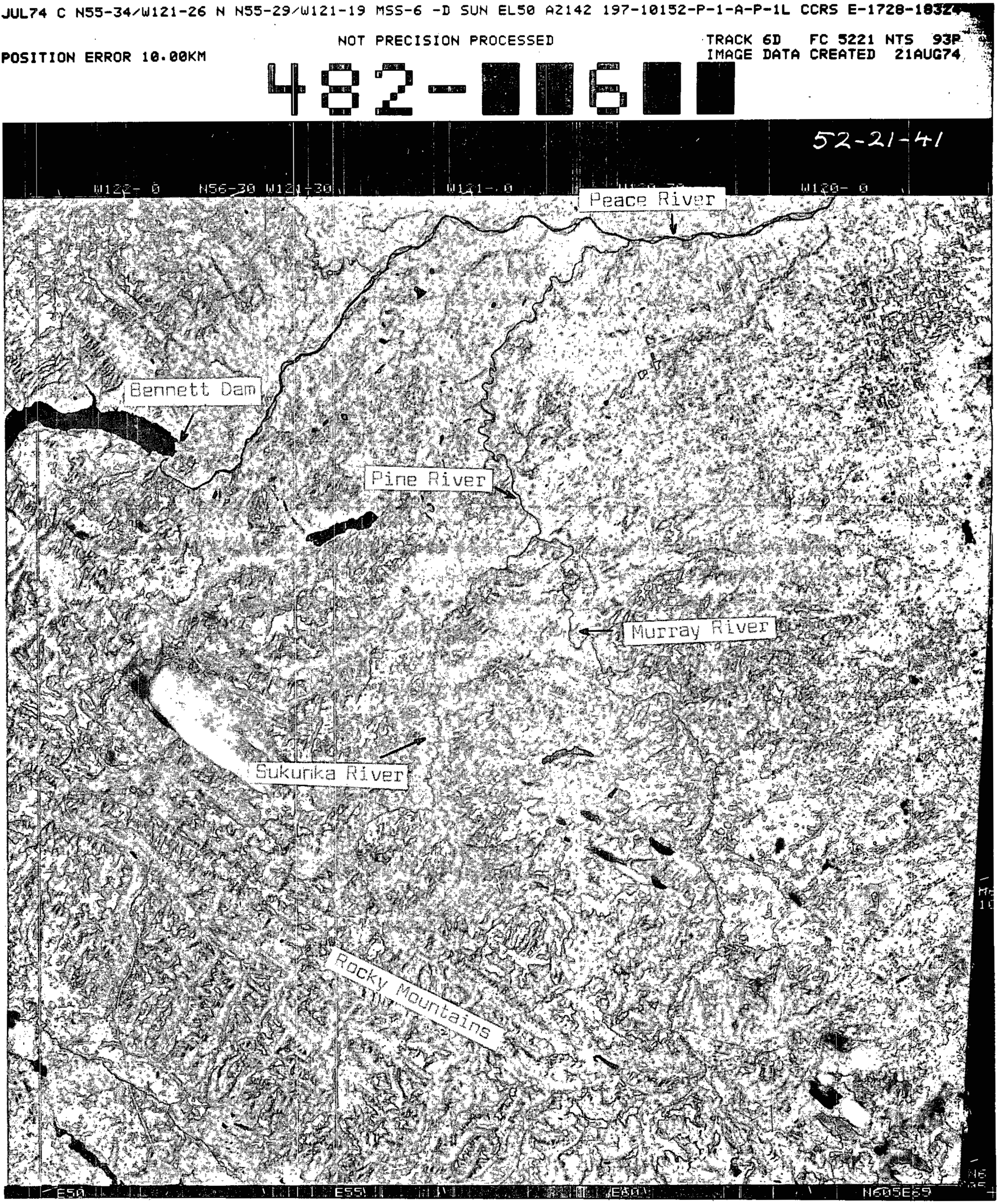


Plate I : Landsat Overview of Northeast British Columbia Coal Area the foothills, and the Rocky Mountains. A basic cuesta structure of slightly eastward dipping sandstone and shale layers is responsible for the rolling upland topography which is most prominent in the lower and eastern sections of the study area (Mathews 1963). The foothill section is dominated by a series of sub-parallel sandstone ridges which have been faulted and folded. They are underlain by a series of shale, conglomerate and sandstone strata. The headwaters of the two streams originate in the Rocky Mountains which in this part of British Columbia consist of extensively folded and faulted quartzite, shists, limestones, sandstones and shales. The coal deposits are situated in the foothill section and their relationships with coal deposits elsewhere in the Rocky Mountains has been described by Stott (1974). The major deposits belong to the Bullhead, Fort St. John, and Blairmore group, range in thickness from a few centimeters to about three meters, and are usually overlain by marine sandstones.

Chemical data provided by the mining companies (Teck Mining Group Ltd. and Denison Coal Ltd.) indicate that the coal itself has a low sulfur content (range 0.08-0.9%) and low acid production potential. Some 58 overburden samples were also analyzed by B.C. Research (Denison Coal Ltd.) in order to assess the reclamation potential of different strata. Only one sample, a conglomerate, showed an excessive pH value while the rest ranged from pH 6.2 - 9.0. Nutrient deficiency seemed most commonly associated with conglomerates and only three samples (two sandstones and one conglomerate) showed excessive salt content. No analysis of trace and heavy metal content was performed on either the coal or the overburden samples. A summary of Ca, Mg and K contents in the drill core samples is provided in Table 4, Chapter III.

B. Surficial Deposits and Soils

The Quaternary history and surficial deposits have been described by Mathews (1963) who noted that the Cordilleran ice sheet and glaciers originating from the higher parts of the Rocky Mountains have influenced the area considerably. The surficial geology can be divided into five categories:

(1) sorted fluvio-glacial deposits
(2) unsorted morainal material
(3) lacustrine deposits
(4) colluvium
(5) rock outcrops

The sorted fluvio-glacial deposits are prominent along the present drainage system, while the morainal material covers most of the area between valleys. Colluvium is associated with steeper bedrock slopes and exposed bedrock surfaces are most prominent along the ridges of the foothills and in the deeply dissected river valleys in the lower section of the Murray and Pine Rivers. Lacustrine deposits are found in the lower portion of the Murray River. The rivers have cut canyon type trenches in the lower section of the Murray and Pine Valleys, where weathered shale, fluvio-glacial and lacustrine deposits often form unstable slopes. Bank failure, erosion and periodic flooding seem to be the dominant surficial processes in this area.

The soils in the lower portion of the watershed have been described by Farstad et al (1965) while the upper section is currently being mapped by the Resource Analysis Branch (contact: T. Boydell). Soils associated with the above mentioned surficial deposits fall into these orders: Regosolic, Brunisolic, Luvisolic and Podzolic. The morainal soils are usually moderately calcareous, ranging in texture from sandy loam to clay loam, and have moderately high base saturation (Feller and Moberly Soil Series). They are dominant in the lower Sukunka and northeastern Murray watershed. In the lower Murray Valley soils on Fluvio-glacial deposits belong to the Beryl series (east banks) and Sundance-Twidwell series (western banks). They have loamy sand to sandy loam texture, and lower Ca and Fe content than their till counterparts. Lacustrine soils in the Lone Prairie area (NW-Murray River) belong to the Prestville and Sukunka series with high base saturation and potentially high salt content. Finally, residual podzolic soils developed on sandstone bedrock (Tremblay series) contain low exchangeable cations and have generally coarser textures.

C. Vegetation and Land Use

Based on E.L.U.S.C. (1977) the area is dominated by forest vegetation ranging from White Spruce to subalpine Fir, Engelman Spruce, Western Hemlock, and Western Red Cedar. Altitudinal zonations have been well established. The forests are considered mature with low to moderate production potential and are currently being logged in a number of locations within the watershed. Climate and topography are responsible for low agricultural potential but in the Lower Murray Valley (Lone Prairie) a substantial amount of land has been cleared and is currently used for cattle, feed, and grain production. Other land uses of interest are exploration for gas and coal, and road construction.

D. Climate

An extensive climatic network has been set up by the Resource Analysis Branch (contact: T. Chamberlin) but, as noted by E.L.U.S.C. (1977), it takes a record of at least four years before a reliable evaluation can be made. In very general terms and based on records from Chetwynd and Dawson Creek it is evident that winters are cold and long (at least five months with a mean daily temperature of below zero) and precipitation is low (400 - 450 mm). It has been suggested (E.L.U.S.C. 1977) that break-up occurs on March 20th (± 5 days) and freeze-up takes place on October 31st (± 5 days).

E. Hydrological Conditions

Water Survey of Canada has maintained a gauging station on the Pine River since 1961 (below the Murray River confluence). New gauging stations are currently being set up on the Murray and Sukunka Rivers but no data have yet been collected (for details on the gauging program see Chapter IV).

Based on the single station record the general flow regime of the Pine River was assessed in Figures 1 and 2. Peak flow usually occurs during the May-June period, with minor secondary peaks in August, September and October, probably the result of thunderstorms. The lowest flow conditions, from the 16-year record, usually occur in March.

