REPORT #
RRTAC 93-3

Catalogue of Technologies for Reducing the Environmental Impact of Fine Tailings from Oil Sand Processing

by

B.J. Fuhr, Alberta Research Council

D.E. Rose, Dereng Enterprises Ltd.

and

D. Taplin, Komex International Ltd.

Prepared for

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(Reclamation Research Technical Advisory Committee)

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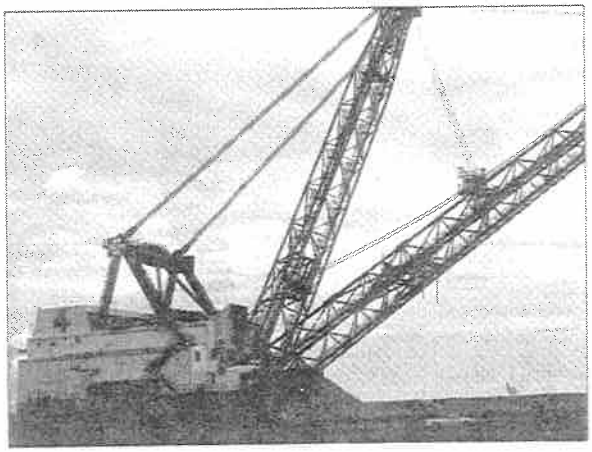

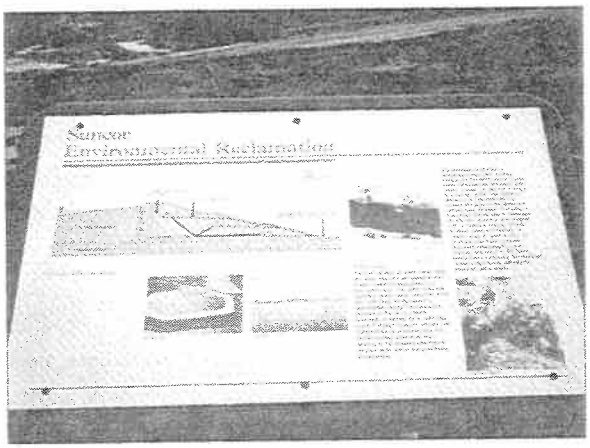

Members: Chris Powter (Chairman) - Alberta Environmental Protection; Martin Fung - Syncrude Canada Limited; Al Fedkenheuer - NOVA Corporation of Alberta; Paul Layte - Alberta Environmental Centre; Sam Takyi - Alberta Environmental Protection; Steve Tuttle - Suncor Inc.

DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Conservation and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the authors and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

The list of technologies incorporated in this report was developed after discussions with government and industry staff. Exclusion of any technologies was unintentional.

REVIEWS

This report was reviewed by members of RRTAC, the Oil Sands Reclamation Research Program, Rick Nelson (AOSTRA), Ted Lord (Syncrude Canada Limited), Bob Burns (Suncor Inc.), and Tom Dereniwski (Esso Resources).

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ABSTRACT

A catalogue containing 22 technologies for reducing the environmental impact of fine tailings derived from oil sand processing has been assembled. The simple format which was developed as part of this study consisted of a spreadsheet outline of the technologies and a process summary for each technology. The format of the catalogue allows for convenient updating. Information contained in the catalogue was obtained directly from the proponents of the technologies.

No evaluation or ranking of the technologies was carried out at this stage since this was not included in the scope of work. Such evaluation would require a more detailed information base and the development of a suitable set of criteria. However, a detailed set of questions was prepared that highlights the environmentally related information that a proponent should have. These questions should help to form a basis for comparisons among the technologies.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Over the years, many technologies have been suggested for reducing the environmental problems caused by fine tailings resulting from the processing of oil sand. The purpose of this project, which was commissioned by the Reclamation Research Technical Advisory Committee (RRTAC), was to collect and organize the information on these technologies currently proposed in a simple catalogue format (Fuhr et al., 1993). Of most interest were processes which would decrease the fine tailings water content. These processes generally fall into three categories:

1. new extraction processes which produce a lower water content fine tailings,
2. an increase of the fines capture in the coarse sand tailings, and
3. processes or treatments for fine tailings which decrease their water content.

During the project, technology proponents were contacted and their responses were summarized.

Evaluation or ranking of each of these technologies was not an objective of this project. However, a detailed list of questions was prepared that highlights the environmentally related information that a proponent should have. These questions should form the basis for comparison among the technologies.

A glossary of terms and acronyms used in this report is included in the Appendix.

2. BACKGROUND

2.1 MINING CONSIDERATIONS

An efficient and economic management of the exploitation of an energy resource such as oil sands requires the development of a detailed mine plan. This mine plan takes into consideration a host of factors including plant capacity, mine configuration, feed quality of various facies, stripping requirements, ground water conditions and material requirements for construction of impoundments and in-pit buffers. Regulations governing mineable ores are specified by the Energy Resources Conservation Board (ERCB). Lower bound feed qualities for Suncor Inc. and Syncrude Canada Ltd. are 8% and 6% (w/w) respectively, defined so as to maximize oil recovery from the oil sands.

This directive to maximize resource utilization has led to processing of oil sand having lower bitumen and higher fines content, which has led in turn to proportionately greater accumulation of dispersed clay and fines in the tailings ponds. If this criterion of oil sand cutoff grade is maintained for future operations, then new processes must be able to handle this material as well, in consideration of both recovery and reclamation.

2.2 BITUMEN EXTRACTION

The Clark Hot Water Extraction Process (CHWEP) utilized by current surface mining operations (Suncor and Syncrude), involves slurrying of oil sand with hot water and small amounts of sodium hydroxide (caustic) prior to bitumen separation. The caustic functions as a pH control and a release agent for natural surfactants associated with the bitumen to assist recovery, while minimizing solids and water carried with the bitumen. Air injection and agitation are employed for secondary recovery of finer bitumen particles which might otherwise be lost to tailings. These more aggressive steps result in greater contamination of the bitumen froth product with mineral and solids, and for this reason are used only when necessary.

Bitumen froth contains unacceptable levels of mineral and water for current coker upgrading processes. Froth can be dewatered in many ways, but the most effective ways involve dilution with a solvent; the most practical solvent has been coker naphtha, readily available from the associated upgrading operations. Gravity separation of diluted bitumen works fairly well, although associated solids handling is not a simple engineering problem to overcome. Traditionally, centrifugation has been installed initially and gravity separation systems have been retrofitted to complement the centrifuges and perhaps plant capacity. This is partly because centrifuge capacity is relatively easy to engineer, but also because some diluted bitumen froth does not separate well without addition of demulsifier along with aggressive techniques like centrifugation. Earlier operations were hampered by problems of this nature, occurring mostly in froth treatment, and engineering was directed toward finding ways of improving primary extraction froth quality.

This and other similar process constraints have not changed, but now there is greater attention being devoted to the tailings pond problems, most notably fine tailings accumulation. Proponents of novel technology experience difficulty in understanding operator reluctance to employ revolutionary processes which might mitigate certain aspects of the tailings problem, but which might seriously compromise another aspect of the operation such as that just outlined. Oil sands operations are truly a "complex", with considerable interaction between unit operations. Hence, the absolute potential for any novel process is not always obvious.

Storage and transport of the primary extraction bitumen froth are requirements that are not easy to engineer. Because of the extremely high viscosity of bitumen, pumping of froth at the current high temperatures is sometimes difficult, even though the froth has a high water content. Addition of solvent prior to transport from the plant is not acceptable for the following two reasons:

1. There would be separation of solids in storage, which would create serious handling problems and an expensive tankage system.

2. Primary extraction is a large materials handling plant which does not require hazardous atmosphere electrical classification. Introduction of naphtha in the plant would change this, at tremendous cost.

Likewise, reducing plant operating temperature would result in bitumen froth with substantially higher viscosity. To maintain capacity there would be a necessity to modify and improve the froth handling system, which would be a major engineering feat.

The physical size of the current or future operations necessary to handle the large quantities of oil sand and product mean that materials handling engineering impacts significantly on process design decisions. Conversely, an apparently minor process variation can have a major impact on materials handling requirements, and hence on cost. Retrofitting of a process innovation to an existing operation may not be easy, depending on the perturbation it creates in the plant. Development of a new process configuration requires delineation of the total materials handling requirements for an effective and efficient operation; this requirement has often meant the failure of apparently attractive process concepts.

2.3 TAILINGS DISPOSAL

The residual slurry after bitumen removal in extraction is termed "tailings", designating a waste stream discharged from the plant to impoundment. Mineral content of the slurry is usually 45% to 55% (w/w), as required for efficient upstream process performance. The coarse sand fraction of the tailings and entrapped fines are utilized in the construction of the tailings pond dykes; the remaining fines and water being stored within the pond. Upon settling in the tailings pond, a good portion of the contained water clarifies to 1% solids or less, suitable for recycle to the plant. The clay and fines contained within the tailings pond slowly settle to form a fluid zone of "mature fine tailings" with a solids content of approximately 30% (w/w). Its accumulation (along with entrapped impurities) creates a storage and reclamation problem.

Methods for dewatering this material are available. However, the cost associated with dewatering all fine tailings presently being stored by Syncrude and Suncor by commercially proven techniques is quite prohibitive. Some suggested alternative disposal scenarios include:

1. sandwich disposal using alternate layers of centrifuged fine tailings and sand,
2. spreading of thin layers to promote evaporation and freeze-thaw, and
3. mixing mature fine tailings with overburden.

Costs and associated level of engineering and environmental risk differ for each of these disposal scenarios. Long term storage of fluid mature fine tailings within an above grade impoundment is not considered an acceptable option. Capture of high amounts of fines in the coarse material can impact on dyke stability and mode of construction.

