Cattail Biomass to Energy:

Commercial-scale harvesting of cattail biomass for biocarbon and solid fuel

Richard E. Grosshans, IISD and Lorne Grieger, PAMI

iisd International Institute for Sustainable Development / Institut international du développement durable

PAMI — Innovative Solutions for Agriculture and Beyond

iisd.org

IISD REPORT
March 2013

Published by the International Institute for Sustainable Development.

International Institute for Sustainable Development

The International Institute for Sustainable Development (IISD) contributes to sustainable development by advancing policy recommendations on international trade and investment, economic policy, climate change and energy, and management of natural and social capital, as well as the enabling role of communication technologies in these areas. We report on international negotiations and disseminate knowledge gained through collaborative projects, resulting in more rigorous research, capacity building in developing countries, better networks spanning the North and the South, and better global connections among researchers, practitioners, citizens and policy-makers.

IISD's vision is better living for all—sustainably; its mission is to champion innovation, enabling societies to live sustainably. IISD is registered as a charitable organization in Canada and has 501(c)(3) status in the United States. IISD receives core operating support from the Government of Canada, provided through the International Development Research Centre (IDRC), from the Danish Ministry of Foreign Affairs and from the Province of Manitoba. The Institute receives project funding from numerous governments inside and outside Canada, United Nations agencies, foundations and the private sector.

Head Office
161 Portage Avenue East, 6th Floor, Winnipeg, Manitoba, Canada R3B 0Y4
Tel: +1 (204) 958-7700 | Fax: +1 (204) 958-7710 | Website: www.iisd.org

Cattail Biomass to Energy: Commercial-scale harvesting of cattail biomass for biocarbon and solid fuel

March 2013

Richard E. Grosshans, Lead Research Scientist, IISD
Lorne Grieger, Project Manager, PAMI

Acknowledgements

Thanks to the Prairie Agricultural Machinery Institute (PAMI) for their dedicated work in the cattail harvesting project, harvesting logistics, and contributions to this report. Also thanks to the significant cooperation from MacDon Industries Ltd. for the loaning of equipment, and to the La Salle Redboine Conservation District for their assistance in the success of this pilot-scale research project to demonstrate the commercial viability of cattail as a biomass feedstock for biocarbon, bioenergy, and nutrient capture.

Funding for this project was provided by Manitoba Liquor and Lotteries Corporation, Manitoba Hydro, the Province of Manitoba, and Environment Canada through the Lake Winnipeg Basin Stewardship fund.

Executive Summary

The International Institute for Sustainable Development (IISD) has explored the opportunity to use cattail (*Typha* spp.) as an alternative bioenergy feedstock and watershed nutrient-management tool. Previous research has been performed on a smaller scale to determine potential for phosphorus (P) capture. IISD, in collaboration with the Prairie Agricultural Machinery Institute (PAMI), conducted cattail harvest trials using commercial-scale equipment on cattail stands growing in wet and low-lying areas.

Cattails were cut and harvested, using existing grain and forage equipment commercially available, in the ditches along Highway #1 and at Pelly's Lake, a wetland area near Holland, Manitoba. Cattails were cut and windrowed at both locations using a windrower from MacDon Industries Ltd., a cooperating partner in the project. A medium square baler was used to collect the cattails from the ditches, and round balers were used to collect the cattails from Pelly's Lake. The conditions at the specific sites dictated the type of baler required.

The growing season during which the cattails were harvested had below-normal precipitation, which made cutting the cattails with commercial grain harvesting equipment easier. Baling operations were hampered by above-normal precipitation later in the year. Challenges encountered during harvesting included stuck equipment, the volume of cattails in the wetland areas, and the potential for equipment damage at the harvest sites.

A total of 41.4 tonnes of cattail biomass was harvested along Highway #1, east of Elie, Manitoba, with a calculated potential cattail biomass yield within this site of up to 222 tonnes. An estimated 40 kilograms (kg) of P was collected from the harvest of 189 square cattail bales (50.6 tonnes wet basis), with a potential total P capture and recovery of up to 244 kg. A calculated total of 220 tonnes of cattail biomass was harvested from the Pelly's Lake wetland near Holland, Manitoba with a calculated potential cattail biomass yield within this site of up to 703 tonnes. A total capture of 191 kg of P was collected from the harvest of 575 round cattail bales (329.4 tonnes wet basis), with a potential total P capture and recovery of up to 703 kilograms.

A cost estimate was performed based on the field operations necessary to collect the cattails from both the ditches and wetland areas. A premium may be required when using agricultural equipment to account for risk associated with operating outside of typical field conditions. Successfully managing water levels could greatly enhance efficiencies and costs.

The first phase of the Cattail Biomass Harvesting and Biocarbon project successfully demonstrated cattails can be harvested as a biomass feedstock using existing grain and forage equipment, particularly if the conditions are suitable. Wetland areas are especially productive and produce significant quantities of cattails. A total of 60 cattail bales have been shipped to Saskatchewan to produce biocarbon, which will be used for field-scale agricultural crop fertilizer trials and greenhouse fertility and soil trials.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

Manitoba Hydro is conducting a series of demonstration projects as part of its "Power Smart Bioenergy Optimization Program" to showcase potentially cost-effective clean and renewable energy technologies capable of converting biomass and by-products into useful energy. The primary objective of the current biocarbon demonstration project being supported by the Clean Energy Fund (CEF) is demonstrating how a carbon-rich substance called biocarbon can be produced from biomass material through a slow pyrolysis or carbonization process. The initial focus was on the use of wood chips as a feedstock, but there was potential to evaluate alternate biomass sources that offer a means to lower the cost for producing biocarbon. Additionally, beyond the application of biocarbon as an alternative to fossil coal for energy production, biocarbon has excellent potential to improve soil fertility and offer carbon sequestration and storage in agricultural soils.