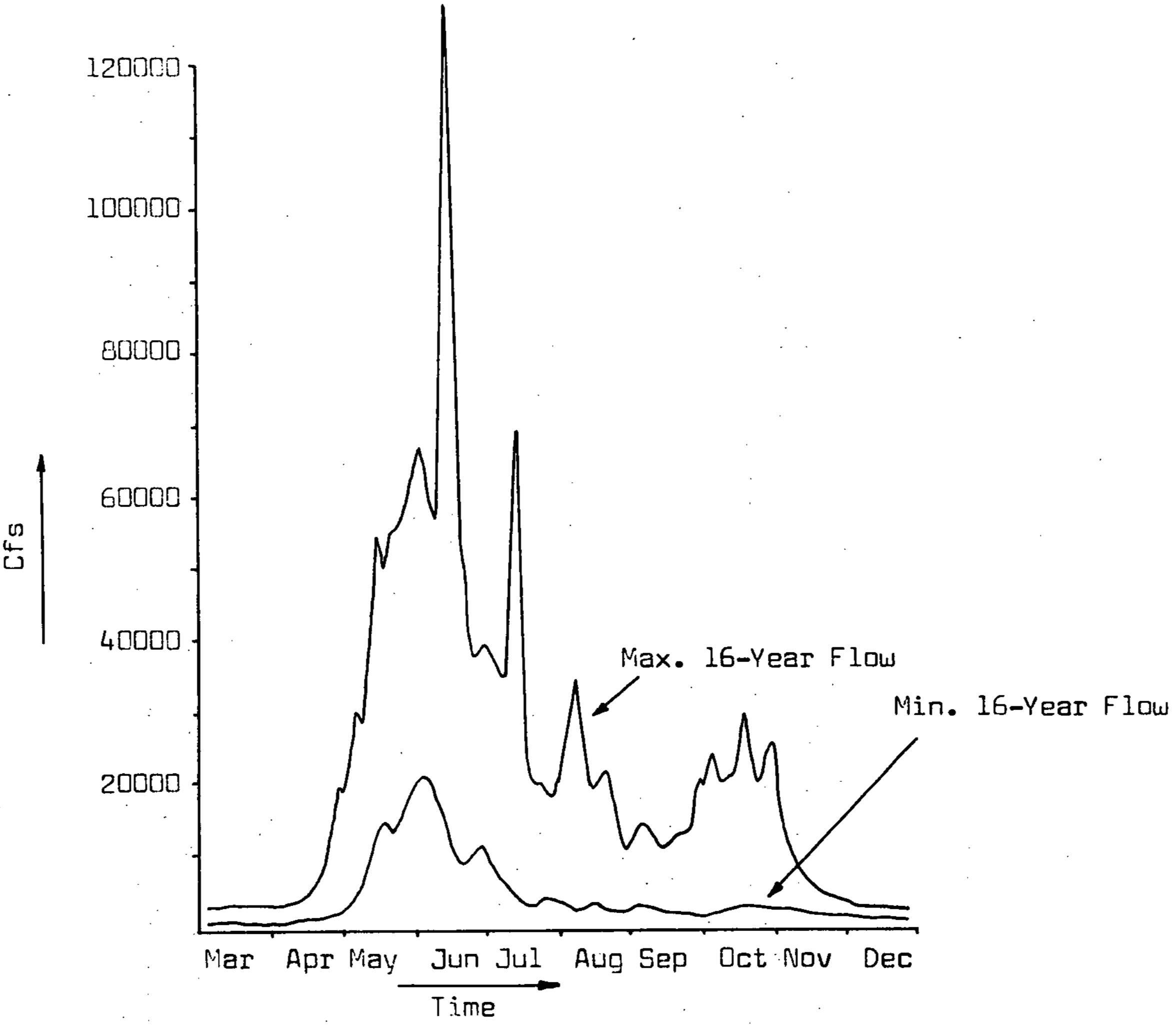
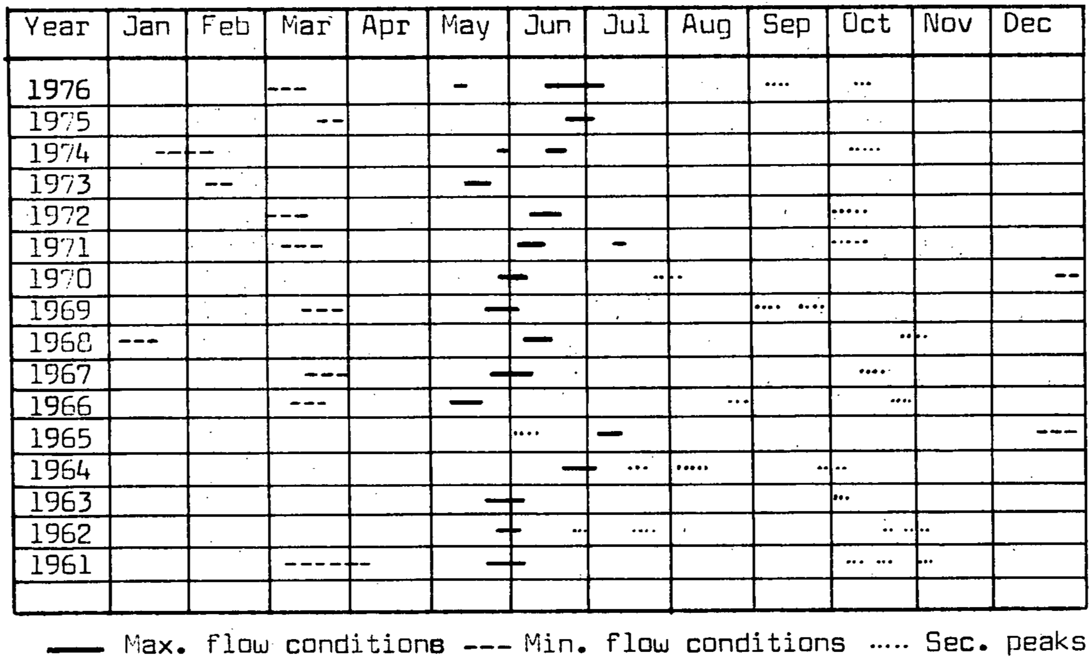


Figure 1 : 16- Year Hydrograph



Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976			---		—	—	—		....	...		
1975			--			—						
1974	--	--			—	—				.....		
1973		--			—							
1972			---			—				.....		
1971			---			—	—			.....		
1970					—	—	....					--
1969			---		—				....			
1968	---					—				..	..	
1967			---		—	—				....		
1966			---		—			...		....		
1965						....	—					---
1964						—	...	.....	..	..		
1963					—	—				...		
1962					—	—	...	....		.. ....		
1961			------	-	—	—				... ...	...	

— Max. flow conditions --- Min. flow conditions ..... Sec. peaks

Figure 2 : Flow Regime of Pine River, at East Pine.

F. Water Quality Conditions

Water samples from the Murray, Sukunka, and Pine Rivers, as well as from a number of tributaries, have been analyzed on a regular basis during the 1976 and 1977 field seasons by the Water Investigation Branch (contact: L. Regan). Complementary data for the Pine River at its confluence with the Peace River were available through the Water Quality Branch in Vancouver (courtesy of S. Sheehan). The data from these two sources were used for an analysis of the temporal and spatial conditions of the three rivers. In each case only the upstream and downstream stations were used (station # 177701 to # 177706). The locations of the sampling stations are indicated in Figure 3 on the following page.

1. Temporal trends

Using both the 1976 and 1977 seasonal data a number of chemical parameters showed a distinct seasonal trend at all stations. The most clearly visible of these were: specific conductance, dissolved Ca, and dissolved Mg (see Figures 4, 5 and 6). These three parameters seem to be related to water flow, having low values during peak flow periods and high values for low flow conditions. The trend seems to persist for both the 1976 and 1977 seasons. Unfortunately no data exist for the five-month winter season to complete the cycle, and the flow information cannot be used for correlating flow rates with water chemistry since the gauging site on the Pine River is unsuited for water quality analysis.

A similar but somewhat less distinct seasonal trend was found for filterable residues but no such evidence was present for total residues. Total iron on the other hand showed high values during peak flow periods with a steady decrease during summer and fall (Figure 7). Unfortunately only four corresponding sets of samples could be used for all six stations covering both the 1976 and 1977 seasons, thus limiting the reliability of this observation.

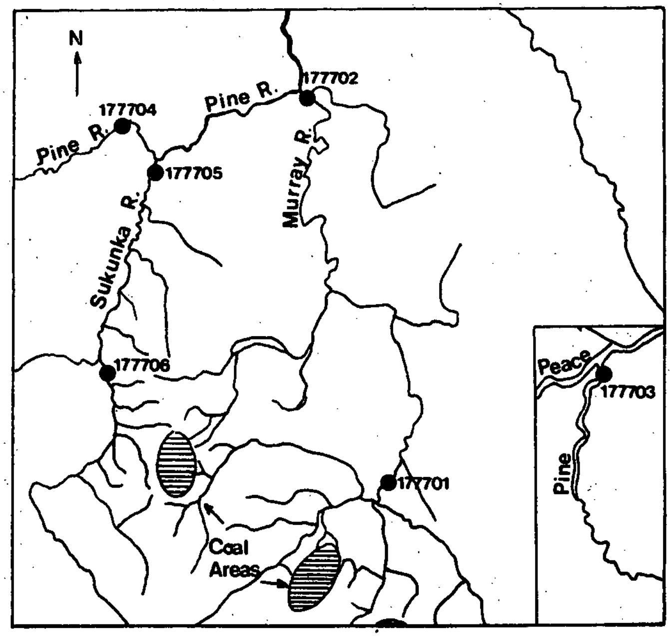


Figure 3 : Locations of Water Quality Sampling Stations.

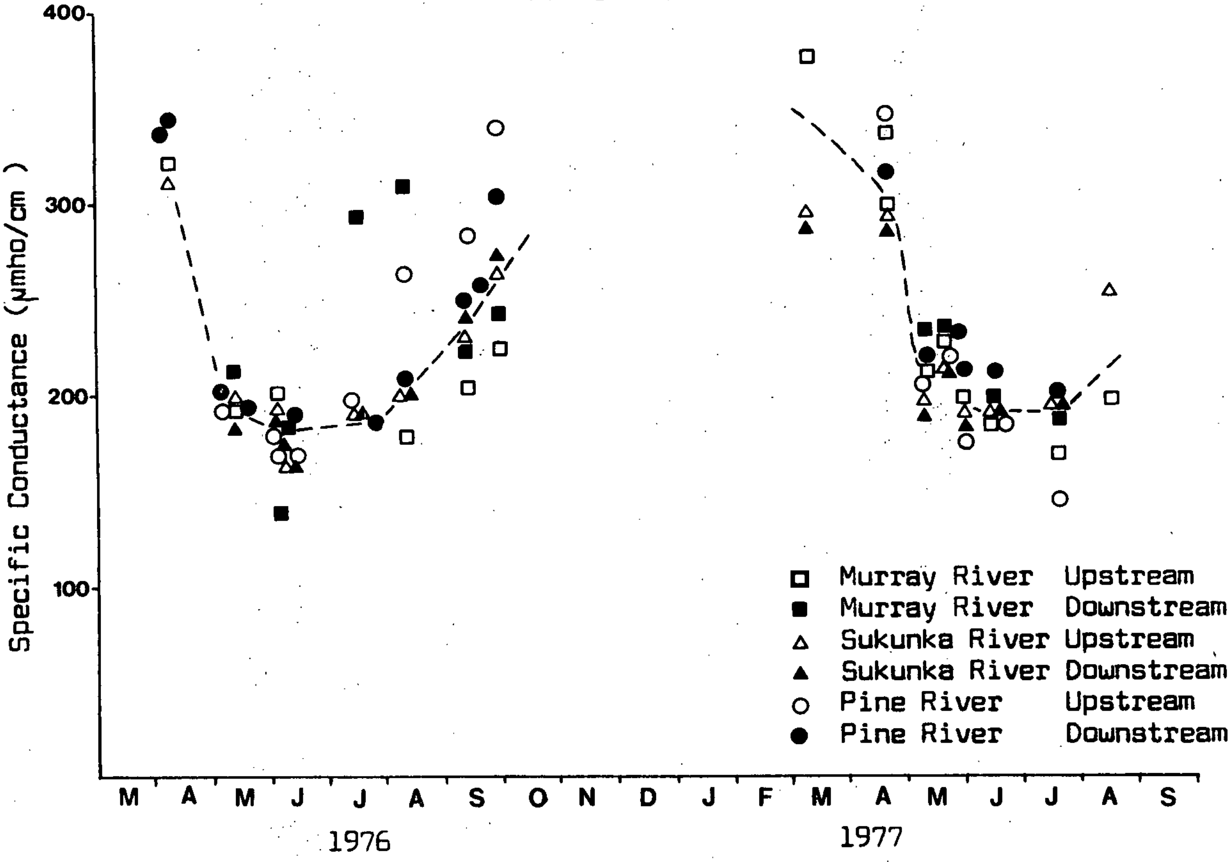


Figure 4 : Seasonal Trend of Specific Conductance.

