BIOENGINEERING TECHNIQUES FOR REVEGETATION OF RIPARIAN AREAS AT THE COLOMAC MINE, NWT

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ABSTRACT

Factors such as nutrient poor soils, harsh climate, remote locations, and high costs make revegetating disturbed areas in northern environments a challenge. We present a case study where novel bioengineering and project planning techniques were employed to revegetate and remediate riparian areas at Colomac Mine, an abandoned gold mine 220 km north of Yellowknife, NT. The revegetation plan focused on establishing pioneer species and facilitating natural recovery and succession. A 'rough and loose' technique was used to allow the soil to capture and retain moisture, trap windborne seed, promote easy root penetration and prevent erosion. Harvesting and planting of local willow cuttings, alder seeds, and sedge plugs ensured that the vegetation at these sites was adapted to local climate and soils. Multi-year monitoring was initiated which included vegetation counts and photographic documentation. Initial results have shown success rates of 60-100% plant survival on the majority of areas where bioengineering techniques were used. In contrast, poor revegetation success rates of 8-33% plant survival were experienced in areas where techniques were either used incorrectly or implemented too late in the season. The bioengineering techniques implemented at Colomac Mine provided a successful, cost effective, and local approach to revegetation in a northern environment.

Key Words: Revegetation, Riparian, Bioengineering, Remediation, Monitoring

INTRODUCTION

Mining operations result in residual chemical and physical impacts to the landscape. Often, the primary remedial objectives for mine site closure focus on the chemical and physical hazards, with minimal consideration to rehabilitation or restoration of the environment to a more natural state. However, integrating revegetation activity with remediation work has been garnering more recognition, as the overall sustainability of remediation projects is being recognized. In Canada's Northwest Territories (NT), many abandoned mine sites are under federal responsibility and require remediation. The high cost of remediation in remote locations and the harsh growing conditions make revegetating disturbed areas in northern environments a challenge.

Revegetation strategies for large disturbed areas have evolved to focus on the use of natural processes to initiate and speed up the recovery of natural plant succession. Soil bioengineering techniques for site preparation, and the use of locally collected pioneer species for revegetation are being used as a cost efficient approach to restore vegetation that is compatible with the surrounding habitat at disturbed mining sites (Polster 2011a). These approaches and techniques were used for revegetation along the shoreline and riparian areas during remediation at the Colomac Mine.

SITE DESCRIPTION

Colomac Mine (Colomac), a former gold mine located approximately 220 km north of Yellowknife, NT, Canada (64º 23' 42" N // 115º 07' 16" W), is a contaminated site under the custodial responsibility of Aboriginal Affairs and Northern Development Canada (AANDC). AANDC has managed the site through the Federal Contaminated Sites Action Plan (FCSAP) since 1999. The site is situated between Baton and Steeves Lakes and is surrounded by numerous small lakes. Access to the site is by air only. The primary infrastructure of the mine was located along the shoreline of Steeves Lake.

During operations, natural drainages and lakes on the mine site were in-filled with waste rock. Historic petroleum hydrocarbon releases adversely impacted the sediments along Steeves Lake shoreline and required remedial action. The remediation option selected involved the construction of a berm to contain the hydrocarbons and the capping of impacted sediments along 750 metres of the shoreline. The construction of this containment berm and cap impacted fish habitat in the shoreline area and required implementation of a revegetation plan for several areas, including the new Steeves Lake shoreline, the restored Truck Lake to Steeves Lake Shoreline, Riparian and Wetland Area (Truck Lake Channel), and the restored Dam 2 Drainage Riparian Area (Dam 2).

REVEGETATION TREATMENT AREAS

Steeves Lake Shoreline

The constructed shoreline along Steeves Lake is an engineered system of hydrocarbon containment and filtration covering approximately 750 m of the impacted shoreline. The width of the constructed shoreline varies according to the extent of sediment impact, creating a total area of 10,218 m^2 which was covered with a mixture of peat and silty sand. An armoured 1 m by 1 m by 750 m trench was constructed along the outer edge of the newly constructed shoreline. The trench was lined with landscape fabric and filled with peat and silty sand to provide a substrate suitable for revegetation (Figure 1). After construction, remnant alder (*Alnus sp.*), black spruce (*Picea mariana)***,** white spruce (*Picea glauca)*, willow (*Salix* sp.), sedges (*Carex sp*.), Labrador tea (*Ledum groenlandicum*) and bog rosemary (*Andromeda polifolia*) remained along the original shoreline.