In addition to cost considerations for fine tailings dewatering or treatment there are technical factors associated with modification of the tailings disposal system. From an operations perspective, disposal of tailings is critical to maintaining plant capacity on an hour-by-hour basis. The system is expensive to operate and maintain, and is usually designed with an extra tailings line compared to the number of process lines to permit flexibility in relocation at the dyke or switching if a line fails. Failure of a pump train usually requires dumping the pump tank and draining part of the line to avoid sandup. Any operation (test or otherwise) superimposed on this system which might impair availability or capacity poses a significant potential threat to operating efficiency. Thus, the adaptation or modification to a tailings line or total tailings system for purely reclamation considerations may not be simple.

Modification to the discharge system at the pond edge, or additional treatment at that location, is complicated by the difficulty of handling such a large flow of hot slurry. There is considerable difficulty of access except with heavy equipment, and there is a need for mobility due to changing terrain. A small conceptual variation creates a major design and operating difficulty at this location.

When addressing tailings as a system, one should note that a substantial amount of tailings are generated from the froth treatment plant, although considerably less than from extraction. This material is relatively dilute, but contains problematic material such as fines and residual naphtha. This stream flows to the tailings pond separately, and therefore, also contributes to the problem of fine tailings.

Surface water from the tailings pond is recycled to the extraction plant, so processes involving chemical modification must not conflict with the chemical needs of the plant process. Where there is an expectation of recycling water recovered from fine tailings to "extinction" in the extraction plant, any conflict in this respect could produce serious process or recovery problems for the operation. This proviso applies mainly, of course, to retrofit operations for the CHWEP operation as presently practiced.

An alternate approach to tailings disposal being proposed by the existing operating companies is the water capping or wetland scenario. This process involves disposal of mature fine tailings in mined-out pits and capping with water. Development of shoreline vegetation, and biological mitigation of potential contaminants in the fine tailings would presumably permit creation of an acceptable wetland environment. Large scale tests are currently being conducted by the operators to demonstrate this technique in an operating environment. However, since this approach does not address the goal of lower fine tailings water content it will not be discussed further in this report. Recent information on this topic may be found in the proceedings of the "Oil Sands, our Petroleum Future" Conference (Gulley and MacKinnon, 1993).

3. SOURCES OF DATA

The questionnaire shown in Figure 1 was sent to each of the proponents of the technologies. This initial means of data gathering was normally followed up by telephone or personal interview. This information which, in some cases, included hard copy descriptions of the processes and experiments supplied by the proponents, was condensed into the individual process summaries. Each proponent was given the opportunity to comment on their specific process summary before it was included in the catalogue.

To further aid in identifying relevant technologies, use was made of the Alberta Oil Sands Index (AOSI) and the Heavy Oil Enhanced Recovery (HERI) databases of AOSTRA Library and Information Services, and of the Energy Resources Conservation Board library listings.

Due to time constraints, certain eligible technologies may have been overlooked. The catalogue format, however, allows for easy updating.

Figure 1. Oil Sand Process/Tailings Treatment Technologies Information Checklist

1. TECHNOLOGY/PROCESS NAME . . . . . .

2. OWNER/DEVELOPER . . . . . .

3. CONTACT PERSON(S) . . . . . .
   Telephone # . . . . . .
   Address . . . . . .
   . . . . . .

4. DEVELOPMENT HISTORY: Laboratory . . . . . .
   Pilot . . . . . .
   Demo . . . . . .
   Commercial . . . . . .

5. CURRENT STATUS: Active . . . . . .
   Other . . . . . .

6. PROCESS APPLICATION/LOCATION: . . . . . .
   Mining: Existing . . . . . New . . . . . Other . . . . . .
   Process: Existing . . . . . New . . . . . Other . . . . . .
   Tailings: Tailings . . . . . New . . . . . Other . . . . . .
   Location in the Tailings System . . . . . .

7. IS THERE INFORMATION AND DATA AVAILABLE REGARDING THE FOLLOWING? (Indicate Y or N):
   Process Description . . . . . Material Balance . . . . . .
   Mineral Balance . . . . . Fines/Clay Balance . . . . . .
   Bitumen Distribution for Various Ore Grades/Facies . . . . . .
   Geotechnical Test Data on Tailings Material/Product . . . . . .
   Equipment Requirements . . . . . Economic Analyses . . . . . .

8. DISCLOSURE OF THE TECHNOLOGY HAS BEEN MADE THROUGH: . . . . . .
   Patent(s) . . . . . (date) . . . . . .
   Paper(s). . . . . (date) . . . . . .
   Report(s) . . . . . .
   Study: In-House . . . . . Independent . . . . . .

Although not essential at this time, an outline of available relevant reports referencing your technology would be helpful

4. CATALOGUE OF TECHNOLOGIES

4.1 SPREADSHEET

The first part of the catalogue is in the form of a spreadsheet shown on the following pages. This format allows the technologies to be readily classified, and some simple comparisons to be made. Those checked off under "OILSAND" or "FROTH" represent new extraction processes which produce lower water content fine tailings. Those under "TAILINGS" are ones for which fines capture is increased. Finally those under "FINE TAILINGS" are ones for treating fresh or mature fine tailings. These data were obtained mainly from the completed questionnaire forms. Much of the information is in the form of yes (X) or no (blank). Estimates of percent solids as provided by the proponents are also included.

4.2 PROCESS SUMMARIES

The second part of the catalogue consists of the process summaries for each technology. The summaries include the name of the owner/operator and the address, telephone and Fax (in parentheses) of the individual contacts. Next, a description of the process and its location/application are given, followed by a developmental history in a tabular format. Technologies where no contact could be located were not included in this catalogue.

All the information contained in these summaries was obtained directly from the proponents, assembled by the authors of this report and approved for publication by the respective proponents. No attempt was made to compare and evaluate these technologies.

Fine Tailings Technology Catalogue Spreadsheet

PROCESS NAME	STREAM TREATED				DEVELOPMENT HISTORY			
	OILSAND	FROTH	TAILINGS	FINE TAILINGS	LAB	PILOT	DEMO	COMMER
ATP	X				X	X		
CCDS	X				X	X		
CANOXY: Oil Sand (SRT)	X				X	X		
: Fine Tailings				X	X	X		
ESSO: Oslo Cold Water Ext'n (OCWE)	X				X	X	X	
: Oslo Hot Water Ext'n (OHWE)	X				X	X		
INDUSTRY/GOVT: Evaporation				X	X	X	X	
: Freeze/Thaw				X	X	X	X	
KRUYER: Oleophilic Sieve	X			X	X	X	X	
PREUSSAG: Prime I				X	X			
: Prime II				X	X			
: Prime III	X				X			
RTR: Oil Sand	X				X		X	
: Froth		X			X		X	
: Tailings				X	X	X	X	
SESA	X				X			
SOLV-EX: Oil Sand	X					X		
: Fine Tailings				X	X	X		
SCL: Fine Tailings/Overburden Mixed				X	X	X	X	
SCL/SUNCOR: Lime Addition			X		X	X		
: "Spiking"			X	X	X		X	
TPC			X		X			

GLOSSARY OF TERMS

OILSAND: Oil sand as-mined
FROTH: Bitumen froth product (primary extraction)
TAILINGS: Waste mineral slurry from extraction
FINE TAILINGS: Accumulated clay/fines phase in ponds

LAB: Small laboratory-scale batch tests
PILOT: 0.2 to 5 t/h, continuous
DEMO: 5 to 100 t/h (arbitrary)
COMMER: in commercial operation

Fine Tailings Technology Catalogue Spreadsheet

PROCESS NAME	BALANCES & DATA AVAILABLE			GEOTECHNICAL	FINES % SOLIDS
	MATERIAL	MINERAL	CLAY/FINES		
AOSTRA TACIUK	X	X		Preliminary Tests	90+
CCDS	X	X			No Change*
CANOXY: Oil Sand (SRT)	X	X	X		30 (60)**
: Fine Tailings	X	X	X		30 (60)
ESSO: Oslo Cold Water Ext'n (OCWE)	X	X	X	X	30 (60)
: Oslo Hot Water Ext'n (OHWE)	X	X	X	X	30 (60)
INDUSTRY/GOV'T: Evaporation	X		X		60+
: Freeze/Thaw	X		X	X	55+
KRUYER: Oleophilic Sieve	X	X	X		No Change*
PREUSSAG: Prime I	X	X			90+
: Prime II	X	X			90+
: Prime III	X	X			90+
RTR: Oil Sand	X	X	X	X	30 (60)
: Froth	X	X			30 (60)
: Tailings	X	X			30 (60)
SESA	X	X	X	X	90
SOLV-EX: Oil Sand	X	X	X		50 (90)
: Fine Tailings	X	X	X	Sample Available	50 (90)
SCL: Fine Tailings/Overburden Mixed	X		X	X	60+
SCL/SUNCOR: Lime Addition	X		X	X	No Change*
: "Spiking"	X		X	X	No Change*
TPC	X	X	X	X	90+

GLOSSARY OF TERMS

MATERIAL BALANCE: Total distributional balance of bitumen, diluent, mineral and water
MINERAL BALANCE: Distribution balance of sand and fines
CLAY/FINES BALANCE: Distribution balance of specific size fractions less than 22 micron
GEOTECHNICAL: Specific ASTM tests on settled mineral

* No Change denotes no change in solids content, but potential reduction in total volume of fine tailings produced.
** Typically will be the number without parentheses, but can reach the parenthesized value with appropriate treatment.