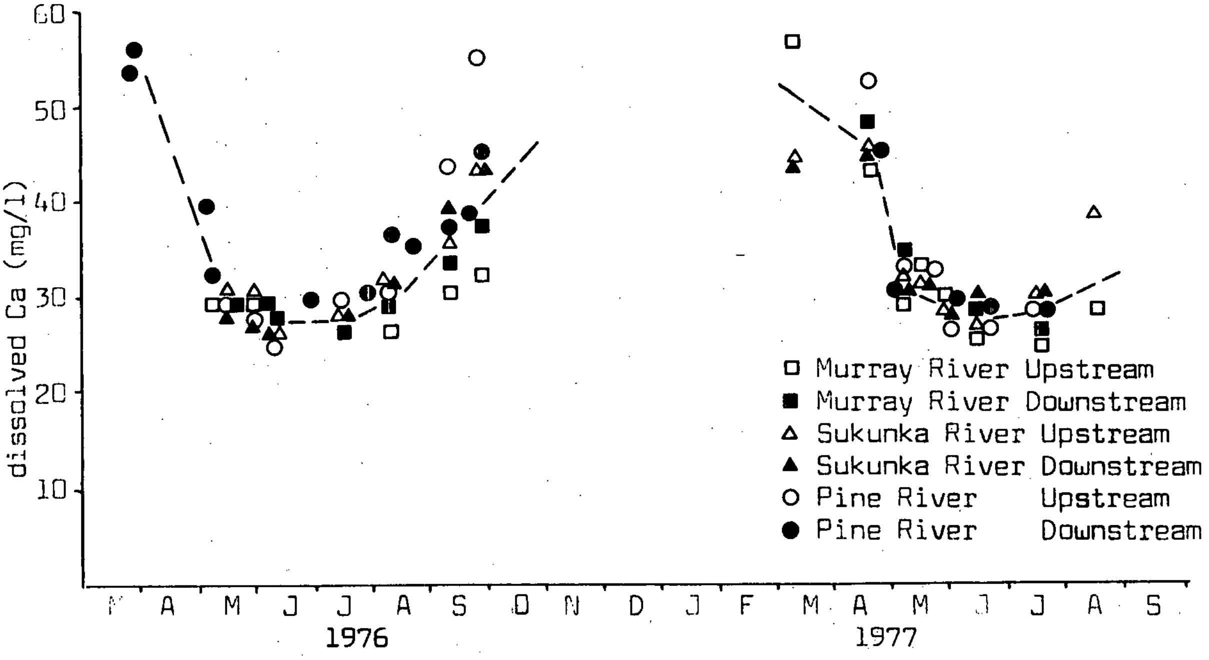


Figure 5 : Seasonal Variation of Dissolved Ca (Sukunka, Murray, & Pine River)

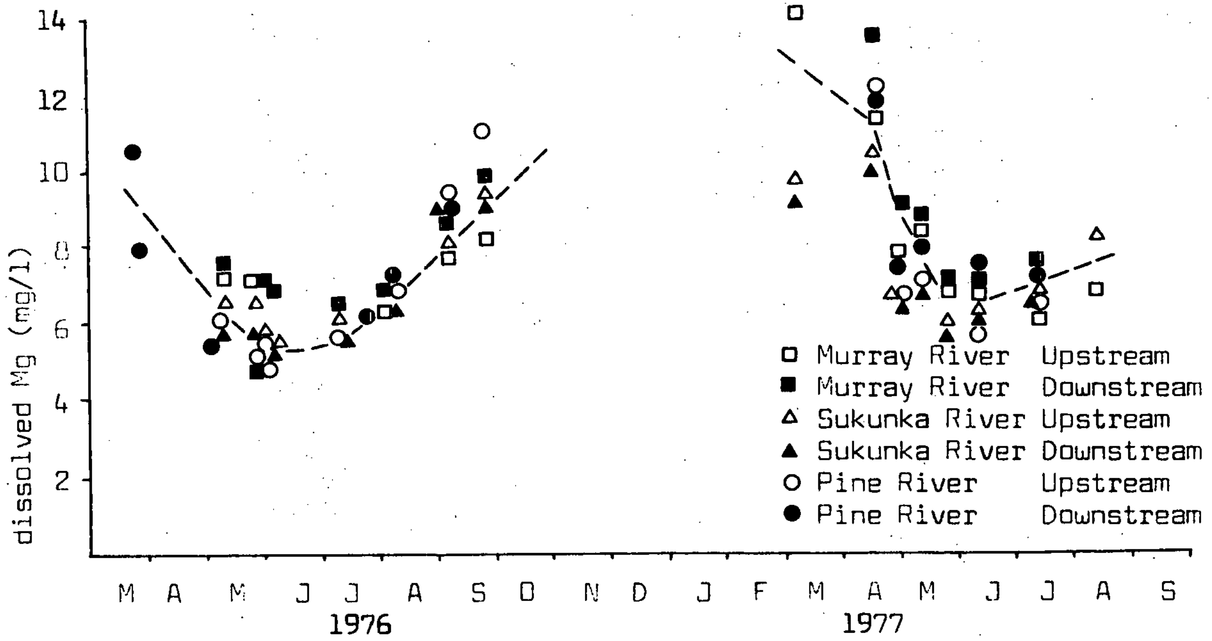


Figure 6 : Seasonal Variation of Dissolved Mg (Sukunka, Murray, & Pine River)