Truck Lake Channel

Truck Lake Channel was constructed to reconnect Truck Lake and Steeves Lake. The revegetation objective was to re-establish approximately 7,300 m^2 of riparian vegetation along the channel and the Truck Lake shoreline. It consisted of a 240 m long meandering constructed channel bordered by rocky terrace zones, which were covered with a light layer of peat and silty sand, and upland benches of original ground (Figure 1). A short braided stream and wetland catchment area of peat and silty sand was constructed at the Truck Lake outlet. Along the Truck Lake shoreline, waste rock fill was removed to expose the original shoreline which was then covered with peat and silty sand.

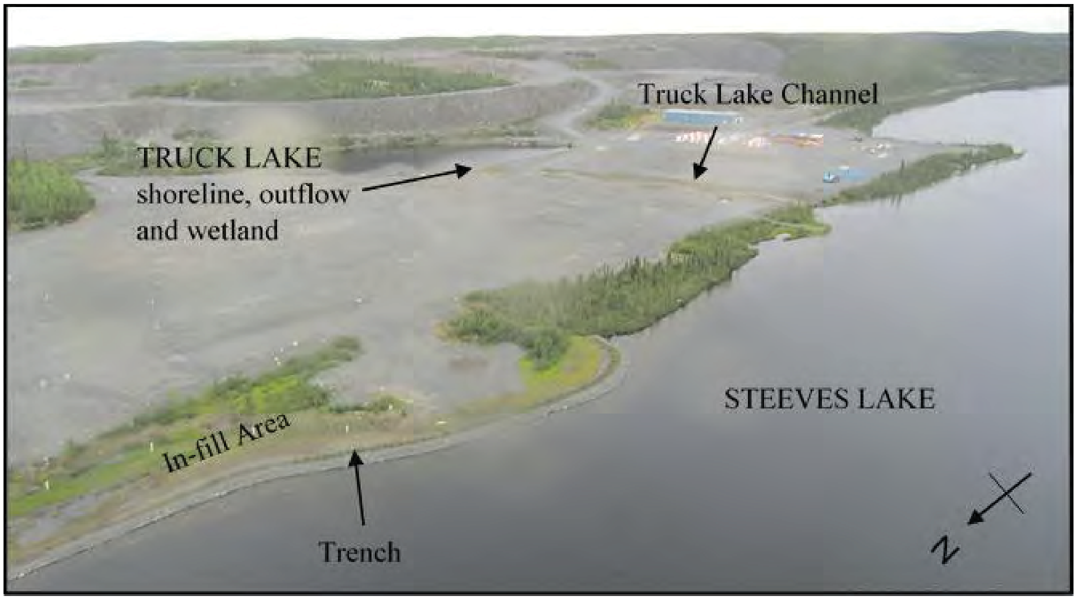

Figure 1. Arial view of the south end of Steeves Lake Shoreline and the new channel connecting Truck Lake to Steeves Lake. Dam 2 site is located 5.5 km NE from Truck Lake Channel outlet into Steeves Lake.

Dam 2 Drainage Riparian Area (Dam 2)

The Dam 2 channel flows from Tailings Lake to North Pond at the northern end of the site and was constructed as a 140 linear metre meandering channel with ten riffles.

REVEGETATION APPROACH

Identifying and emulating natural conditions at the site to be restored can assist in natural recovery solutions (Polster 2010). Understanding the naturally occurring pioneer and successional species in the surrounding environment becomes an important step in determining a suitable revegetation approach. Early in the planning phase, the need for expertise in revegetation strategies and local capacity were identified as limitations. An expert in revegetation, David Polster, was engaged and came to the site to provide recommendations and two days of hands-on training on revegetation approaches. Training ensured that all project personnel understood how to properly implement the revegetation plan and techniques.

Identification of limitations to the establishment of vegetation at the site was an important first step in determining the appropriate site preparation method (Clewell and Aronson 2007, Polster 2011a). Limitations to natural recovery at the Colomac revegetation sites included extensive areas of compacted waste rock with no soil, low precipitation, extreme cold temperatures, and a short growing season (Polster 2010). The areas to be revegetated consisted of waste rock aggregate covered to the extent possible with a peat and silty sand blend to re-establish the organic soils necessary for recovery of vegetation (Aboriginal Engineering 2010). Peat material for remediation and construction activity was salvaged from other areas on the site that had been disturbed.