Fine Tailings Technology Catalogue Spreadsheet

PROCESS NAME	ENGINEERING		ECONOMIC ANALYSIS	DISCLOSURE		STUDIES	
	DESIGN	EQUIP.		PATENT	PAPER	INTERNAL	EXTERNAL
AOSTRA TACIUK	X	X	X	X	X	X	X
CCDS	X	X		Pending	Pending		
CANOXY: Oil Sand (SRT)	Preliminary	Preliminary		Pending		X	
: Fine Tailings		X		Pending		X	
ESSO: Oslo Cold Water Ext'n (OCWE)	X	X	X	X	X	X	X
: Oslo Hot Water Ext'n (OHWE)	X	X	X	Pending		X	X
INDUSTRY/GOV'T: Evaporation					X	X	
: Freeze/Thaw					X	X	X
KRUYER: Oleophilic Sieve	X	X	X	X	X		X
PREUSSAG: Prime I	X	X	X	X			
: Prime II	X	X	X	X			
: Prime III	X	X	X	X			
RTR: Oil Sand	X	X	X	X	X	X	X
: Froth	X	X	X	X	X	X	X
: Tailings	X	X	X	X	X	X	X
SESA	X	X	X	X	X	X	X
SOLV-EX: Oil Sand	X	X	X	X		X	X
: Fine Tailings	X	X	X	Pending		X	X
SCL: Fine Tailings/Overburden Mixed	X	X	X		X	X	X
SCL/SUNCOR: Lime Addition					X	X	X
: "Spiking"	X	X	X		X	X	
TPC	X	X	X	X		X	

GLOSSARY OF TERMS

DESIGN: Process flow diagram (PFD), process and instrumentation design (P&ID) specifications sufficient for feasibility cost estimate.
EQUIP.: Special equipment specifications suitable for vendor quotes.
ECONOMIC ANALYSIS: Capital and operating costs developed, prorated to cost per m^3 of fine tailings or per tonne of oil sand.

PROCESS AOSTRA TACIUK PROCESSOR (ATP)

OWNER/OPERATOR UMATAC/AOSTRA

CONTACT PERSONNEL R. Kosarycz

18th Flr,700 4 Ave. SW
Calgary, AB T2P 3J4
403-297-3380 (297-3665)

PROCESS SUMMARY

The ATP applies high temperature in a rotating kiln to oil sand so as to volatilize and crack the hydrocarbons and recover them in downstream fractionation operations. Carbon residue is burned off in a separate zone of the reactor to assist in generation of heat for the process. The hot sand waste is recycled and provides heat recovery via indirect contact with the feed stream before discharge from the processor.

PROCESS LOCATION/APPLICATION

The process is applied to the oil sand as mined, as an alternative to the current CHWEP. It may be applied to any streams associated with current extraction operations as well.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1974			Ongoing
BENCH				
PILOT	1992	Various	5 t/h	Active
DEMONSTRATION				
COMMERCIAL				
OTHER	*			

COMMENTS

Replaces extraction and coking operations. Generates a dry solid waste.

Batch tests have been carried out on bitumen froth, sludges, and froth treatment plant tailings (oil plus heavy metals recovery).

*Settling tests were performed on tailings with/without oil coating.

PROCESS CCDS EXTRACTION PROCESS

OWNER/OPERATOR BITMIN RESOURCES LTD. (Kilborn/Fording)

CONTACT PERSONNEL J.M Somers

#1000, 205 9th Ave.SE
Calgary, AB T2G 0R4
403-260-9805 (265-8794)

PROCESS SUMMARY

The CCDS process involves hot water conditioning with countercurrent flow of bitumen slurry and stripped sand. The combination of "gentle" conditioning and no caustic reduces the dispersion of clay, so that much of the feed clay discharges from the conditioning drum with the sand. This stream is directed to backfill in the mined-out pit or storage elsewhere. Clay fines with the bitumen slurry are settled with or without chemical assistance after recovery of the bitumen, and this material can be combined with the other tailings for disposal.

PROCESS LOCATION/APPLICATION

The process is applied to the oil sand as mined, as an alternative to the current CHWEP. Retrofitting to current operations is possible but requires major revision to systems for materials handling.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB				
BENCH	1991			Complete
PILOT	1992	app. 6 wks	2 t/h	Complete
DEMONSTRATION				Under review*
COMMERCIAL				
OTHER				

COMMENTS

*Material balances and economic analysis prepared. 20 t/h Demo plant design underway.

PROCESS CANADIAN OXY SAND REDUCTION TECHNOLOGY (SRT)

OWNER/OPERATOR CANADIAN OCCIDENTAL PETROLEUM LTD.

CONTACT PERSONNEL Erdal Yildirim

1500-635 8 Ave.SW
Calgary, AB T2P 3Z1
403-234-6073 (263-8673)

PROCESS SUMMARY

The process involves conditioning of oil sand in medium temperature water using proprietary surfactants. Subsequent unit operations include air injection and phase separation by mechanical means for removing a major fraction of the solids during a short residence time. A small fraction of the total solids (fine tailings) remaining in the product settles fairly rapidly to permit recycle of supernatant water.

PROCESS LOCATION/APPLICATION

The process is applied to the oil sand at or near a mine site, as an alternative to the current CHWEP, to eliminate the transportation of sand.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1991-93	Continuous		Active
BENCH	1991-93	Continuous		Active
PILOT	1991	3 months	2 t/h	Active
DEMONSTRATION				
COMMERCIAL				
OTHER				

COMMENTS

A computerized design for a 100 t/h skid-mounted pilot unit has been prepared. Plans are underway for a field pilot program.

PROCESS CANADIAN OXY FINE TAILINGS SLUDGE PROCESSING & BITUMEN RECOVERY

OWNER/OPERATOR CANADIAN OCCIDENTAL PETROLEUM LTD.

CONTACT PERSONNEL Erdal Yildirim

1500-635 8 Ave.SW
Calgary, AB T2P 3Z1
403-234-6073 (263-8673)

PROCESS SUMMARY

The process involves dilution and conditioning of fine tailings, followed by two stages of flotation (without/with reagent) to remove most of the bitumen. Subsequent treatment includes combinations of chemical addition for flocculation and mechanical solids separation, such as filtration, cycloning and/or centrifugation.

PROCESS LOCATION/APPLICATION

The process has been applied to the mature fine tailings as obtained from the Syncrude and Suncor tailings ponds.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1991-93	Continuous		Active
BENCH	1992-93	3 months		Active
PILOT	1991	2 months	3 drums	Active
DEMONSTRATION				*
COMMERCIAL				
OTHER				

COMMENTS

Techniques tested for solids separation were designed to permit flexibility to be consistent with tailings disposal from the oil sands extraction operation.

*Discussions are underway with current operators regarding a demonstration size test program.

PROCESS OSLO COLD WATER EXTRACTION (OCWE)

OWNER/OPERATOR ESSO RESOURCES

CONTACT PERSONNEL Tom Dereniwski

3535 Research Road NW
Calgary, AB T2L 2K8
403-284-7430 (284-7488)

PROCESS SUMMARY

The OSLO Cold Water Extraction process is a water slurry process similar in concept to the CHWEP, but uses alternative chemicals to caustic and cool process temperatures, thus reducing clay dispersion and operating costs. Various alternative approaches to assist bitumen recovery are employed, such as strategic injection of air.

PROCESS LOCATION/APPLICATION

The process is applied to the oil sand as mined, as an alternative to the current CHWEP.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1986-87			
BENCH				
PILOT	1988			
DEMONSTRATION	1989-90		20 t/h	*
COMMERCIAL				
OTHER				

COMMENTS

*Testwork has included investigation of the feasibility of layered tailings (sand surcharge). Consolidation of fines to 60% solids has been reported.

PROCESS OSLO HOT WATER EXTRACTION (OHWE)

OWNER/OPERATOR ESSO RESOURCES

CONTACT PERSONNEL Tom Dereniwski

3535 Research Road NW
Calgary, AB T2L 2K8
403-284-7430 (284-7488)

PROCESS SUMMARY

The OSLO Hot Water Extraction process is a water slurry process similar in concept to the CHWEP, but uses alternative chemicals to caustic, thus reducing clay dispersion. Various alternative approaches to assist bitumen recovery are employed, such as strategic injection of air.

PROCESS LOCATION/APPLICATION

The process is applied to the oil sand as mined, as an alternative to the current CHWEP.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1989-90			
BENCH				
PILOT	1991		1 t/h	
DEMONSTRATION				
COMMERCIAL				
OTHER				

COMMENTS

The process was also tested by OSLO in 1991 at 2 t/h.

PROCESS EVAPORATION/EVAPOTRANSPIRATION

OWNER/OPERATOR INDUSTRY/GOV'T. (Non-proprietary)

CONTACT PERSONNEL Richard Johnson — Alberta Environmental Centre, Vegreville, AB, T9C 1T4, 403-632-8252 (632-8379)

Bob Burns — Suncor Inc., Tailings Development, Box 4001, Fort McMurray, AB, T9H 3E3, 403-743-6981 (791-8399)

Ted Lord — Syncrude Canada Ltd., 10120-17th St., Edmonton, AB T6P 1V8, 403-449-2907 (449-2805)

PROCESS SUMMARY

The process involves disposal of fine tailings in a manner to create a large surface area and thus accelerate the loss of water via evaporation. Application and development of vegetation assists the dewatering process via evapotranspiration.

PROCESS LOCATION/APPLICATION

The process is applied to recent or mature fine tailings.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1985-86	2 years	Pots	Complete
BENCH	1985-86	2 years	Barrels	Complete
PILOT	1986-87	2 years	Pits ($2m^3$)	Complete
DEMONSTRATION	1988-92	5 years	Ponds (up to 1000 m^3)*	On-going
COMMERCIAL				
OTHER				

COMMENTS

Ongoing site tests and leaching testwork.
The possibility exists of combining this process with Freeze-Thaw.
*See (Burns et al., 1993).