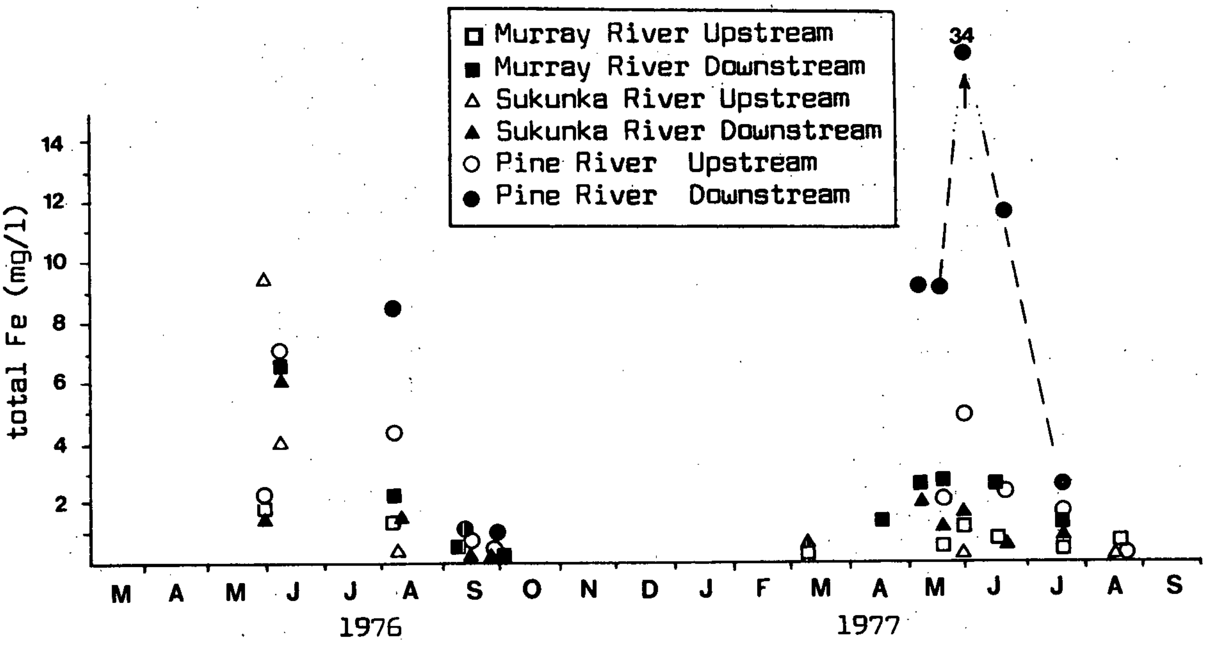


Figure 7 : Seasonal Trend of total Iron Content

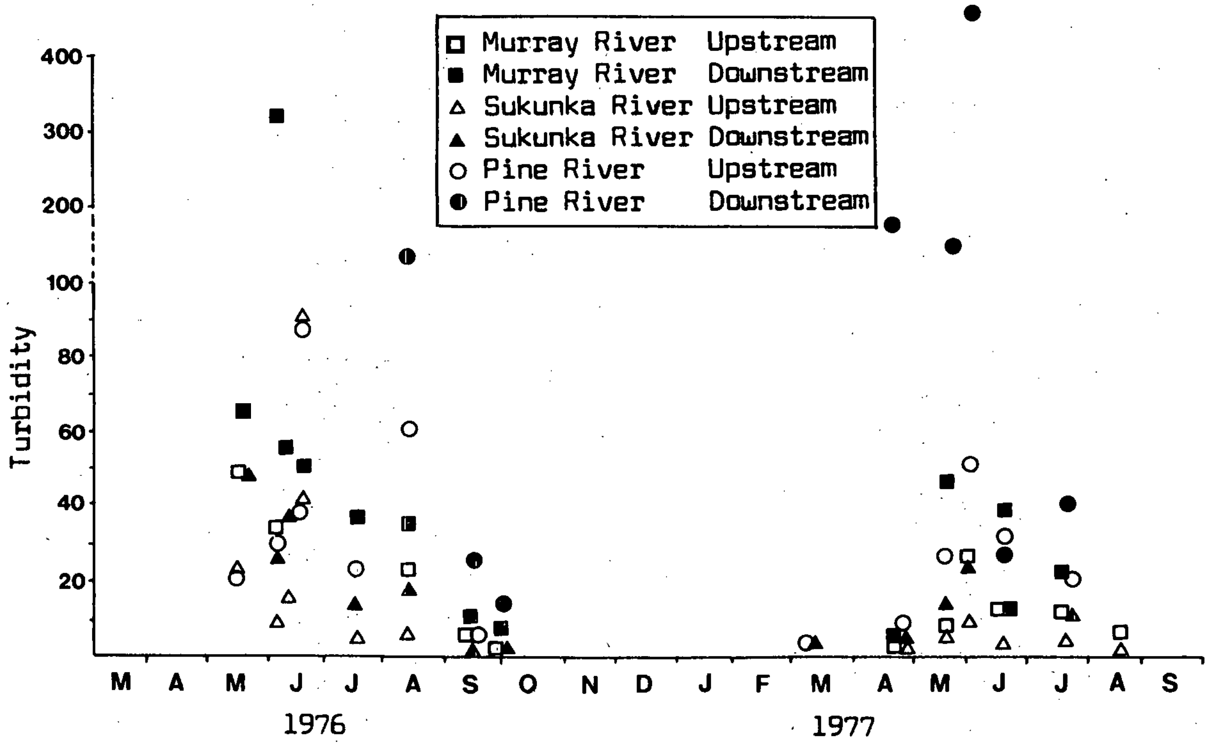


Figure 8: Seasonal Trend for Turbidity

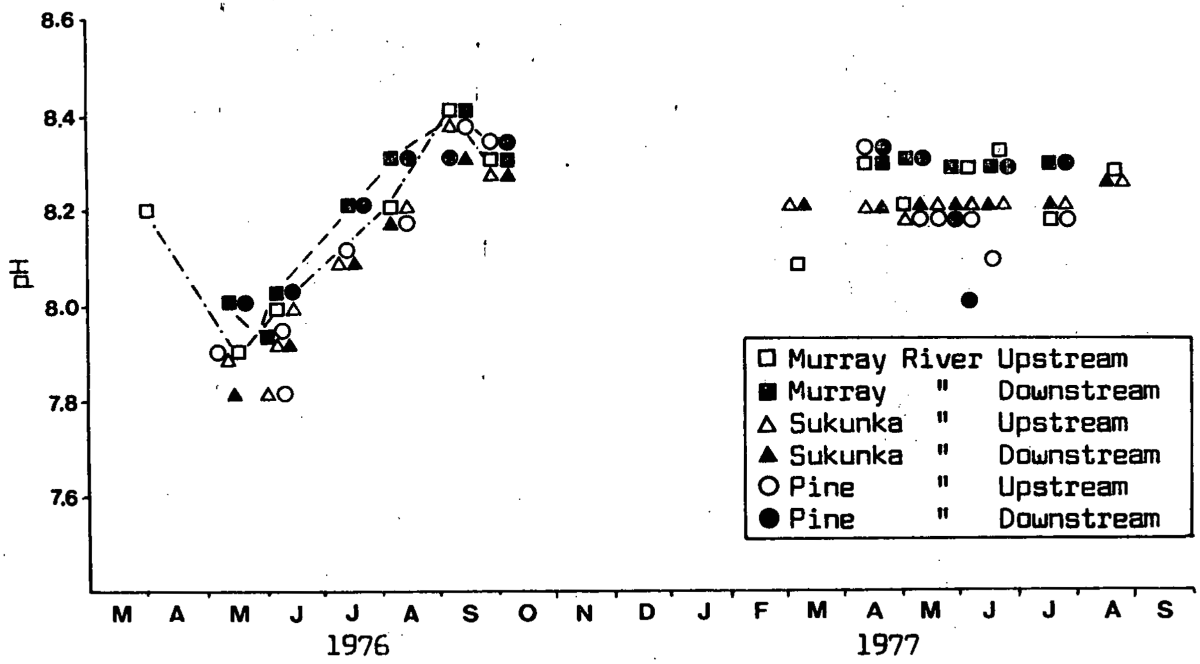


Figure 9 : Possible Seasonal Trend for pH .

Variability for most other parameters was too small to indicate temporal trends with the possible exception of turbidity and pH. Turbidity is often positively related to flow rates and data for the three rivers confirm this to some extent (Figure 8). In the absence of a detailed gauging record at the corresponding sampling station no quantitative comparison could be performed. The pH showed some evidence of cyclic behaviour for the 1976 season (Figure 9). Unfortunately this trend could not be confirmed for the 1977 season and the results are therefore inconclusive.

2. Spatial trends

A number of observations can be made concerning spatial distribution of chemicals. These fall into two categories: (a) changes in downstream concentrations, and (b) differences between the three rivers. As expected the values for a number of parameters were consistently higher at the downstream stations than at the upstream stations. This is particularly so for total iron, specific conductance, turbidity, and total residuals. There were too few simultaneously collected sampling sets in which all six stations were covered. As a result no trends for other parameters could be detected.

In attempting to compare the chemical conditions of the three rivers a number of additional problems were encountered:

(a) It was difficult to determine whether the different stations produce representative chemical data for each river;

(b) in the absence of a gauging record it is impossible to compare flow conditions and regimes of the three rivers;

(c) the size of the basins and their land use are not identical, conditions which affect streams in different ways;

(d) the Murray and Sukunka Rivers are tributaries to the Pine River and contribute to the loadings observed in the downstream station of the Pine River.

Given these problems a comparison between the three rivers raises considerable doubt as to its accuracy and the following should therefore be considered as an exploratory analysis rather than concrete evidence.

The Murray and Sukunka Rivers above their downstream stations and the Pine River above the upstream station are somewhat similar in size, and drain similar rock types. The chemical values for these stations were compared using only simultaneously collected data sets for the 1976 and 1977 seasons (collected during the same time period). The parameters indicated in Figure 10 show consistently higher or lower values when compared with the corresponding stations on the other rivers.

Stations on:	SUKUNKA RIVER	PINE RIVER	
MURRAY RIVER	Total Fe • Sulfate *	Total Fe ••	•• Based on 7 paired observations + Based on 9 paired observations * Based on 4 paired observations Based on 12 paired observations
SUKUNKA RIVER		Total Fe •• Turbidity + Filterable residuals Sulfate *	

Figure 10. Parameters showing consistently different values when compared between the different river systems.

The Sukunka River station showed consistently lower values in total iron and sulfate than the Murray and Pine River counterparts. This was also confirmed in some of the upstream and tributary stations on the Murray and Pine Rivers, thus suggesting that the chemical conditions in the Sukunka River are slightly different. Additional support for this suggestion can be found when analyzing dissolved calcium levels (Figure 11). The upstream and downstream stations on the Murray and Sukunka Rivers do not seem to differ consistently for the March-July period, but the Sukunka levels seem to increase more rapidly during the August-October period for both the 1976 and 1977 seasons. The significance of this increase cannot be tested statistically since too few data points are available and, as in the above case, this remains a suggestion awaiting confirmation by additional sampling.

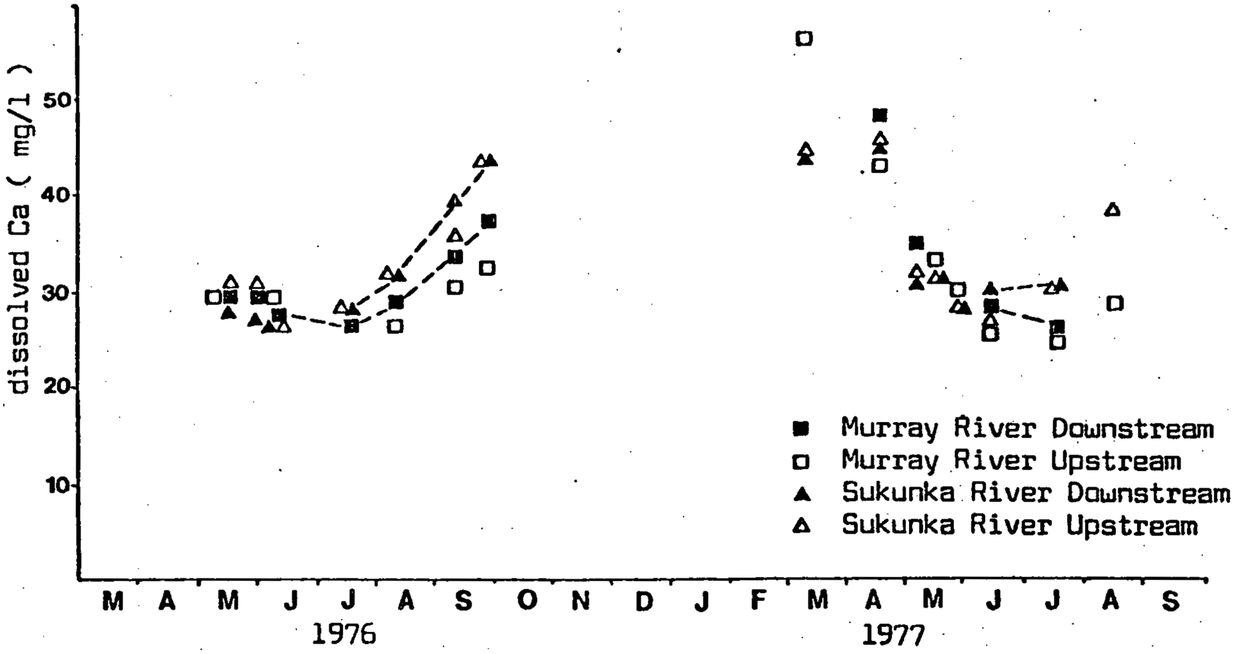


Figure 11: Comparison of Ca levels in the Murray and Sukunka Rivers.