Once the sites were prepared, the revegetation treatments for the riparian areas focused on the establishment of locally collected willows, alders and sedges. These plants develop extensive root systems that stabilize slopes by slowing and redirecting the flow of surface runoff, reduce sediment transportation and minimize the impact of raindrop erosion (Polster 2011b). Willows and alder are pioneering species adapted to growing in nutrient poor soil conditions. Sedge plugs were transplanted along the channel edges and wet areas to quickly establish riparian vegetation. Harvesting and planting of local willow cuttings, alder seeds and sedge plugs ensured that the new vegetation at these sites was adapted to local climate and soils (Polster 2011a).

The soil surface was mechanically disturbed to promote natural revegetation using the 'rough and loose' technique. The technique is implemented with an excavator which creates a checkerboard of small holes and hills, breaks up the substrate creating an environment which will capture and retain moisture, trap windborne seed, promote easy root penetration and prevent erosion (Poster 2011b). Two rough and loose trial plots were established, one at Steeves Lake Shoreline and the other at the Truck Lake Channel, to determine the effectiveness of this technique and the impact it would have on construction design and hydrocarbon containment in these areas.

REVEGETATION TREATMENT APPLICATIONS

Willows (*Salix sp.*) were used as they are a quickly established woody pioneer species and harvesting has little impact on the environment because only the stems are cut and replacement shoots grow quickly from the undisturbed crown roots. The cuttings are best harvested in the fall when they are dormant and their stored carbohydrates are at a maximum so they can benefit from the higher moisture availability during freshet (Polster 2011b). The harvested willows were trimmed and soaked in Steeves Lake for at least 6 days before planting. The willows were cut into 1.2 m lengths and planted using an excavator to pull back the substrate to a depth of 1.0 m and placing five cuttings into the hole (Gravel Bar Method). Only single cuttings were planted in the Steeves Lake 'rough and loose' trial plot and Truck Lake Channel wetland area. Once planted, the new roots and shoots grow from the auxiliary buds on the cuttings (Polster 2011b).

Alder (*Alnus sp.*), a nitrogen fixing plant, germinates easily from seed (Polster 2011b). Seeds from cones harvested in the fall were spread on the appointed sites. The seeds are easily collected, very light weight and stored refrigerated, making this a cost effective method to treat large areas (100 g of seed per hectare).

Sedge (*Carex sp*.) plugs have the benefit of carrying seeds and roots from many other plants which can germinate and increase wetland plant diversity. Sedge plugs were transplanted to re-establish wetland vegetation in low-lying wet areas and along the banks of the new channels. The plugs were harvested from a nearby wetland. Less than 10% of the plants at the donor sites were harvested to minimize impacts.

The shorelines, channel terraces and upland benches were lightly seeded by hand with native grass seed mix (15 kg of seed/ha): *Poa glauca, Festuca saximontana***,** *Festuca brevissima (Festuca ovina* ssp.

alaskana), Elymus alaskanus [ssp. *latiglumis*] and the quickly germinating annual rye, *Lolium multiflorum.*

Steeves Lake Shoreline

The shoreline trench was treated with five 1.2 m long willow cuttings every 1.5 to 4 m and hand spread alder seed. The in-fill area between the constructed berm and the old shoreline was lightly seeded with alder and native grass. In addition, sedge plugs were planted in low lying wet areas. A 100 m^2 rough and loose trial plot was located at the south end of the of the in-fill area (Figure 1).

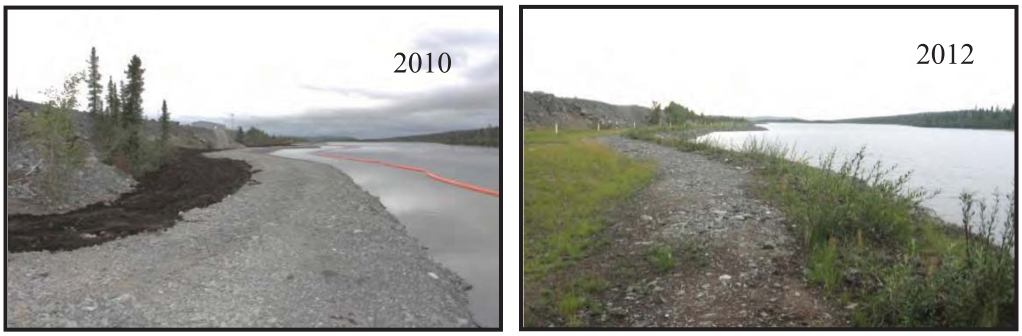

Figure 2. Steeves Lake shoreline before (2010) and after (2012) revegetation efforts.