PROCESS FREEZE/THAW

OWNER/OPERATOR INDUSTRY/GOV'T. (NON-PROPRIETARY)

CONTACT PERSONNEL

Ted Lord — Syncrude Canada Ltd.
10120-17 St.
Edmonton, AB T6P 1V8
403-449-2907 (449-2805)

Dave Sego — University of Alberta
303G Civil/Elect. Bldg.
Edmonton, AB T6G 2G7
403-492-2059 (492-0249)

Bob Burns — Suncor Inc., Box 4001
Fort McMurray, AB T9H 3E3
403-743-6981 (791-8399)

Richard Johnson — Alberta Environmental Centre
Vegreville, AB T9C 1T4
403-632-8252 (632-8379)

PROCESS SUMMARY

The process can involve pH adjustment of mature fine tailings and subjection to freezing temperatures which forces migration of water from the collapsed clay/water structure. Subsequent thawing permits drainage of the freed water from the system. Much of the testwork is directed to practical methods of facilitating this technique in an operating seasonal environment in northern Alberta.

PROCESS LOCATION/APPLICATION

The process is applied to recent or mature fine tailings.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1985-86	2 years	Pots	Complete
BENCH	1985-86	2 years	Barrels	Complete
PILOT	1986-88	2 Years	Pits ($2m^3$)	Complete
DEMONSTRATION	1988-92	5 Years	Ponds (up to 1000 m^3)	On-going
COMMERCIAL				
OTHER				

COMMENTS

Exposure of thin layers of the treated tailings to freezing conditions is an important aspect of the process, as is subsequent removal of the expressed water.

PROCESS OLEOPHILIC SIEVE

OWNER/OPERATOR OLEOPHILIC SIEVE DEVELOPMENT OF CANADA LTD.

CONTACT PERSONNEL Jan Kruyer

9707-67A Street
Edmonton, AB T6B 1S3
403-466-9588 (same FAX)

PROCESS SUMMARY

The process involves processing of mature fine tailings with an Oleophilic Sieve separator. This is a flexible oleophilic (attaches to or attracts oil) apertured steel process belt which is passed through the fine tailings suspension. The bitumen attaches to the belt and is continually removed by jets of air, steam, water, or combinations thereof.

PROCESS LOCATION/APPLICATION

The process is applied to the mature fine tailings from oil sand operation tailings ponds. It has been previously proposed as a replacement for or addition to the current CHWEP.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1975			
BENCH				
PILOT	pre 1990		2 t/h	
DEMONSTRATION	1985			
COMMERCIAL				
OTHER				

COMMENTS

The process has been proposed for treating combined oil sand and fine tailings. Improvements to give better recovery of higher quality bitumen product have also been devised.

Use of caustic is not essential for this facility to capture oil; hence it has the potential to function effectively with oil sand slurry/conditioning processes other than the CHWEP.

PROCESS PRIME I

OWNER/OPERATOR PREUSSAG/NOELL

CONTACT PERSONNEL B. Diefenbach

BK Interconsult Ltd.
10420-80 Avenue
Edmonton, AB T6E 5T7
403-468-1968 (433-3935)

PROCESS SUMMARY

Mature fine tailings are preheated and combined with solvent. The mixture is cycloned and centrifuged. The light phase flows to a solvent recovery operation, with partially diluted bitumen as the product. The heavy phase is treated in a solvent recovery/drying operation, and the stripped solids are sent to disposal.

PROCESS LOCATION/APPLICATION

The process is applied to mature fine tailings.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1992	*	100mL	Complete
BENCH				
PILOT				
DEMONSTRATION				
COMMERCIAL				
OTHER				

COMMENTS

*Several tests were conducted.

Heat transfer coefficients and boiling point elevation calculated.

Various solvents were tested.

PROCESS PRIME II

OWNER/OPERATOR PREUSSAG/NOELL

CONTACT PERSONNEL B. Diefenbach

BK Interconsult Ltd.
10420-80 Avenue
Edmonton, AB T6E 5T7
403-468-1968 (433-3935)

PROCESS SUMMARY

Mature fine tailings are preheated, degassed and processed in a proprietary sludge evaporator/dryer. Dried fine tailings are mechanically removed and sent to disposal. Vapours are compressed and condensed in the upstream evaporator for overall thermal efficiency.

PROCESS LOCATION/APPLICATION

The process is applied to mature fine tailings.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1992		0.5 kg	
BENCH				
PILOT				
DEMONSTRATION				
COMMERCIAL				*
OTHER				

COMMENTS

Unit operations parameters were defined. Fine tailings dried to 54% solids content became firm in a short time.

*Costs for a modular plant have been calculated.

PROCESS PRIME III

OWNER/OPERATOR PREUSSAG/NOELL

CONTACT PERSONNEL B. Diefenbach

BK Interconsult Ltd.
10420-80 Avenue
Edmonton, AB T6E 5T7
403-468-1968 (433-3935)

PROCESS SUMMARY

Crushed screened oil sand is conditioned with benzene and separated. The light phase flows to a 2-stage settler and evaporator operation, generating recycle solvent and a dilute bitumen product. The process involves a vapour recompression operation to improve thermodynamic efficiency. The solids are heated and steam-stripped to recover solvent prior to disposal.

PROCESS LOCATION/APPLICATION

The process is applied to oil sand as mined.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1992		200 mL *	Complete
BENCH				
PILOT				
DEMONSTRATION				
COMMERCIAL				
OTHER				

COMMENTS

*Several tests were conducted.

PROCESS RTR (Oil Sand)

OWNER/OPERATOR RTR Oil Sands Alberta Ltd.

CONTACT PERSONNEL Aldo Corti

22189-401 9 Ave. SW
Calgary, AB T2P 4J5
403-233-9254 (251-6756)

PROCESS SUMMARY

The RTR Process involves slurrying of oil sand with hot water and caustic in a comparatively gentle conditioning operation so as to minimize clay dispersion. A high water/oil sand ratio is used, and bitumen is recovered via separation and flotation. Chemicals are added to flotation tailings prior to thickening. Thickener overflow is pH adjusted and recycled directly back to the process. Underflow may be transported directly to disposal at 25+ % solids, or centrifuged in scroll centrifuges to produce a high solids (55+ %) cake for disposal.

PROCESS LOCATION/APPLICATION

The process is applied to as-mined oil sand. It may be retrofitted to an existing CHWEP operation, with considerable modification to the existing unit operations.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	pre 1978			Complete
BENCH				
PILOT	*			
DEMONSTRATION	1978-82		20 t/h	Complete
COMMERCIAL				
OTHER				

COMMENTS

There is a diluent-assisted comparable process developed originally for oil shales.

*Process was tested by OSLO in 1989-90 as part of a larger extraction technology test program. Scale of operation was approximately 2 t/h. These data were reported in an internal OSLO document.

PROCESS RTR (Bitumen Froth)

OWNER/OPERATOR RTR Oil Sands Alberta Ltd.

CONTACT PERSONNEL Aldo Corti

22189-401 9 Ave. SW
Calgary, AB T2P 4J5
403-233-9254 (251-6756)

PROCESS SUMMARY

The RTR Process involves naphtha dilution of bitumen froth and treatment of the diluted froth in proprietary equipment to remove the water and solids. This stream is centrifuged to produce a high (50% to 60%) solids cake for disposal.

PROCESS LOCATION/APPLICATION

The process is applied to the bitumen froth product from primary extraction of oil sands bitumen.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1979-80			
BENCH				
PILOT				
DEMONSTRATION	1978-82		20 t/h*	complete
COMMERCIAL				
OTHER				

COMMENTS

*Oil sand rate.

This process applies also to bitumen and heavy oil streams recovered from in-situ operations.

PROCESS RTR (Tailings Densification)

OWNER/OPERATOR RTR Oil Sands Alberta Ltd.

CONTACT PERSONNEL Aldo Corti

22189-401 9 Ave. SW
Calgary, AB T2P 4J5
403-233-9254 (251-6756)

PROCESS SUMMARY

The RTR Process (Tailings) involves heating, dilution and chemical treatment of dredged mature fine tailings to facilitate thickening, recovery of contained water, and centrifugation of thickener underflow to produce a cake as per the process employed for oil sand processing. If necessary, operations to separate and recover contained bitumen can be employed as well.(1)

PROCESS LOCATION/APPLICATION

The process is applied to mature fine tailings.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1978			
BENCH				
PILOT	1986		0.5 t/h	Complete
DEMONSTRATION	1978-82		20 t/h(2)	Complete
COMMERCIAL				
OTHER				

COMMENTS

(1) Diluent-assist is possible as a variation of this process, with associated considerations of occurrence or recovery of residual trace diluent in effluent streams.

(2) Oil sand rate.

PROCESS SESA (SOLVENT EXTRACTION/SPHERICAL AGGLOMERATION)

OWNER/OPERATOR TERRA ENERGY (NRC)

CONTACT PERSONNEL Stephen Dunn

204-4603 Varsity Dr. NW
Calgary, AB T3A 2V7
403-247-2171 (288-2201)

PROCESS SUMMARY

The SESA process involves contacting oil sand with naphtha solvent which dissolves the bitumen. With controlled additions of small amounts of water, the solids form agglomerates (lightly bonded lumps or nodules) in a size range of 0.5 to 1.5 mm. Separation of the solids from the solvent-bitumen solution is followed by the recovery of the solvent from the solids and disposal of solids (at about 90% solids) to the mined-out area. No special chemicals are used.

PROCESS LOCATION/APPLICATION

The process is applied to the oil sand as mined, as an alternative to the current CHWEP.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	Ongoing			
BENCH	Pre 1987	1 year	0.6 t/d	Complete
PILOT				Designed
DEMONSTRATION				
COMMERCIAL				
OTHER				

COMMENTS

Developments include a bench scale pilot plant, a study/comparison with the CHWEP, and the design of a larger pilot plant (10 t/h) in 1988-90.

Tests of the process for oil contaminated soil remediation have been successfully conducted.