3. General water quality conditions

As pointed out by E.L.U.S.C. (1977) and the Ministry of Environment Water Investigation Branch (1976 a, b, c) the three rivers have moderately hard alkaline waters with high levels of turbidity, color, iron and Mn. The iron values consistently exceed recommended EPA drinking water standards (0.3 mg/l) in the downstream sections of the streams. Mn-levels also exceed standards (0.05 mg/l), though less consistently. Turbidity and color values exceed provincial drinking water standards, particularly during freshet, thus suggesting problems with water supply. Finally the waters are generally low in trace and heavy metals.

4. Summary of water quality conditions

Seasonal cycles were found to exist for specific conductance, dissolved Ca, dissolved Mg, filterable residues, total iron, and turbidity. There is some indication that the first four parameters show an inverse relationship with flow rates while total iron and turbidity increased during peak flow and decreased during low flow. Additional data are required to confirm these suggestions.

Spatial trends were twofold: (1) an increase in values downstream for specific conductance, total residues, turbidity, and total iron, and (2) slightly different chemical conditions for the Sukunka River consisting of lower total iron and sulfate values and slight increases in dissolved Ca values during low flow periods.

General water quality conditions were: moderately hard alkaline waters with high turbidity, color, total iron and Mn values, all exceeding drinking water standards at various times.

G. Sediments

With the exception of a limited study on Carbon Creek (Utah Mines Ltd.) no sediment samples have been analyzed for chemical content. Consequently an exploratory study was carried out in August 1977 during which 12 bed sediment samples were collected and their extractable and total metal content determined. The aims of the project were to establish the general chemical composition of the sediments, to investigate whether differences exist between the three rivers, and to evaluate possible relationships between sediment composition and the geology in each watershed.

1. Field conditions and location of samples

The samples were collected during the August 29-31 field trip at the locations shown in Figure 12. Water conditions during the sampling period showed moderately high values for specific conductance (225-350 mhos/cm), high pH levels (8.0-8.5), low turbidity and moderately low flow. Covering the upstream and downstream sections four samples each were collected in the Murray and the Sukunka watersheds, and three were collected from the Pine River.

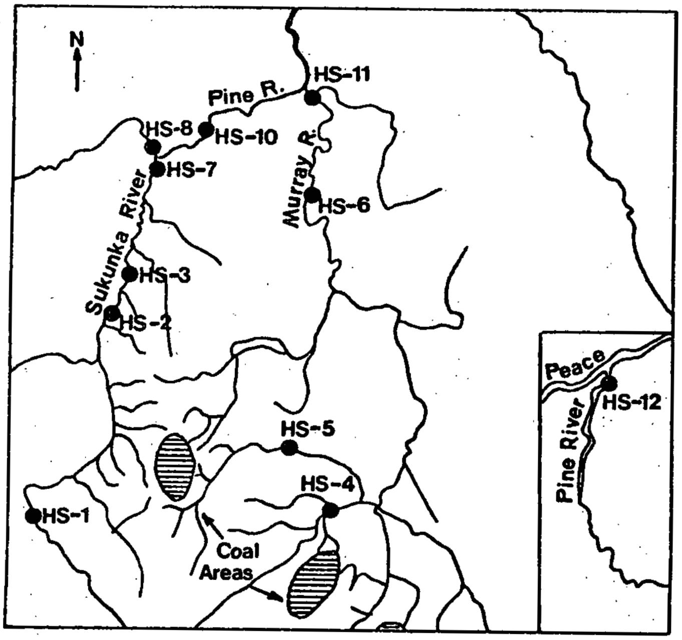


Figure 12: Location of sediment samples.

Some of the water quality parameters measured during the sampling showed consistently that the Pine River had higher pH values (8.0-8.3 vs 8.5) and higher specific conductance levels (225-300 vs 310-350) than either the Murray or the Sukunka Rivers. Also it was noted that the predominantly gravel beds in the three rivers were all covered with a grey-brown flocculate, a sample of which was collected on the Sukunka River and also analyzed.

2. Description of sediment sample analysis

The 12 samples were dried in the Water Quality laboratory and separated into three size fractions each by sieving (< 20 mesh, 20-80 mesh, < 80 mesh fractions). Hydrofluoric acid digestion for total element analysis was performed on the latter two fractions while HCl extraction for non-residuals was limited to the 80 mesh fraction. Hot acid digestion (perchloric and nitric acid) was also performed for a number of elements to verify the results obtained by the HF digestion method. Levels of non-residuals were determined for the following elements: Cu, Fe, Pb, Zn, Mn, Ba, Ca, Mg, Na and K. Total residual values were determined for the same elements except Na and K for which methodological problems prevented reliable analysis.

3. Results of analysis

From the analytical data presented in Appendix II it is evident that, for Canadian conditions, Cu, Pb, Zn and Hg values were generally low and Fe, Ca, Mn, and Mg were generally high. A statistical analysis was performed to determine whether the distribution of values in each river system differed from one another. Given the small and uneven sample size, the non-parametric Mann Whitney Significance Test (Siegel 1956) was used. As can be seen from Figure 13 significant differences (at $\alpha = 0.05$) were found particularly between the Sukunka and the Pine Rivers.

TOTALS → / NON RESIDUALS ↓	Sukunka River	Murray River	Pine River
Sukunka River		Ca^2	Mn^1, Ca^2 Fe^{1,2}, Mg^2
Murray River	Ca^1, Mg^1 Ba^1		Mn^1
Pine River	Ca^1, Mg^1 Fe^1, K^1		

1 $<$ 80 mesh fraction
2 20-80 mesh fraction

Figure 13. Comparison between river systems emphasizing those parameters showing significant differences at $\alpha = 0.05$.

The elements which seem to be useful as distinguishing characteristics are Mn, Ca, Mg and Fe.

It should be noted that such a test is not totally justified since the Pine River samples are partially influenced by both the Sukunka and

Murray Rivers, and therefore cannot be considered an independent sample set. To remedy this problem the distribution of the non-residuals was plotted in Figure 14 in which the sediments from the Murray and Sukunka Rivers were compared with individual samples from the Pine River.

The upstream sample from the Pine River showed a higher value of Fe and K and a lower value of Ca than the sediments from the Sukunka system. Despite the serious limitations of using a single sample for comparison these findings confirm those found in the analysis of the water quality data. Another observation of interest is the fact that the flocculate-sample showed considerably higher Na, K, Mn and Fe values than all other samples (see Figure 14). It is possible that bacteria are partially responsible for producing the flocculate but further investigation is necessary to understand the processes involved.

A spatial comparison of the total metal content is provided in Figure 15 in which the drainage system and sediment concentration are represented schematically. Again slightly higher Ca and lower Fe values were found for the Sukunka samples when compared with those of the Pine River. This is even more accentuated when the data from the coarser fraction are compared. The latter is usually more representative of the lithological source and, based on the summary of the drill core data provided in Table 4, it is suggested that the higher Ca values could be attributed to the greater influence of shale and siltstone bedrock within the watershed. Unfortunately this hypothesis cannot be confirmed until the geological mapping of the area has been completed by the Mines and Reclamation Branch in Victoria.

Table 4. Summary of chemical data from drill core samples

DRILL CORE MATERIAL	Ca (lb/ac)			Mg (lb/ac)			K (lb/ac)		
	$\bar{x}$	σ	n	$\bar{x}$	σ	n	$\bar{x}$	σ	n
conglomerate	500		6	61	19	6	50		6
sandstone	2898	2377	23	366	151	23	50	74	23
claystone	1593	456	8	418	106	8	293	118	8
siltstone	3464	1238	7	487	169	7	333	77	7
shale	4409	2132	12	427	148	12	264	100	12

Based on data provided by Denison Coal Ltd.

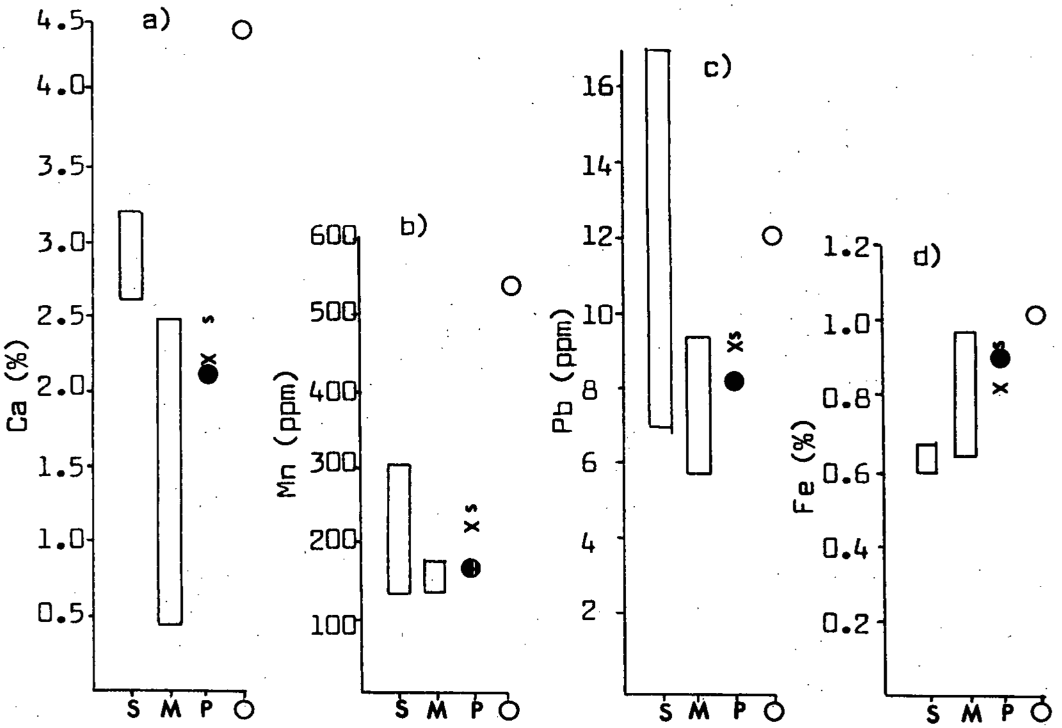
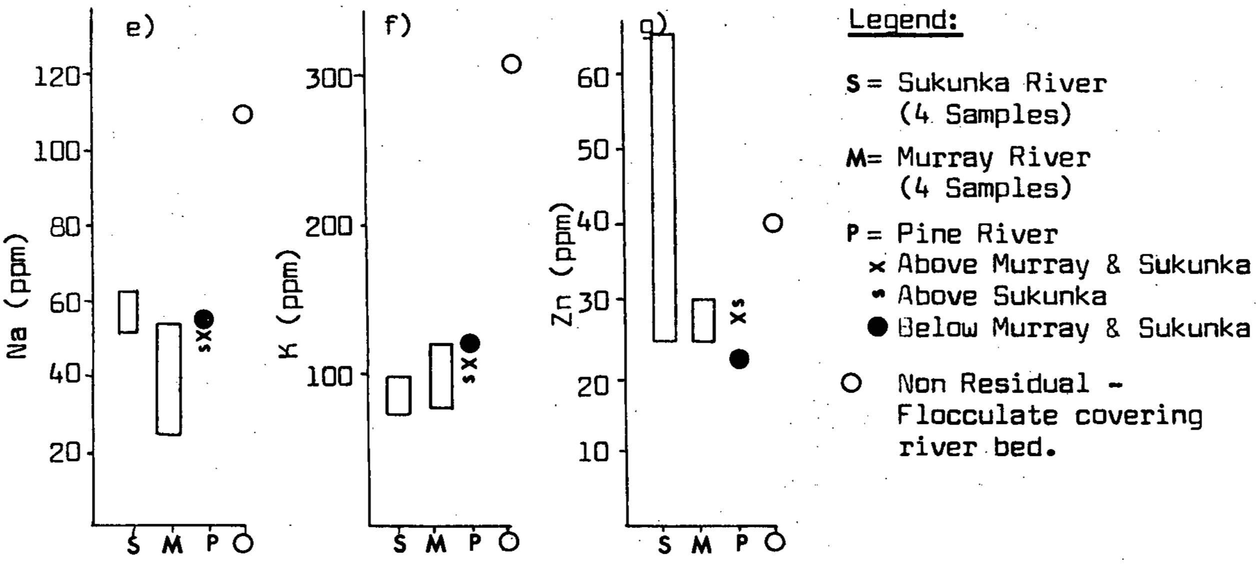