Truck Lake Channel

The wetland catchment area was 'rough and loosed', however, on the channel terrace the waste rock material collapsed in on the excavated holes and the checkerboard pattern of depressions and mounds could not be maintained. Erosion control mat was laid along the Truck Lake Outflow banks and islands to prevent bank erosion during spring freshet (Figure 3). Willow cuttings were planted with an excavator along the Truck Lake shore and channel, sedges were planted in selected areas along the channel and the whole area was seeded with alder and native grass.

Figure 3. Top pictures, Truck Lake Channel before (2010) and after (2012) revegetation efforts. Lower pictures, Truck Lake Channel outflow area before (2010) and after (2012) revegetation efforts.

Dam 2 Drainage Riparian Area (Dam 2)

In 2010, construction of the Dam 2 drainage was finished and water flowed in the channel. Revegetation included planting 40 sedge plugs in the channel and sowing native grass and alder seed along the channel terraces and upland banks (Figure 4).

Figure 4. Dam 2 channel before (2010) and after (2012) revegetation efforts.

MONITORING

A monitoring plan was developed to evaluate the success of the revegetation effort over time. Monitoring was conducted over the first two seasons and subsequent monitoring will be done each year for five years and again in the 10th year after planting (AANDC 2013). The focus of short-term monitoring was on the success of the revegetation work itself in terms of the survival and growth of the target pioneering species and coverage. Future assessment will focus on assessing successional trajectories, ecosystem function and structure, to measure the change over time, and evaluate the overall sustainability of the revegetation effort in these disturbed areas. Photographs before re-vegetation and each successive year will provide a good visual record of plant growth.

RESULTS

Monitoring of plant survival and growth in 2012 showed that the majority of the re-vegetation areas, where the soil bioengineering techniques were used, met or exceeded expected success rates for survival and coverage. Assessments of the Steeves Lake Shoreline and Truck Lake Channel areas were completed in August of 2011 and 2012; however, the remote location and decommissioned road precluded access to the Dam 2 site in 2011. The short-term revegetation success was determined by the number of planted willow cuttings that sprouted shoots, the number of sedge plugs that survived the transplant and the percentage of each site covered by vegetation (Tables 1 and 2).

Planting Success

Willows were most successful along the Steeves Lake Shoreline Trench – 69% survival in 2011 and 60% survival in 2011, where the soils had been ‘rough and loosed’ and sufficient moisture was available (Table 1). The sedges were most successful in the Steeves Lake Shoreline In-fill Area and the Dam 2 Site showing 100% survival where a wetland environment existed and were less successful in the Truck Lake Channel and Outflow showing 75% and 83% survival rates where water in the channel dried up in the summer resulting in the transplanted sedges dying or struggling (Table 1). The goal was to have 2 alder seedlings germinate per metre square across the site. In 2011, the alder seedlings were very small (< 1.0 cm). By 2012 these seedlings had grown to 1-10 cm. They were most successful in the areas that were 'rough and loosed' in the Steeves Lake Shoreline and the Truck Lake Outflow Areas. They were absent at the Truck Lake Shoreline where the soils were compacted. Native grass seed germinated at all sites and were most prolific where the soils were 'rough and loosened' and moist (Table 2).

Table 1. Survival rate of the willow cuttings and sedge plugs planted in 2010. Percent success was calculated based on the number of cuttings/plugs planted. 1 ND: no data, unable to access site in 2011 (FRC 2012).