PROCESS SOLV-EX (Oil Sand)

OWNER/OPERATOR SOLV-EX CORP

CONTACT PERSONNEL John Rendall

#320-1650 University Blvd NE
Albuquerque NM 87102
505-243-7701 (243-7705)

PROCESS SUMMARY

The process involves slurrying of oil sand with hot water, further dilution with suitable diluent/solvent, and separation of the hydrocarbon stream. The sand slurry is subjected to hot water washing and then drainage/dewatering. Fine solids are thickened, centrifuged and dried to remove residual solvent.

PROCESS LOCATION/APPLICATION

The process is applied to the oil sand as mined as an alternative process to the CHWEP.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB				
BENCH				
PILOT	1987-88	3 months	2 t/h	complete*
DEMONSTRATION				
COMMERCIAL				
OTHER				

COMMENTS

*Current plans include piloting for sand rejection at the mine site, followed by solvent extraction of fine tailings. Twenty tonnes of low grade (7.5% w/w bitumen) oil sand was processed by this method. Further similar testwork is planned for average grade oil sand.

Development is directed to recovery of valuable metals from tailings to improve economics.

PROCESS SOLV-EX (Fine Tailings)

OWNER/OPERATOR SOLV-EX CORP

CONTACT PERSONNEL John Rendall

#320-1650 University Blvd NE
Albuquerque NM 87102
505-243-7701 (243-7705)

PROCESS SUMMARY

The process involves dilution of mature fine tailings with water and solvent, followed by chemical conditioning and centrifugation at controlled conditions. The partially-dewatered solids fraction is dried for solvent recovery, agglomerated and acid-leached to dissolve recoverable metals. The slurry is filtered and washed to produce cake at approximately 80% solids for disposal.

PROCESS LOCATION/APPLICATION

The process is applied to the mature fine tailings from existing oil sand tailings ponds.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1992	1 week		Complete
BENCH	1992	1 month	40 to 80L (batch)	
PILOT	1992-93	4 months	2.5 m^3/h	Complete
DEMONSTRATION				Design*
COMMERCIAL				Design*
OTHER				

COMMENTS

Most recent testwork was conducted on mature fine tailings from two operating plants. Products from treatment of fine tailings are clean recycle water (<1% solids, pH 7) and backfill cake (25% water, passing relevant EPA tests).

Acid leach liquor has been sent to laboratories to confirm metals content and marketability.

*Design underway for demonstration (50 to 100 m^3/h) and commercial (500 m^3/h) modular plants.

PROCESS FINE TAILINGS/OVERBURDEN MIXED

OWNER/OPERATOR SYNCRUDE

CONTACT PERSONNEL Ted Lord

Syncrude Canada Ltd.
10120-17 St.
Edmonton, AB T6P 1V8
403-449-2907 (449-2805)

PROCESS SUMMARY

Clay-containing overburden to be mined and relocated is mechanically combined with mature fine tailings at or prior to disposal. Techniques tested include pipeline, earth mover and spreader (dragline). The relatively dry clay in the overburden absorbs water from the fine tailings, resulting in a significant reduction in water/clay ratio (net solids of 60% to 70%), hence a more acceptable material for in-pit disposal. Tests were directed to determining the takeup of fine tailings water and geotechnical competence of the resulting material.

PROCESS LOCATION/APPLICATION

This process is applied to mature fine tailings.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1984-93			
BENCH				
PILOT	1985-93		8k m^3 deposit	(1)
DEMONSTRATION				
COMMERCIAL				
OTHER	1985-89		5k m^3 to 27k m^3 deposit	(2)

COMMENTS

(1) Pilot tests are continuing at the Saskatchewan Research Council Pipeline Centre. Ratios of 1:2 fine tailings: overburden by volume are considered optimum. Feed/pumping systems are being evaluated.

(2) Field tests involved co-disposal using pipeline technologies and dumping of overburden into fine tailings in large pits, and checking absorption of fine tailings into the overburden material.

PROCESS LIME ADDITION TO TAILINGS

OWNER/OPERATOR SYNCRUDE/SUNCOR

CONTACT PERSONNEL

Ted Lord

Syncrude Canada Ltd.
10120-17 St.
Edmonton, AB TP6 1V8
403-449-2907 (449-2805)

Bob Burns

Suncor Inc.
Box 4001
Fort McMurray, AB T9H 3E3
403-743-6981 (791-8399)

PROCESS SUMMARY

Lime is added to combined tailings as it is pumped to the disposal site. Aggregation of dispersed clays and formation of a non-segregating mix increases potential for capture of fines in the sand void spaces, and reduces the formation of fine tailings in the tailings pond.

PROCESS LOCATION/APPLICATION

This technique is applied to tailings as produced in the extraction plant and is designed to increase fines capture.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1992-93			Continuing
BENCH				
PILOT				
DEMONSTRATION				
COMMERCIAL				
OTHER	1990		11k m^3 deposit	Complete

COMMENTS

Low slope angles of deposited material suggest that product requires containment. Lab tests are directed toward prediction of field performance.

The success of this technique depends upon proper water management.

PROCESS "SPIKING"

OWNER/OPERATOR SYNCRUDE/SUNCOR

CONTACT PERSONNEL

Ted Lord
Syncrude Canada Ltd.
10120- 17 St.
Edmonton, AB T6P 1V8
403-449-2907 (449-2805)

Bob Burns
Suncor Inc.
Box 4001
Fort McMurray, AB T9H 3E3
403-743-6981 (791-8399)

PROCESS SUMMARY

Mature fine tailings is recycled from the tailings pond replacing dilution water of tailings as pumped from the extraction plant. The aim is to increase the capture of fine solids in the sand interstices at the disposal site, displacing thin fine tailings which would otherwise fill these void spaces.

PROCESS LOCATION/APPLICATION

This technique is applied to mature fine tailings with live tailings as-produced and is designed to increase fines capture.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1988			Completed
BENCH				
PILOT				
DEMONSTRATION				
COMMERCIAL				
OTHER	1990		600 m^3/h	(1)

COMMENTS

(1) Combined material (1:6 vol ratio fine tailings:plant tailings) was pumped to a contained cell (11k m^3); slope angle and fines capture were measured. Syncrude has indicated a 100% increase in fines capture over normal (from 4% to 8%), with a possible net 0.17 m^3 fine tailings trapped per m^3 of coarse sand.

PROCESS TPC

OWNER/OPERATOR T.P. CLARKE

CONTACT PERSONNEL Brian Cook

1340 Weber Centre
5555 Calgary Trail
Edmonton, AB T6H 5P9
403-437-0743 (438-6695)

PROCESS SUMMARY

The TPC process involves treating the combined tailings streams by elutriation of the combined feed, followed by decanting, then filtration. The filter cake is washed with diluent for bitumen recovery and then hot water to recover solvent. The "dry" filter cake solids are then transported for disposal.

PROCESS LOCATION/APPLICATION

The process is applied to the tailings from the CHWEP as currently practiced. It is proposed that mature fine tailings could be re-introduced to the operating plant and, after suitable preparation such as dilution and flocculation, be combined and processed with live tailings.

DEVELOPMENT HISTORY (Most Recent)

TESTWORK	DATE	DURATION	RATE	STATUS
LAB	1951-91			
BENCH				
PILOT				
DEMONSTRATION				
COMMERCIAL				
OTHER				

COMMENTS

Implicit to the process is the use of "Prayon" Tilting Pan filters as manufactured by the Bird Machine Co. These are industrial segmented filters that incorporate multi-function batch operations such as filtration, backflush, decantation, etc. as required at various stages of the process.

5. QUESTIONS FOR PRELIMINARY EVALUATION OF FINE TAILINGS PROCESSES OR TREATMENTS

5.1 CATEGORY

Does the Process/Treatment "fit" into one of the categories depicted in Figures 2, 3 or 4? These may be described as follows:

(1) New Extraction Process, producing a new tailings stream containing less water than that from the existing CHWEP.

(2) CHWEP, with increased capture of fines in the coarse sand.

(3) CHWEP with Process/Treatment of the fine tailings to produce generally a dewatered fine tailings and waste water.

5.2 ENGINEERING

(1)
- What is the feedstock for the process (oil sand, tailings, fine tailings, etc.)?
- Please provide a process description on a separate page and include a simplified process flow diagram if possible.

(2)
- What unit operations are included in the process? Please include mechanical as well as process unit operations.
- How sensitive are the control requirements within and between these unit operations?
- How well proven are these unit operations with this type of material at this scale?
- How well have relevant process kinetics and scale-up parameters been defined?
- Please provide typical examples if possible.