Figure 14 : Concentrations of Non-Residuals (HCl - Extraction) in the three rivers . (less than 80 mesh fraction)
a) Ca, b) Mn, c) Pb, d) Fe,



e) Na, f) K, g) Zn.

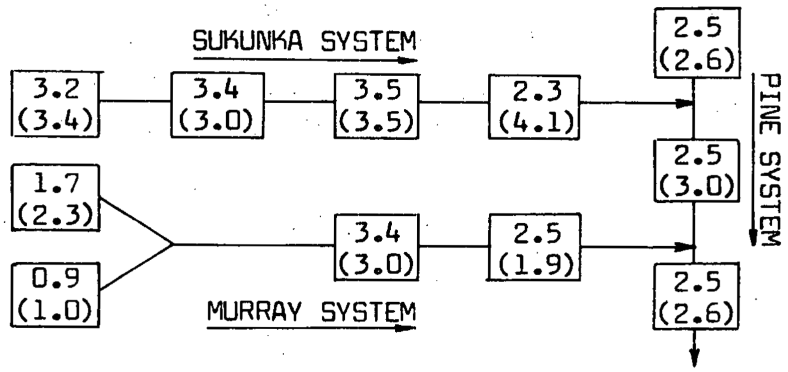


Figure 15a.

Ca variability
(in %)

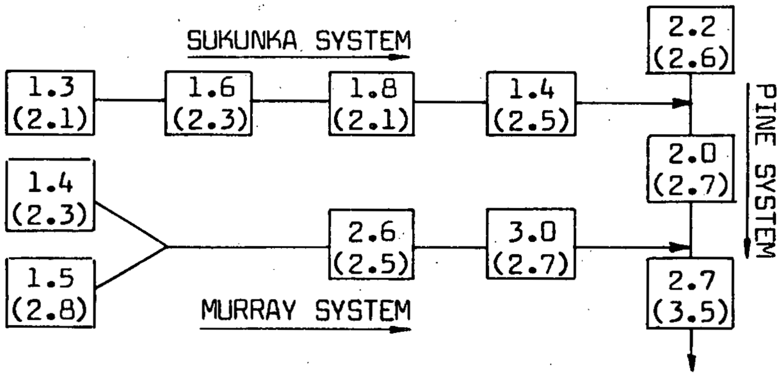


Figure 15b.

Fe variability
(in %)

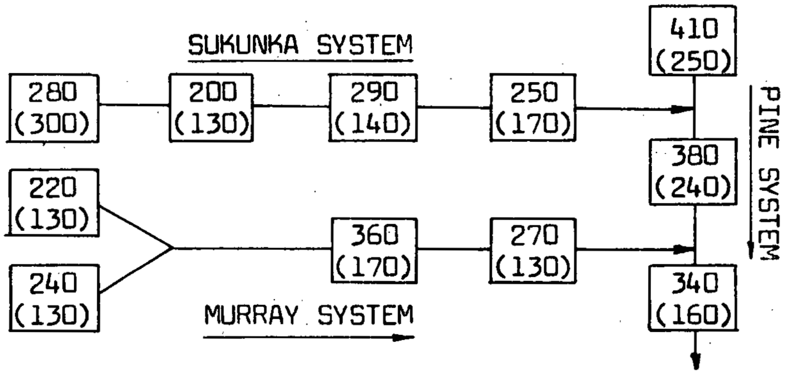


Figure 15c.

Mn variability
(ppm)

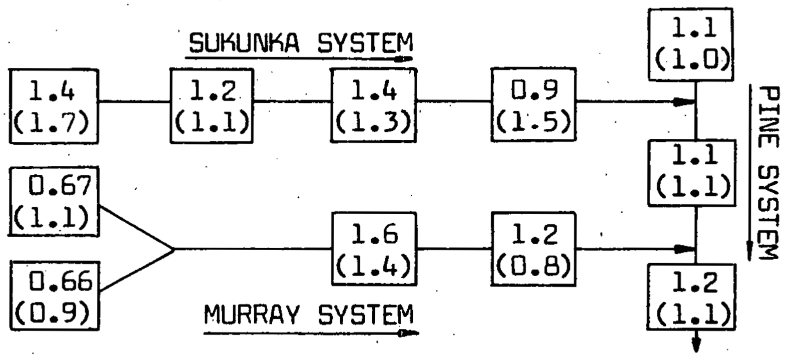


Figure 15d.

Mg variability
(in %)

Figure 15 a-d. Variability of selected chemicals in sediments of each river system. (Note: numbers in parentheses = 20-80 mesh fraction; numbers without parentheses = < 80 mesh fraction.)

Another anomaly is observed in the Murray system where the middle station (HS-6) shows consistently higher values of Ca, Mg and Mn than either the upstream or downstream sediments. At this location the river has cut through lacustrine deposits and is influenced by drainage of that area. Lacustrine deposits in the Peace River have high soluble salts and Ca and Mg values. Forest clearing for agriculture in the Lone Prairie lacustrine area is active and its influence on the sediments in this section of the Murray drainage is clearly evident. This hypothesis is further enforced by the fact that Fe levels, not indicative of lacustrine deposits, do not show this anomaly.

4. Summary of sediment analysis

Concentrations of Pb, Cu, Zn and Hg were found to be low while Ca, Mg, Fe and Mn values were generally high. A sample of the grey-brown flocculate which covers the river gravel in all systems was found to have considerably higher values of Na, K, Mn and Fe than any of the other sediments analyzed. The process involved in the formation of the flocculate should be studied more closely as it greatly influences water chemistry.

No consistent upstream-downstream trends were found but considerable evidence was produced to indicate that chemical conditions in the Sukunka system are slightly different from those of the Pine River. It is suggested that these differences are a result of lithological variations between the watersheds.

Finally an anomaly was found in the middle section of the Murray system where high Ca, Mg and Mn values were observed. Geomorphological conditions together with land use are thought to be responsible for these differences.

IV. DEVELOPMENT ACTIVITIES AND PROGRAMS FOR WATER QUALITY ANALYSIS IN THE NORTHEAST B.C. COAL AREA

A general introduction into some of the activities in the Northeast coal area is provided by E.L.U.S.C. (1977) and will not be repeated here. Instead, in this chapter an attempt is made to summarize current and planned activities and to outline those environmental programs relevant to water quality analysis.

It is somewhat difficult to provide a comprehensive overview since the majority of the programs for development are still in the early planning stage. It is important to point out that in the case of the Northeast B.C. area we are not dealing with a simple strip mining operation in isolation but with a complex integrated network of activities which are either directly dependent on the mining operation or complementary to it. Current activities include:

- construction of access and logging roads,
- logging operations,
- gas exploration drilling,
- coal exploration drilling,

Planned future programs consist of:

- construction of haul and access roads,
- construction of railway link,
- development of a town site (5000-10000 people),
- coal strip mining (extraction and reclamation),
- coal underground mining,
- gas extraction with possible construction of pipeline,
- construction and operation of coal washing and sorting facilities,
- construction and operation of gas scrubbing plant (on the Pine River).

Most, if not all, of these activities could have a potential impact on water quality and quantity and it is essential that they all be considered in any impact analysis.

Guidelines published by the Coal Task Force (1976) indicate the types of environmental programs and analyses that are required for coal strip mining operations. Responsibilities for some of the other activities are not clearly defined and to understand conditions and determine potential impacts three types of programs were initiated:

A. Program of mining companies
B. Provincial Program
C. Federal Program

A. Program of Mining Companies

The situation regarding development is quite dynamic in that numerous programs are planned, a few have been started and are at various stages of development, some have changed, and none have yet been completed. An overview of the most important companies involved in such programs is given in Figure 16 on the following page.

The companies are usually responsible for evaluating the site specific conditions prior to development. With regard to water quality this includes an analysis of both the surface and groundwater hydrology, sediments, water quality, effects associated with mining operations and reclamation, and fish and aquatic biology. The sites are usually monitored for one or two years and chemical analysis of water, coal and overburden rock is performed. Some bio-essays have also been made where fish survival in coal and overburden leachate was tested. Denison Coal Ltd., Teck Mining Group and Utah Mines Ltd. have completed what is called a stage one analysis (see B.C. Research 1975 a and b, 1976), and the stage two study is to be completed in the near future. B.P. Exploration Ltd. is about to complete stage one with plans to initiate the stage two project.