Site	Zone	Plants	Plant Location	Number Planted 2010	Survival				Observations
					2011		2012		
					#	%	#	%	
STEEVES LAKE SHORELINE	Wetland	Sedge plugs	Wet areas	52	52	100	52	100	Growing vigorously and spreading.
	'Rough and Loose' Trial	Willow cuttings	Cuttings planted singly & gravel bar method	80	73	91	73	91	Willow cuttings not growing as well as those in the Trench.
	Trench	Willow cuttings	Planted every 1.5 - 4.0 m along the trench	1125	780	69	684	60	Growing well (shoots up to 2 m long). Some cuttings (2011) were destroyed during installation of drainage channels.
TRUCK LAKE CHANNEL	Shoreline	Willow cuttings	Gravel bar method	350	30	8	30	8	Low success could be due to being planted late in the season & not deep enough (Nov 2010).
	Outflow and Wetland Catchment	Willow cuttings	Gravel bar method along channel	85	28	33	28	33	No cause of low survival rate, those that survived were doing well in 2011 & 2012. Shoots grew from willow cuttings used to stake ECM.
		Sedge plugs	Channel edge	34	28	83	28	83	The sedge plugs that survived are doing well and spreading.
	Channel	Willow cuttings	Gravel bar method above channel	235	103	44	89	38	Cuttings planted well above water table were struggling.
		Sedge plugs	Channel edge	40	30	75	30	75	These plugs were struggling due to absence of water in the channel. Ten plugs were destroyed during channel modifications 2011.
DAM 2	Channel	Sedge plugs	Channel edge	20	ND[1]	ND[1]	20	100	All sedges were growing vigorously and spreading.

Vegetation Cover

Overall, vegetation cover (vertical projection of exposed leaf area onto the ground) was visually estimated for each site (Roberts-Pichette and Gillespie 1999). The 60% vegetation cover at the Steeves Lake Shoreline Trench was the highest (Table 2). Steeves Lake In-fill Area with 36% cover was the only site that had a large area under water (15%) where a wetland has developed in the Steeves Lake Shoreline. Water is collecting in the wetland area because the finished construction topography is lower than specified in the design. Thirty-five native plant species have germinated from windborne seed, increasing biodiversity. Vegetation cover in the Truck Lake Channel and Dam 2 ranged from 10% to 35%. The relatively low success is probably due to generally drier conditions and soils being more compacted relative to the 'rough and loose' sites.

Table 2. Percent vegetation cover was calculated by visual estimate (FRC 2012).

Site	Zone	Percent Cover			Observations
		Vegetation	Bare Ground	Water	
STEEVES LAKE SHORELINE	In-fill Area, Wetland & Rough and Loose Trial	36	49	15	Vegetation was growing well, there were some bare patches where equipment had torn up the site in 2011. Many species growing from windborne seeds.
	Trench	60	40	0	Many small seedlings germinated from windborne seed.
TRUCK LAKE CHANNEL	Shoreline	10	90	0	Very sparse vegetation cover, many seedlings, 9 species germinated from windborne seed, soil was dry with mud cracks
	Outflow	20	80	0	Many small seedlings germinated from windborne seed. This site was disturbed in 2011 The wetland was dry with mud cracks forming.
	Channel	35	65	0	Channel was dry, soil was damp under under rip rap, sedges were struggling. There was more moisture in 2012 than in 2011
DAM 2	Channel, terrace, upland bench	20	80	0	Plants growing on the terrace were smaller, less robust than those growing along the bank of the channel. Terrace dry rocky surface

DISCUSSION

Willow, alder, and sedges established within the revegetated areas and will likely continue to grow. The revegetation efforts at Steeves Lake Shoreline showed the best results. In particular, the areas that were prepared with peat and had the 'rough and loose' method applied demonstrated the highest initial success rates for plant survival and coverage, as well as increased biodiversity. The soil bioengineering techniques involving willow cutting treatments showed the most success when implemented correctly and in areas with adequate moisture and failed when techniques were used incorrectly and planting was attempted too late in the year.

Engineering design challenges, unexpected conditions, and implementation practices at Steeves Lake Shoreline and Truck Lake Channel affected the success of the revegetation effort in these areas. The unexpected ponding of water on the Steeves Lake Shoreline cap caused an extensive die-back of the pre-existing vegetation, but encouraged more wetland vegetation to establish than originally anticipated. At the Truck Lake Channel, the compacted soils, inadequate soil depth, poor nutrient conditions and the unexpected absence of water in the channel will continue to hinder the recovery of vegetation. The poor survival rate of the willow cuttings planted along the Truck Lake shoreline resulted when the revegetation plan was not followed and late planting (November 2010) with inadequate planting depths was attempted. Earlier consideration of revegetation options for this project may have permitted more suitable environments for plant germination and growth to be incorporated into the engineering design, in areas such as the Truck Lake Channel, and necessary adjustments made in the revegetation sites to enhance natural recovery.