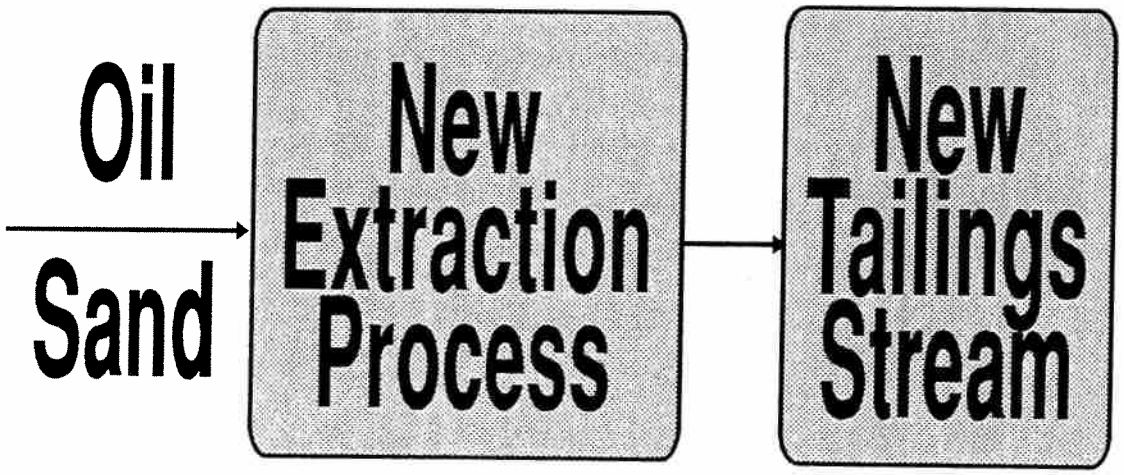

Figure 2: New Extraction Process

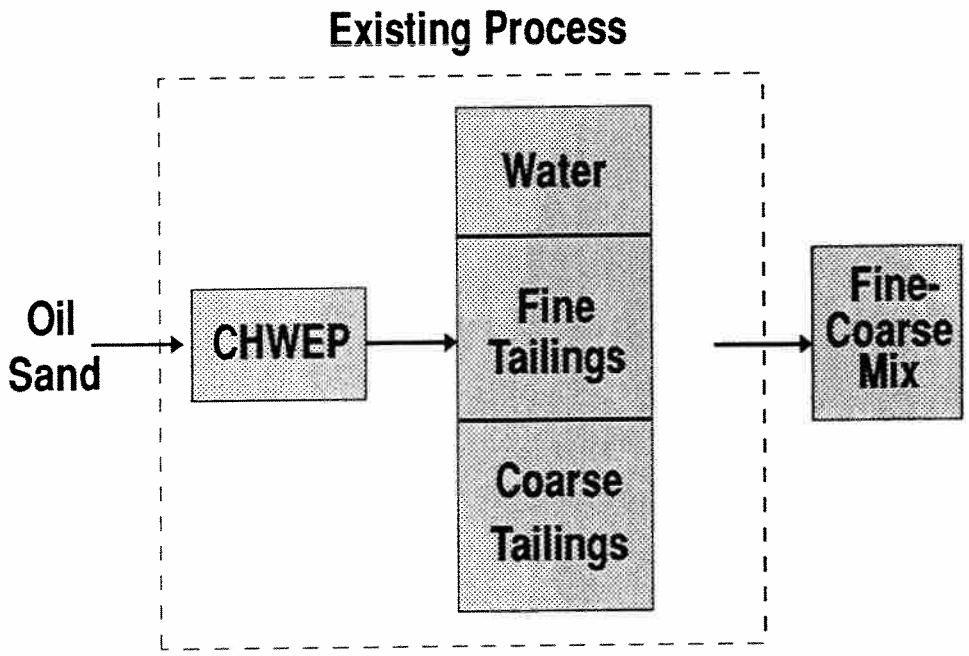

Figure 3: CHWEP with Increased Fines Capture

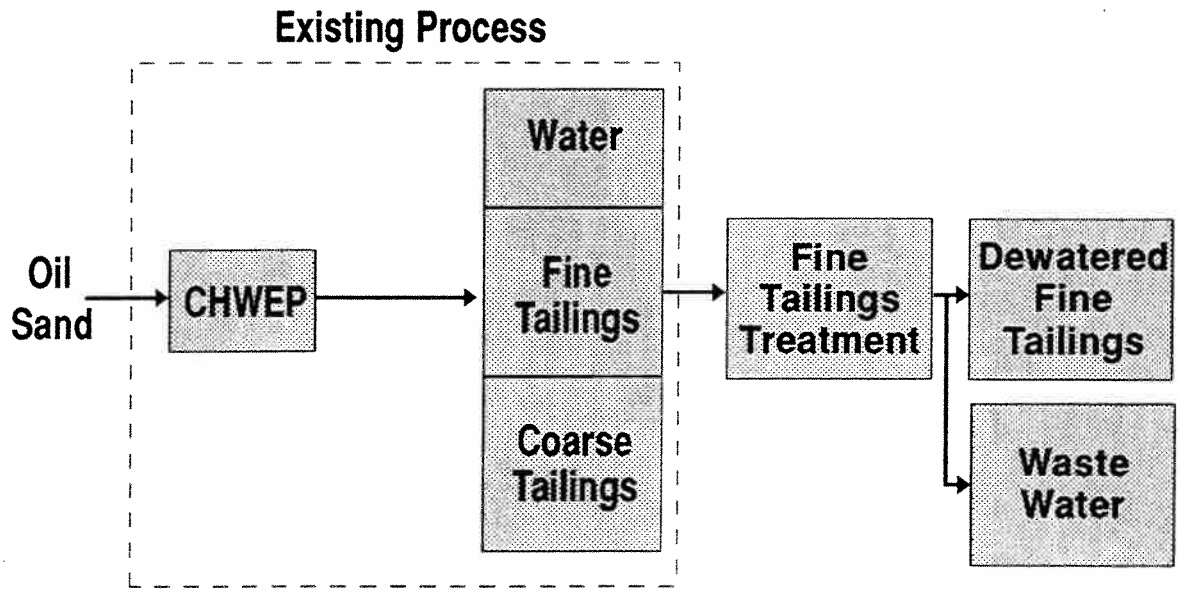

Figure 4: Fine Tailings Treatment

(3)
- What is the testing and development history for the process/treatment? Please include details of timing, duration, scale and feedstock; differentiate between laboratory, bench and pilot operation.
- Has a schedule for a demonstration or commercial facility been developed:

(4) What test details are available for review?

(5) What material and energy balance information is available?

(6)
- Is the process designed to be retrofitted to existing extraction or tailings operations?
- If so, what concerns might there be regarding its compatibility.

(7) How stable is the process? Please take into consideration such aspects as feed variation, process upset or shutdown, and other specific process parameters.

(8)
- Are there special materials handling requirements associated with the process?
- How well proven are the various materials handling operations required for the process?

(9)
- What are the utilities and chemical requirements for the process/treatment?
- What special control difficulties might there be with utilities and chemical systems?

(10)
- What aspects of the process/treatment might be potentially hazardous?
- Is there a need for special protection systems or training?
- What electrical classification would be required for the facility?

(11) Is the process described in a patent, paper or preprint? If so, please provide references.

5.3 WASTE PRODUCT CHARACTERIZATION

(1) Are the products of the process/treatment dewatered (may include partially dewatered) tailings plus water (plus other), or dewatered tailings only?

(2)
- What is the volume ratio of waste product to feed? Product may be dewatered tailings and water; feed may be fine tailings or oil sand.
- Can this be expressed as ratio of waste product to synthetic crude?

(3)
- What are the ranges in bitumen, solids and water content of the product?
- For the solids portion, indicate (if possible) the fines (- 44 μ) and coarse distribution as well as the complete particle size distribution.
- For the water portion, please indicate (if possible) the total suspended and dissolved solids, the ion concentrations and pH, and the dissolved organic content in terms of total organic carbon, biological oxygen demand and chemical oxygen demand.

(4) If a solid product is produced, what are its engineering and geotechnical properties? Items such as rheology/pumpability, strength, sedimentation and consolidation properties should be included.

(5)
- Will any of the properties in (3) or (4) change with time?
- If so, at what rate and to what level?

(6)
- What are the options for disposal of the products from the process/treatment?
- How suitable will the dewatered fine tailings be for disposal in-pit or above-grade, and what further treatment may be required to make it suitable for disposal?

(7) What are the product characteristics affecting the environment? For solids, address both acute and chronic toxicity and leachability (organics, salts and heavy metals); for water, address acute and chronic toxicity, natural detoxification, and any special treatment requirements to meet effluent guidelines.

(8) What testwork (indicate whether lab or field and the scale) has been conducted to determine the suitability of the fine tailings to revegetation and overall reclamation?

(9)
- What atmospheric emissions will result from the operation of the process/treatment?
- What special requirements will be necessary for their mitigation?

(10)
- Are there any useful or saleable by-products resulting from the process/treatment?
- If so, what are they, and where would they be useful?

(11)
- Are the waste products and their properties described in a paper or publication?
- If so, please provide references.

5.4 ECONOMICS

(1)
- What information is available regarding capital and operating costs for the process/treatment?
- How detailed is this information?

(2)
- Have there been economic feasibility studies performed for the process/treatment?
- Were these performed in-house or by outside consultant?
- How definitive were the cost estimates?
- When were they performed, and are they available for review?

(3) How much incremental cost per barrel of synthetic crude oil production do you estimate will be required to incorporate the process/treatment into existing operations?

6. CONCLUSIONS

A convenient format was designed to catalogue technologies for reducing the environmental impact of fine tailings from oil sand processing. Information on these technologies was obtained from the proponents themselves on the basis of completed questionnaire forms and personal interviews. Updating the catalogue will be relatively simple as additional information becomes available.

A detailed set of questions was prepared that highlights the environmentally related information that a proponent should have. These questions should help to form a basis for comparisons among the technologies.

7. REFERENCES

Fuhr, B., C. Powter, D. Taplin and D. Rose, 1993. Catalogue of Technologies for Reducing the Environmental Impact of Fine Tails from Oil Sand Processing. IN: Oil Sands: Our Petroleum Future Conference. J.K. Liu (Editor). Alberta Oil Sands Technology and Research Authority, Edmonton, Alberta.

Gulley, J.R. and M. MacKinnon, 1993. Fine Tails Reclamation Utilizing a Wet Landscape Approach. IN: Oil Sands: Our Petroleum Future Conference. J.K. Liu (Editor). Alberta Oil Sands Technology and Research Authority, Edmonton, Alberta.

Burns, R., G. Cuddy and R. Lahaie, 1993. Dewatering of Fine Tails by Natural Evaporation. IN: Oil Sands: Our Petroleum Future Conference. J.K. Liu (Editor). Alberta Oil Sands Technology and Research Authority, Edmonton, Alberta.