All these companies have large mining programs which include open pit and underground mining, construction and operation of treatment facilities, building of reservoirs, transportation networks and reclamation activities. Initial production start-up is planned for 1979 with peak operation beginning in 1984. Extensive exploration mining has taken place both in 1975 and

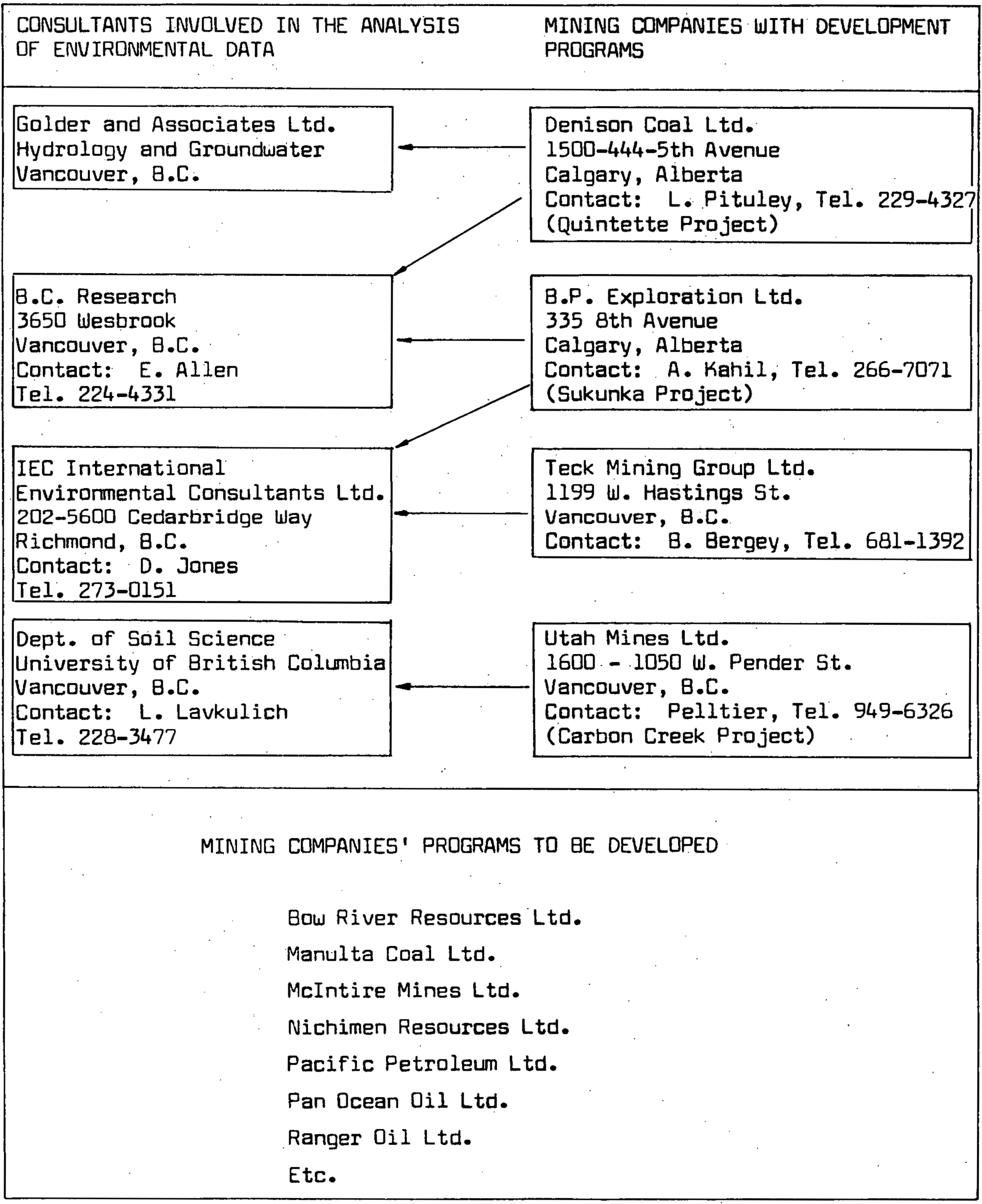


Figure 16. Companies involved in Northeast B.C. Coal Development.

1976-1977. Some limited environmental programs were initiated in 1975, and only Denison Coal Ltd. and Utah Mines have actively pursued their studies during the 1977 season, for which the data are not yet available.

B. Provincial Programs

The Provincial water quality program was initiated in 1976 and is directed towards a regional assessment of conditions and possible impacts caused by mining development. The program consists of water quality monitoring and an exploratory analysis of sediments in the Murray, Sukunka and Pine Rivers and in a number of tributaries. It is carried out by sections of the Resource Analysis and Water Investigation Branch. E.L.U.S.C. is responsible for the overall coordination.

The monitoring program has covered both the 1976 and 1977 spring to fall periods during which samples were collected at roughly monthly intervals. Most of the basic nutrients, trace and heavy metals were analyzed and the data have been compiled in unpublished reports (Ministry of Environment Water Investigation Branch, 1976 a, b, c, and 1977). In 1976 a separate program was initiated to assess water quality for potential water supply of the planned townsite, and in 1977 an exploratory sampling of suspended sediments was started. The main program is primarily concerned with established so-called "base line data" and because long term information is necessary only few attempts have been made to determine impacts and potential effects of the different development schemes (E.L.U.S.C. 1977).

C. Federal-Provincial Programs

These programs are essentially complementary to the Provincial programs and have been restricted to a reconnaissance survey of bed-sediments and a water quantity and sediment monitoring program. The water gauging program consists of the establishment and operation of six hydrometric stations on the Murray and Sukunka System. For a description of the location of the stations see Appendix I.

A sediment program has also been proposed to establish sediment rates and provide relevant data. The operation of four such stations (see Appendix I) has been suggested and Don Dobson (Water Survey) is currently working on the details of the program.

The aim of the bed sediment sampling program was simply to determine the general metal levels in the sediment of the three streams. It consisted of an analysis of 12 samples collected by the author during August 1977, the results of which have been described in Chapter III.

D. Summary of Programs

Detailed site specific investigations are to be completed shortly for three of the main mining sites, and a fourth is slightly less advanced. The evaluation will include an analysis of the surface and groundwater hydrology, sediments, water quality monitoring for at least one year and chemical analysis of coal and overburden rocks.

The regional baseline monitoring program is presently covering both the 1976 and 1977 seasons, during which nutrients, trace and heavy metals were analyzed on approximately a one-month basis. The Federal-Provincial program will concentrate on water gauging and sediment sampling. The water gauging program became operational in October 1977 and the sediment transport sampling program will become operational in April 1978. Finally, a reconnaissance metal analysis of sediments has been performed from a single set of samples during the August 1977 field period.

V. PROBLEMS AND POSSIBLE IMPACTS OF DEVELOPMENT AND MINING OPERATIONS ON WATER QUALITY

Judging from past experience (see literature review, Chapter II) some water quality deterioration seems to be an unavoidable result of coal strip mining. An assessment of the degree of tolerable deterioration is beyond the scope of this report and the present chapter merely tries to point out some of the more important problems which have the potential of deteriorating water quality conditions in the Northeast B.C. coal area.

A. Multi-stage and Multi-type Development

Given the multi-type development which includes strip mining, underground mining, coal washing and sorting, logging, construction of roads, railways, and towns, etc., it is extremely difficult to predict the overall effects of development on water quality. Some of these operations will certainly compound the problems making it more difficult to identify causes. This is made even more complex by the fact that most environmental studies are oriented towards one type of development and have been carried out during a period when a number of changes in the watershed have already taken place. Unfortunately no overall development plan exists thus making it difficult for an integrated overall assessment to be made.

It has been suggested that water quality is a good indicator of environmental conditions, and changes will likely be indicative of the amount of disturbance and stage of development within the watershed. The most likely effects in the study area will relate to water quantity and use, mineralization, and sedimentation, all of which are discussed below.

B. Water Quality and Use

Despite the absence of gauging records it is evident that the demand on water supply will be great in a number of locations within the mining area. Some companies have proposed to construct storage reservoirs in order to assure adequate water supply for the coal washing and sorting operations which will be carried out near the mine site. An additional supply is needed for the hydraulic underground mining in the same area. It appears that the local run-off during low flow conditions is insufficient for some of these mining operations. Given the world's energy situation it is noteworthy that coal washing operations in particular will be more intensive in the near future in order to produce cleaner fuel and thus reduce pollution. Such a development has been forecast by Environmental Science and Technology (1977) and will have serious implications for future water needs in the study area. Additional water supply is needed for the townsite development (5000-10000 people), a problem which, as pointed out by E.L.U.S.C. (1977), has yet to be solved.

Increased water demand and water uses will most likely affect the downstream water quality conditions. Depending on how much water is temporarily tied up in different operations the flow rates might be reduced, and parameters such as specific conductance, concentrations of filterable residues, hardness, etc., which are inversely related to flow, might reach excessively high values. This problem is further aggravated by the input of new minerals into the stream system thus diminishing dilution potential during low flow.

There is also the danger of increased stream run-off during storm periods. This causes particular concern since large surfaces will be exposed in each watershed by strip mining and clear cut logging. In areas where the vegetation is removed surface run-off will increase and temporary storage and retention will be reduced. Increasing flooding and accelerated stream bank erosion is expected downstream. This is of particular concern for the lower sections of the Pine and Peace River where unstable banks are common and erosion processes already active.

C. Mineralization

As noted in Chapter II increased mineralization of both ground and surface water is most likely to occur as a result of strip mining operations. Given the low pyrite content in the coal and overburden material, no acid production is expected. This is further enforced by the fact that surface waters are alkaline and have a good neutralization potential. Experiences from other low sulfur mining operations have indicated however that increases in salts, specific conductance, dissolved solids, Fe, Mn, SO_4 and Zn are common. Since we already have naturally high iron and manganese levels (above EPA drinking water standards on numerous occasions downstream), this problem is likely to be aggravated. The situation is already causing difficulties for the municipal water supply of Chetwynd where a treatment reservoir and water storage facilities have been constructed to ameliorate the problem. It is also noteworthy that pastures irrigated by water containing 14 mg/l of iron have shown to decrease milk production and the body weight of dairy cattle (Coup and Campbell 1964, and National Academy of Science 1974). Total iron levels in the Pine River downstream have occasionally reached 34 mg/l of Fe, and additional increases as a result of fresh bedrock exposure and mining will worsen the downstream water conditions especially in agricultural areas.

Most other metal concentrations were found to be low (except Mn) but additional information is required in order to predict metal content in mine drainage. Initial tests from coal leachate showed 10 mg/kg leached coal concentration in Cu, Pb, Zn, Cd, and Hg (personal communication by J. Leach) but no mine spoil leachates have been analyzed for metal content. It is suggested that leachates, used in future bio-essays for fish survival tests, be analyzed for trace and heavy metal content.