The remote location of the Colomac Mine site and post-remediation condition presented logistical challenges for monitoring the revegetation effort. The cost for site visits was high and access to Dam 2 was limited because of decommissioned roads requiring all-terrain vehicles to conduct some monitoring activities. This resulted in less time available for monitoring than initially planned.

CONCLUSIONS AND RECOMMENDATIONS

The experience at Colomac demonstrated the ability to incorporate revegetation and natural recovery into remediation plans. The success of implementing these treatments requires: 1) revegetation objectives for the site to be identified; 2) consideration of revegetation early in project planning; 3) recognition of the importance of expertise and people trained in revegetation; 4) need for flexibility and adaptive management in implementing the revegetation plan; and 5) recognition of the sustainability of the revegetation effort. There needs to be a willingness to adapt standard remediation contract specifications to move away from traditional focus on seeding to include alternative approaches that use soil bioengineering techniques and natural process to assist in revegetation of the site.

Preparing a site using the 'rough and loose' technique facilitated successful revegetation. It was easy to incorporate during the remediation, as equipment and people were available on the site, and it helped natural revegetation occur. The identification and use of materials readily available, including salvaged peat and locally collected pioneer plants proved to be an efficient and cost effective method for revegetation of large areas at this remote site.

Also, to measure success and build on revegetation and restoration experience in the north, appropriate monitoring strategies need to be implemented. Monitoring of revegetation area recovery should be incorporated into both short and long-term monitoring programs. Short-term monitoring will assess performance in the treatment areas and identify any immediate issues that may require maintenance or corrective action. Long-term monitoring will evaluate sustainability of the restoration/revegetation focusing on overall plant health and establishment, as well as the change in species composition and structure over time. The bioengineering techniques implemented at Colomac provided a successful, cost effective, and local approach to revegetation in a northern environment.

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Overcoming Northern Challenges

Proceedings of the 2013 Northern Latitudes Mining Reclamation Workshop and

38th Annual Meeting of the Canadian Land Reclamation Association

Whitehorse, Yukon September 9 – 12, 2013

CLRA | ACRSD
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Northern Latitudes Mining Reclamation Workshop

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Knight	Galena Hill, Yukon, Ecosystem Mapping Project
Polster	Natural Processes: An Effective Model For Mine Reclamation
Dustin	Implementation of contaminated water management system upgrades to allow for dewatering of two open pits at the Vangorda Plateau, Faro Mine Complex, Yukon
Kempenaar, Marques and McClure	Tools for Arctic Revegetation: What's in Your Toolbox?
Smreciu, Gould, and Wood	Establishment of Native Boearl Plant Species On Reclaimed Oil Sands Mining Disturbances
Keefer	Twin Sisters Native Plant Nursery
Pedlar-Hobbs, Ludgate and Luchinski	Key Factors in Developing and Implementing a Successful Reclamation Plan
Chang, et.al	Effects of Soil Aggregates Sizes (paper not attached)
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Janin	Passive treatment of drainage waters: Promoting metals sorption to enhance metal removal efficiency
Stewart and Siciliano	Biological Soil Crusts and Native Species for Northern Mine Site Restoration
Nadeau and Huggard	Restoration Planning and Application of Ecological Succession Principals
Simpson	Defining Disturbance and Recovery - the influence of landscape specific ecological responses to oil and gas linear disturbances in Yukon

NORTHERN LATITUDES MINING RECLAMATION WORKSHOP

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The first Workshop was held in Whitehorse, Yukon Territory, Canada in 2001 and it has been held every two years since, alternating between Canada and Alaska. The primary sponsors of the Workshop include the Yukon Geological Survey, Indian and Northern Affairs Canada, Natural Resources Canada, US Department of the Interior Bureau of Land Management, and the State of Alaska Department of Natural Resources.

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- To incorporate the advances from research and practical experience into land reclamation planning and practice.
- To collect information relating to land reclamation and publish periodicals, books and leaflets which the Association may think desirable.
- To encourage education in the field of land reclamation.
- To provide awards for noteworthy achievements in the field of land reclamation.

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