APPENDIX

GLOSSARY OF TERMS

BITUMEN	The heavy viscous hydrocarbon associated with the Athabasca Oil Sand deposits. It contains some mineral and sulphur contaminant material.
CAUSTIC	Sodium hydroxide, used to assist the current commercial bitumen extraction process. It assists in detaching bitumen from sand particles, but unfortunately contributes to stability of clay particle dispersion.
CENTRIFUGE	Machinery which utilizes centrifugal (rotating) force to accelerate the separation of materials of different specific gravities.
CHWEP	The Clark Hot Water Extraction Process that has been used by current operators (Suncor and Syncrude) to separate bitumen from mined oil sand. It requires sodium hydroxide (caustic) which unfortunately disperses clays, creating a swelling problem with waste mineral slurry.
CLAY	Fine mineral of varying composition, resistant to settling due to particle size (micron size) and other factors promoting dispersion stability.
COKER	Refinery unit which heats bitumen to separate carbon and lighter hydrocarbon. The carbon forms "coke" which is either burned or removed from the process, while the lighter hydrocarbons are processed separately to create synthetic crude oil.
EXTRACTION	The separation of bitumen from oil sand.

FINE TAILINGS	A term used in this industry to refer to the material accumulating at the bottom of oil sand tailings ponds. It is a matrix of dispersed clays, fine mineral, residual hydrocarbons and various contaminants. It is also referred to as fine tailings or sludge.
FINES	Mineral which includes fine sand, silts and clays, smaller than about 22 micron. The size split is somewhat arbitrary, related to standard screen mesh and/or analytical technique and the required interpretation.
FROTH	The product of initial or "primary" extraction. The bitumen separates from the oil sand slurry as an aerated froth, containing some fine mineral and water.
FROTH TREATMENT	The second step of extraction, wherein the bitumen froth is diluted with naphtha (light hydrocarbon) and separated from most of the contained water and mineral using centrifuges or various gravity settling devices. Because the naphtha is easily ignited, this operation is physically separated from the much larger primary extraction plant.
HYDROTREAT	To add hydrogen to the oil via special refinery processing. A primary purpose in this operation is to convert impurity sulphur compounds to hydrogen sulphide for easy separation.
RECLAMATION	All practicable and reasonable methods of conducting an activity to ensure (1) stable, non-hazardous, non-erodable, favourably drained soil conditions, and (2) equivalent land capability.
RETROFIT	To add new facilities to an existing operation.
SLURRY	Mixture of water and mineral of varying concentration.

SURFACTANT — Water-soluble chemical which affects the surface chemistry of dispersed particles.

TAILINGS — The waste effluent from oil sand extraction; usually a mixture of water and mineral, plus residual unrecovered hydrocarbon. Until storage space is available in mined-out pits, it must be retained in a large pond surrounded by sand dykes; these are a combination of overburden material and sand deposited from the tailings itself. It is also called whole tailings, plant tailings or combined tailings.

RECLAMATION RESEARCH REPORTS

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes. Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-2: Alberta's Reclamation Research Program - 1979. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,190,006 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

4. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. No longer available.**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

5. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

6. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available; replaced by RRTAC 89-4.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

7. **RRTAC 81-1: The Alberta Government's Reclamation Research Program - 1980. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,455,680 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

8. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

9. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

10. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

11. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

12. **RRTAC 82-3: The Alberta Government's Reclamation Research Program - 1981. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,499,525 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

13. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials (See RRTAC 92-4).

14. **RRTAC 83-2: The Alberta Government's Reclamation Research Program - 1982. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,536,142 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

15. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

16. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

17. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

18. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

19. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

20. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report describes the expenditure of $1,529,483 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

21. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

22. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. No longer available.**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

23. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. No longer available.**

This report describes the expenditure of $1,320,516 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

24. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

25. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. No longer available.**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

26. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

27. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

28. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

29. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

30. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

31. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report describes the expenditure of $1,168,436 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

32. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. No longer available.**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

33. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

34. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. No longer available.**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. No longer available.**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

36. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. No longer available.**

This report describes the expenditure of $1,186,000 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

37. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

38. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

39. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

40. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

41. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

42. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

43. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

44. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. No longer available.**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

45. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

46. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

47. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. No longer available.**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

48. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their un-inoculated counterparts.

49. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

50. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. No longer available.**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

51. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

52. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

53. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

54. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. No longer available.**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

55. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. No longer available.**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

56. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

57. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

58. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

59. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. No longer available.**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

60. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. ISBN 0-7732-0878-X. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

61. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition. Hardy BBT Limited. 436 pp. ISBN 0-7732-0882-8. $10.00.**

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that precedes each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

62. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw. 188 pp. No longer available.**

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

63. **RRTAC 89-6: Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta. T.M. Macyk, F.I. Nikiforuk, S.A. Abboud and Z.W. Widtman. 228 pp. No longer available.**

This report summarizes a three-year study of the chemistry of freshwater gel, KCl, NaCl, DAP, and invert drilling wastes, both solids and liquids, from three regions in Alberta: Cold Lake, Eastern Slopes, and Peace River/Grande Prairie. A greenhouse study also examined the effects of adding various amounts of waste to soil on grass growth and soil chemistry. Methods for sampling drilling wastes are recommended.

64. **RRTAC 89-7: A User's Guide for the Prediction of Post-Mining Groundwater Chemistry from Overburden Characteristics. M.R. Trudell and D.C. Cheel. 55 pp. $5.00**

This report provides the detailed procedure and methodology that is required to produce a prediction of post-mining groundwater chemistry for plains coal mines, based on the soluble salt characteristics of overburden materials. The fundamental component of the prediction procedure is the geochemical model PHREEQE, developed by the U.S. Geological Survey, which is in the public domain and has been adapted for use on personal computers.

65. **RRTAC 90-1: Reclamation Research Annual Report - 1989. 62 pp. No longer available.**

This annual report describes the expenditure of $480,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

66. **RRTAC 90-2: Initial Selection for Salt Tolerance in Rocky Mountain Accessions of Slender Wheatgrass and Alpine Bluegrass. R. Hermesh, J. Woosaree, B.A. Darroch, S.N. Acharya and A. Smreciu. 40 pp. $5.00**

Selected lines of slender wheatgrass and alpine bluegrass collected from alpine and subalpine regions of Alberta as part of another native grass project were evaluated for their ability to emerge in a saline medium. Eleven slender wheatgrass and 72 alpine bluegrass lines had a higher percentage emergence than the Orbit Tall Wheatgrass control (a commonly available commercial grass). This means that as well as an ability to grow in high elevation areas, these lines may also be suitable for use in areas where saline soil conditions are present. Thus, their usefulness for reclamation has expanded.

67. **RRTAC 90-3: Natural Plant Invasion into Reclaimed Oil Sands Mine Sites. Hardy BBT Limited. 65 pp. $5.00**

Vegetation data from reclaimed sites on the Syncrude and Suncor oil sands mines have been summarized and related to site and factors and reclamation methods. Natural invasion into sites seeded to agronomic grasses and legumes was minimal even after 15 years. Invasion was slightly greater in sites seeded to native species, but was greatest on sites that were not seeded. Invasion was mostly from agronomic species and native forbs; native shrub and tree invasion was minimal.

68. **RRTAC 90-4: Physical and Hydrological Characteristics of Ponds in Reclaimed Upland Landscape Settings and their Impact on Agricultural Capability. S.R. Moran, T.M. Macyk, M.R. Trudell and M.E. Pigot, Alberta Research Council. 76 pp. $5.00**

The report details the results and conclusions from studying a pond in a reclaimed upland site in Vesta Mine. The pond formed as a result of two factors: (1) a berm which channelled meltwater into a series of subsidence depressions, forming a closed basin; and (2) low hydraulic conductivity in the lower subsoil and upper spoil as a result of compaction during placement and grading which did not allow for rapid drainage of ponded water. Ponds such as this in the reclaimed landscape can affect agricultural capability by: (1) reducing the amount of farmable land (however, the area covered by these ponds in this region is less than half of that found in unmined areas); and, (2) creating the conditions necessary for the progressive development of saline and potentially sodic soils in the area adjacent to the pond.

69. **RRTAC 90-5: Review of the Effects of Storage on Topsoil Quality. Thurber Consultants Ltd., Land Resources Network Ltd., and Norwest Soil Research Ltd. 116 pp. $10.00**

The international literature was reviewed to determine the potential effects of storage on topsoil quality. Conclusions from the review indicated that storage does not appear to have any severe and longterm effects on topsoil quality. Chemical changes may be rectified with the use of fertilizers or manure. Physical changes appear to be potentially less serious than changes in soil quality associated with the stripping and respreading operations. Soil biotic populations appear to revert to pre-disturbance levels of activity within acceptable timeframes. Broad, shallow storage piles that are seeded to acceptable grass and legume species are recommended; agrochemical use should be carefully controlled to ensure soil biota are not destroyed.

70. **RRTAC 90-6: Proceedings of the Industry/Government Three-Lift Soils Handling Workshop. Deloitte & Touche. 168 pp. $10.00**

This report documents the results of a two-day workshop on the issue of three-lift soils handling for pipelines. The workshop was organized and funded by RRTAC, the Canadian Petroleum Association and the Independent Petroleum Association of Canada. Day one focused on presentation of government and industry views on the criteria for three-lift, the rationale and field data in support of three- and two-lift procedures, and an examination of the various soil handling methods in use. During day two, five working groups discussed four issues: alternatives to three-lift; interim criteria and suggested revisions; research needs; definitions of terms. The results of the workshop are being used by a government/industry committee to revise soils handling criteria for pipelines.

71. **RRTAC 90-7: Reclamation of Disturbed Alpine Lands: A Literature Review. Hardy BBT Limited. 209 pp. $10.00**

This review covers current information from North American sources on measures needed to reclaim alpine disturbances. The review provides information on pertinent Acts and regulations with respect to development and environmental protection of alpine areas. It also discusses: alpine environmental conditions; current disturbances to alpine areas; reclamation planning; site and surface preparation; revegetation; and, fertilization. The report also provides a list of research and information needs for alpine reclamation in Alberta.