Increases in dissolved solids are likely to occur during fall and winter when flow conditions are low. Additions from increased surface run-off, draining freshly exposed bedrock, and from sedimentation caused by earth moving operations could result in increasingly high values which are detrimental both to fish and to downstream water use.

D. Sedimentation

Increased sedimentation is considered by far the most serious problem in the study area. The sediment rates are naturally high in the downstream sections of the rivers, particularly during freshets. This is partially indicated by excessive turbidity values and is attributed to intensive mass-wasting along the river banks. The lower sections of the Murray and Pine Rivers have deeply dissected canyons with numerous unstable banks made up of alluvium, lacustrine and weathered shale materials. Surface mining activities accelerate natural mass wasting processes and short, high intensity storms can initiate forces which remove large amounts of surface material.

The northeast coal area is particularly suited for mass wasting and sediment transport since, based on the hydrograph in Figure 1, a number of substantial secondary peak flows dominate the summer and fall period. These are attributed to thunderstorm activities. In addition the area has a substantial relief, a climate which inhibits revegetation and numerous development activities during which the vegetation cover is removed exposing the soil surfaces. In the latter instance, clear-cut logging, clearing of right-of-ways for access roads, railway corridors, seismic lines and strip mining are most important.

As noted by Doyle (1976) "one of the primary rules for good erosion and sedimentation control is that all earth moving activities be planned in such a manner that the minimum amount of disturbed area will be exposed for the minimum amount of time." Because of the multi-type development and absence of overall plan a large area in both watersheds will be exposed and, as a result, sedimentation is expected. Until now the sediment conditions have not been assessed satisfactorily, and the proposed Federal Provincial program described in Chapter IV will do little to help identify sediment sources. In addition the present set-up does not allow for a proper assessment and monitoring of the effects of strip-mining on sediment rates, nor can the station network in its present form be used to establish mining regulations (Personal communication by D. Dobson). The usefulness of the sediment program to establish representative sediment rates for the watersheds and for the area as a whole is also questioned in view of the drastic land use modifications which continue to take place. Finally the chemical composition of sediments shows generally low metal values except for Fe and Mn. Iron is of particular interest since it plays an important part in the formation of a grey-brown flocculate which covers the bed of all downstream sections of the three rivers. Concentrations in the flocculate are considerably higher than those of the sediments and in order to determine the effect of additional iron input by strip mining it is suggested that the present processes be analyzed in greater detail.

CONCLUSIONS AND RECOMMENDATIONS

The most relevant concerns with regard to present and future water quality conditions in the Northeast B.C. coal area are: 1) integrated effects of multi-type development, 2) water quantity and use, 3) water quality, and 4) sedimentation.

1. Integrated Effects of Multi-type Development

A number of environmental programs are being carried out specifically to evaluate the effects of strip mining while others are designed to provide so-called "baseline" data. The latter are currently being emphasized but unfortunately they are being carried out at a time when major developments and changes within the watershed have already taken place. It is suggested that a greater effort be made to integrate programs in such a way that they are useful in monitoring and determining potential effects of all activities. An overall development plan to include present and future activities should be put together prior to setting up the sediment, water gauging and water quality monitoring program.

2. Water Quantity and Use

The overall development plan should also be consulted before operations such as water storage and flow modifications are carried out. This is of particular concern since future economic developments, especially with regard to coal washing operations, might make excessive demands on the limited water supply within the Murray and Sukunka watersheds.

Upstream water uses for municipal purposes, hydraulic mining and coal washing operations have the potential of deteriorating water quality. This subject should be investigated once detailed development specifications have been published.

3. Water Quality

Present water quality conditions are marginal with Fe and Mn concentrations consistently above drinking water standards. Based on experiences elsewhere this problem is most likely accentuated by strip mining operations thus creating problems with agricultural and local municipal water uses downstream. No evidence was found to suggest other metal problems and because of the low sulfur content in the coal and high alkalinity levels in the water no acid problem is expected.

Dissolved solids and hardness are inversely correlated to flow and increases are expected during low flow conditions because of fresh rock exposure during reclamation. Additional flow regulation during low flow periods should therefore be avoided.

No information on water quality is available for the November to March period and it is suggested that a sampling program be carried out to determine winter conditions and to verify the seasonal trends identified for dissolved solids, Ca and Mg.

Considering the fact that extensive coal washing operations will take place within the watershed it is imperative that further tests be carried out to determine chemical concentrations of metals and organic constituents in coal leachate. This subject is inadequately covered in the stage one report of the mining companies and if it is not covered in the stage two report steps should be taken to assure that this topic be properly investigated.

4. Sedimentation

Bed sediments showed generally low metal concentration except for Fe and Mn. A grey-brown flocculate covering the gravel beds in all downstream sections proved to contain considerably higher metal concentrations in most elements than any other sediment samples analyzed. It is suggested that the cause and process of the formation of the flocculate be examined in greater detail since it might be responsible for the high iron levels in the water.

Sediment levels appear to be high during freshet (partially indicated by high turbidity values), but a more comprehensive analysis of the entire sediment regime should be attempted since increased sedimentation is considered the most crucial problem in strip mining operations. In this context it should be stressed that the requested Federal Provincial program is inadequate in that

1) it will not provide adequate information for setting up mining regulations,
2) the sampling station network cannot be used for monitoring or for enforcing mining regulations,
3) it will not provide representative sediment rates for the watersheds or the area as a whole since drastic land use changes continue to take place and since at least two out of four stations are affected by local agricultural and mining activities.

It is recommended that the current sediment program be replaced by one in which the sediment levels are established in relation to potential source areas and development activities.

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APPENDIX I

DESCRIPTION OF LOCATION OF WATER QUANTITY AND SEDIMENT MONITORING STATIONS

STATION NO. 7FB-004

Dicke Bush Creek near the mouth

Location: 1.8 miles above mouth and confluence with Sukunka River.
At mile 11.5 on the Sukunka Road and 400 ft. upstream from Road Bridge.
Parameters - Water quantity

STATION NO. 7FB-002

Murray near confluence with Pine River below Cowey Creek confluence.

Parameters - Water quantity and Sediment transport

STATION NO. 7FB-006

Murray River above Wolverine River

Location: 5½ miles upstream from mouth of Wolverine River.
Parameters - Water quantity and Sediment transport

STATION NO. 7FB-005

Quality Creek ¼ mile above Timper Preservers Bridge

Location: About ¼ mile upstream from Road Bridge at Wood Preservers Camp and about 3½ miles above the mouth. Approx. 70 miles along Feller Heights Road.
Parameters - Water quantity

STATION NO. 7FB-007

Sukunka River above Chamberlain Creek

Location: Six miles upstream from mouth of Chamberlain Creek. At approx. mile 36 of Sukunka Road.
Parameters - Water Quantity and Sediment transport

STATION NO. 7FB-003

Sukunka River near the mouth*

Location: 8.4 miles upstream from mouth and at site of old sawmill.
Parameters - Water quantity and Sediment transport

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* not in operation.

APPENDIX II. CHEMICAL COMPOSITION OF SEDIMENTS

Table 5. Metal analysis of sediments (Hydrofluoric acid digestion)

Sample #	Cu ppm	Fe %	Pb ppm	Mn ppm	Zn ppm	Hg ppm	Ca %	Mg %
HS-1 a)	50	1.3	<50	280	130	0.064	3.2	1.40
b)	30	2.1	<50	490	190	0.068	3.4	1.70
HS-2 a)	20	1.6	<50	200	110	0.047	3.4	1.20
b)	20	2.3	<50	290	160	0.082	3.0	1.10
HS-3 a)	30	1.8	<50	290	130	0.064	3.5	1.40
b)	30	2.1	<50	340	150	0.071	3.5	1.30
HS-4 a)	70	1.4	<50	220	160	-	1.7	0.67
b)	30	2.3	<50	360	140	0.090	2.3	1.10
HS-5 a)	30	1.5	<50	240	120	0.083	0.9	0.66
b)	30	2.8	<50	420	150	0.086	1.0	0.90
HS-6 a)	20	2.6	<50	360	130	0.073	3.4	1.60
b)	20	2.5	<50	380	130	0.082	3.0	1.40
HS-7 a)	10	1.4	<50	250	90	0.041	2.3	0.91
b)	40	2.5	<50	390	140	0.240	4.1	1.50
HS-8 a)	20	2.2	<50	410	120	0.054	2.5	1.10
b)	40	2.6	<50	600	150	0.096	2.6	1.00
HS-10a)	10	2.0	<50	380	110	0.062	2.5	1.10
b)	30	2.7	<50	460	140	0.100	3.0	1.10
HS-11a)	20	3.0	<50	270	110	0.059	2.5	1.20
b)	20	2.7	<50	350	130	0.100	1.9	0.80
HS-12a)	20	2.7	<50	340	120	0.075	2.5	1.20
b)	20	3.5	<50	400	150	0.078	2.6	1.10
Detection Limit	10	0.005	50	10	10	0.005	0.05	0.05

a) < 80 mesh sediment fractions

b) 20-80 mesh sediment fraction

Table 6. Analysis of non-residual metals in sediments (HCl extraction on 80 mesh fraction)

Elements in ppm

Sample #	Cu	Fe	Pb	Mn	Zn	Ba	Ca	Mg	Na	K
HS - 1	64	3300	17	300	65	120	32000	13000	62	92
HS - 2	13	3500	9	130	33	88	26000	7200	51	78
HS - 3	10	3400	9	140	32	86	29000	8000	54	72
HS - 4	5	3200	6	130	26	140	16000	3000	40	80
HS - 5	5	3500	6	130	25	160	4200	1200	24	86
HS - 6	8	4800	9	170	25	140	25000	5600	55	120
HS - 7	6	3000	9	170	25	98	29000	6400	52	74
HS - 8	8	4500	10	250	32	130	22000	5000	49	94
HS - 9*	9	5000	12	540	40	130	44000	8600	110	310
HS -10	7	4100	10	240	30	110	25000	6200	51	96
HS -11	5	4100	7	130	20	150	18000	3600	44	100
HS -12	6	4500	8	160	21	160	21000	4200	54	120
Detection Limit	0.1	0.5	0.5	0.1	0.1	0.1	100	100	5	5

* Flocculate covering river bottom.