72. **RRTAC 90-8: Plains Hydrology and Reclamation Project: Summary Report. S.R. Moran, M.R. Trudell, T.M. Macyk and D.B. Cheel. 105 pp. $10.00**

This report summarizes a 10-year study on the interactions of groundwater, soils and geology as they affect successful reclamation of surface coal mines in the plains of Alberta. The report covers: Characterization of the Battle River and Wabamun study areas; Properties of reclaimed materials and landscapes; Impacts of mining and reclamation on post-mining land use; and, Implications for reclamation practice and regulation. This project has led to the publication of 18 RRTAC reports and 22 papers in conference proceedings and referred journals.

73. **RRTAC 90-9: Literature Review on the Disposal of Drilling Waste Solids. Monenco Consultants Limited. 83 pp. $5.00**

This report reviews the literature on, and government and industry experience with, burial of drilling waste solids in an Alberta context. The review covers current regulations in Alberta, other provinces, various states in the US and other countries. Definitions of various types of burial are provided, as well as brief summaries of other possible disposal methods. Environmental concerns with the various options are presented as well as limited information on costs and monitoring of burial sites. The main conclusion of the work is that burial is still a viable option for some waste types but that each site and waste type must be evaluated on its own merits.

74. **RRTAC 90-10: Potential Contamination of Shallow Aquifers by Surface Mining of Coal. M.R. Trudell, S.R. Moran and T.M. Macyk. 75 pp. $5.00**

This report presents the results of a field investigation of the movement of salinized groundwater from a mined and reclaimed coal mine near Forestburg into an adjacent unmined area. The movement is considered to be an unusual occurrence resulting from a combination of a hydraulic head that is higher in the mined area than in the adjacent coal aquifer, and the presence of a thin surficial sand aquifer adjacent to the mine. The high hydraulic head results from deep ponds in the reclaimed landscape that recharge the base of the spoil.

75. **RRTAC 91-1: Reclamation Research Annual Report - 1990. Reclamation Research Technical Advisory Committee. 69 pp. No longer available.**

This annual report describes the expenditure of $499 612 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program. The report lists the 70 research reports published under the program.

76. **RRTAC 91-2: Winter Soil Evaluation and Mapping for Regulated Pipelines. A.G. Twardy. 43 pp. ISBN 0-7732-0874-7. $5.00**

Where possible, summer soil evaluations are preferred for pipelines. However, when winter soil evaluations must be done, this report lays out the constraints and requirements for obtaining the best possible information. Specific recommendations include: restricting evaluations to the time of day with the best light conditions; use of core- or auger-equipped drill-trucks; increased frequency of site inspections and soil analyses; and, hiring a well-qualified pedologist. The province's soils are divided into four classes, based on their difficulty of evaluation in winter: slight (most soils); moderate; high; and, severe (salt-affected soils in the Brown and Dark Brown Soil Zones).

77. **RRTAC 91-3: A User Guide to Pit and Quarry Reclamation in Alberta. J.E. Green, T.D. Van Egmond, C. Wylie, I. Jones, L. Knapik and L.R. Paterson. 151 pp. ISBN 0-7732-0876-3. $10.00**

Sand and gravel pits or quarries are usually reclaimed to the original land use, especially if that was better quality agricultural or forested land. However, there are times when alternative land uses are possible. This report outlines some of the alternate land uses for reclaimed sand and gravel pits or quarries, including: agriculture, forestry, wildlife habitat, fish habitat, recreation, and residential and industrial use. The report provides a general introduction to the industry and to the reclamation process, and then outlines some of the factors to consider in selecting a land use and the methods for reclamation. The report is not a detailed guide to reclamation; it is intended to help an operator determine if a land use would be suitable and to guide him or her to other sources of information.

78. **RRTAC 91-4: Soil Physical Properties in Reclamation. M.A. Naeth, D.J. White, D.S. Chanasyk, T.M. Macyk, C.B. Powter and D.J. Thacker. 204 pp. ISBN 0-7732-0880-1. $10.00**

This report provides information from the literature and Alberta sources on a variety of soil physical properties that can be measured on reclaimed sites. Each property is explained, measurement methods, problems, level of accuracy and common soil values are presented, and methods of dealing with the property (prevention, alleviation) are discussed. The report also contains the results of a workshop held to discuss soil physical properties and the state-of-the-art in Alberta.

79. **RRTAC 92-1: Reclamation of Sterilant Affected Sites: A Review of the Issue in Alberta. M. Cotton and M.P. Sharma. 64 pp. ISBN 0-7732-0884-4. No longer available**

This report assesses the extent of sterilant use on oil and gas leases in Alberta, identifies some of the concerns related to reclamation of sterilant affected sites and the common methods for reclaiming these sites, and outlines the methods for sampling and analyzing soils from sterilant affected sites. The report also provides an outline of a research program to address issues raised by government and industry staff.

80. **RRTAC 92-2: Reclamation Research Annual Report - 1991. Reclamation Research Technical Advisory Committee. 55 pp. ISBN 0-7732-0888-7. No longer available.**

This report describes the expenditure of $485,065 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the five program areas, and describes the projects funded under each program. It also lists the 75 research reports that have been published to date.

81. **RRTAC 92-3: Proceedings of the Industry/Government Pipeline Reclamation Success Measurement Workshop. R.J. Mahnic and J.A. Toogood. 62 pp. ISBN 0-7732-0886-0. $5.00.**

This report presents the results of a workshop to identify the soil and vegetation parameters that should be used to assess reclamation success on pipelines in Alberta. Six soil parameters (topsoil admixing; topsoil replacement thickness; compaction; soil loss by erosion; texture; and salinity) and six vegetation parameters (plant density; species composition; ground cover; vigour; weeds/undesirable species; and rooting characteristics) were selected as most important. Working groups discussed these parameters and presented suggested methods for assessing them in the field.

82. **RRTAC 92-4: Oil Sands Soil Reconstruction Project Five Year Summary. HBT AGRA Limited. 109 pp. ISBN 0-7732-0875-5. $10.00**

This report documents a five year study of the effects of clay and peat amendments to oil sand tailings sand on survival and growth of trees and shrubs. Ten species (jack pine, white spruce, serviceberry, silverberry, buffaloberry, pin cherry, prickly/woods rose, Northwest poplar, green alder, and Bebb willow) were planted into tailings sand amended with three levels of peat and three levels of clay. The treatments were incorporated to a depth of 20 cm or 40 cm. Data are provided on plant survival and growth, root size and distribution, disease and small mammal damage, herbaceous cover, soil moisture, soil chemistry, and bulk density.

83. **RRTAC 92-5: A Computer Program to Simulate Groundwater Flow and Contaminant Transport in the Vicinity of Active and Reclaimed Strip Mines: A User's Guide. A.S. Crowe and F.W. Schwartz, SIMCO Groundwater Research Ltd. 104 pp. plus appendix. ISBN 0-7732-0877-1. NOTE: This report is only available from the Alberta Research Council, Publications Centre, 250 Karl Clark Road, P.O. Box 8330, Station F, EDMONTON, Alberta T6H 5R7 as ARC Information Series 119. The cost is $20.00 and the cheque must be made out to the Alberta Research Council.**

The manual describes a computer program that was developed to study the influence of coal strip mining on groundwater flow systems and to simulate the transport of generated contaminants, both spatially and in time, in the vicinity of a mine. All three phases of a strip mine can be simulated: the pre-mining regional groundwater flow system; the mining and reclamation phase; and, the post-mining water level readjustment phase. The model is sufficiently general to enable the user to specify virtually any type of geological conditions, mining scenario, and boundary conditions.

84. **RRTAC 92-6: Alberta Drilling Waste Sump Chemistry Study. Volume I: Report (Volume II: Appendices is only available through the Alberta Research Council, Publications Centre, 250 Karl Clark Road, P.O. Box 8330, Station F, EDMONTON, Alberta T6H 5R7. The cost is $15.00 and the cheque must be made out to the Alberta Research Council.). T.M. Macyk, S.A. Abboud and F.I. Nikiforuk, Alberta Research Council. 217 pp. ISBN 0-7732-0879-8. $10.00.**

This study synthesizes the data from sampling and analysis of the solids and liquids found in 128 drilling waste sumps across Alberta. Drilling waste types sampled included: 72 freshwater gel, 19 invert, 27 KCl, 2 NaCl, and 8 others. Data and statistics are tabulated by waste type, depth of the drill hole, and ERCB administrative region for both the solids and the liquids. Using preliminary loading limits developed by the government/industry Drilling Waste Review Committee, the report presents information on the volume and depth of waste that could be landspread, and the area required for landspreading. The oil and gas industry provided approximately $585,000 for the sampling and analysis phase of this study.

85. **RRTAC 93-1: Reclamation of Native Grasslands in Alberta: A Review of the Literature. D.S. Kerr, L.J. Morrison and K.E. Wilkinson, Environmental Management Associates. 205 pp. plus appendices. ISBN 0-7732-0881-X. $10.00.**

A review of the literature on native grassland reclamation was conducted to summarize the current state of knowledge on reclamation and restoration efforts within Alberta. The review is comprehensive, including an overview of the regulations and guidelines governing land use on native prairie; a description of the dominant grassland ecoregions in Alberta; a review of the common disturbance types, extent and biophysical effects of disturbance on native prairie within Alberta; a description of the factors which influence the degree of disturbance and reclamation; and examples of both natural and enhanced recovery of disturbed sites through the examination of selected case studies.

86. **RRTAC 93-2: Reclamation Research Annual Report - 1992. Reclamation Research Technical Advisory Committee. 56 pp. ISBN 0-7732-0883-6. $5.00.**

This report describes the expenditure of $474,705 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and the research strategies of the five programs, and describes the projects funded under each program. It also lists the 85 research reports that have been published to date.