The purpose of this project add-on was to address the need to diversify the portfolio of biomass feedstocks for biocarbon production beyond woody biomass material, and evaluate the use of cattail (*Typha* spp.) as a biomass feedstock to produce biocarbon and to displace fossil fuel energy in Manitoba. Cattail is a large emergent plant found in wetlands and water-logged areas across North America. This fast-growing, water-tolerant plant can produce considerable biomass within a single growing season with essentially zero input costs. The energy production potential of cattail was studied in the 1970s by the United States Department of Energy, and more recently in Manitoba by IISD, the University of Manitoba, and Ducks Unlimited Canada.

In its ongoing research programs, IISD has demonstrated that not only is cattail a suitable feedstock for use in a variety of bioenergy technologies, but harvesting of cattails provides major environmental and economic co-benefits, such as water-quality improvement and nutrient cycling. As they grow, cattails take up nutrients from the sediment incorporating these components into their plant biomass. Phosphorus is an essential nutrient for plant growth and agriculture, but it is also the element fouling Lake Winnipeg and causing algal blooms. IISD's previous research demonstrated that harvesting the cattail plants removes the bound nutrients (i.e., P) and prevents them from being released back into the water, as occurs when the plants decompose. Harvesting cattail removes captured P and reduces P loading to Lake Winnipeg, while providing a biomass feedstock, the ability to recover phosphorus, habitat restoration and carbon offset credits. Research on cattail harvesting methods is a necessary step to realizing these benefits and to move towards commercial-scale harvesting. The Cattail Biocarbon add-on project builds upon previous research by IISD to explore commercial-scale harvesting and higher-value end uses of harvested cattail biomass.

This project directly enhances the current Clean Energy Fund project by diversifying the portfolio of biomass feedstocks for biocarbon production beyond woody biomass material. It will introduce a novel biomass feedstock for biocarbon with major environmental co-benefits by combining alternative bioenergy production with nutrient capture and removal. Most importantly, the project will demonstrate a practical technology for accessing novel, low-cost bioenergy feedstocks.

2.0 Project Description

While commercial-scale harvesting of wetland biomass is carried out in many parts of the world, it has not been effectively demonstrated in Canada. Harvesting in wetlands and waterlogged areas presents some serious logistical challenges in order to minimize ecological impact and maintain sustainability of the plant community. There is a recognized need to develop and demonstrate commercial-scale cattail harvesting equipment suitable for Canadian wetland conditions. Agricultural equipment typically used in Manitoba is designed for harvesting either commercial forage or grain crops. The most economical means of harvesting the cattail is to use equipment that is currently available for other crops and use it directly or modify it for use with cattails. Because cattails are not a commercial crop, and grow in wetter conditions, modified or more specialized agricultural equipment may ultimately be needed, such as low-weight, ratio-tracked harvesters that are used in Europe for wet agricultural practices.

IISD, with the collaboration of the Prairie Agricultural Machinery Institute (which has over 30 years of experience evaluating and developing machinery through analytical and physical testing methods) evaluated the use of commercially available agricultural equipment to demonstrate that cattails can be harvested economically on a large scale.

Tests will be conducted on the carbonization of cattail biomass into biocarbon to identify harvesting, storage and moisture issues. Biocarbon produced from cattail will be analyzed for energy value and to determine the fates of elements. Ash produced during trial demonstration burns of the biocarbon in solid-fuel burners will also be analyzed to determine fates of elements and recovery of captured phosphorus from cattail biocarbon ash.

Working with researchers from PAMI in Humboldt, Saskatchewan, field-scale agricultural crop and soil trials will be conducted to evaluate biocarbon for soil condition and fertility. Additionally, working with researchers at the University of Manitoba, greenhouse growth trials will be conducted on fertilizer value of the ash post-combustion, and potential phosphorus recovery. These enhancements are anticipated to more clearly define the options for producing biocarbon in a cost-effective manner and identify potential markets for non-energy grade biocarbon.

The key objectives of this research are as follows:

1) Carry out large-scale harvest of cattail biomass for use as a novel and innovative alternative biomass for biocarbon, and nutrient capture.
2) Modify and test conventional agricultural equipment to harvest suitable quantities of cattail for biocarbon demonstration trials.
3) Evaluate harvesting logistics, transport, drying, and storage options.
4) Trial the use of cattail as a sustainable sources of biomass for the production of biocarbon
5) Examine soil conditioning and soil fertility characteristics of biocarbon and ash from combustion trials.

3.0 Progress Update

In 2012, IISD with the collaboration of the Prairie Agricultural Machinery Institute (PAMI) successfully evaluated the use of commercially available agricultural equipment to demonstrate that cattails can be harvested and baled economically on a large scale. Cattail stands growing in two different types of low-lying areas were targeted for the pilot scale study: i) in ditches along highways and ii) wetland areas on marginal agricultural land.

Ditches are man-made channels to control and direct water flow along roadways. They are compacted and sloped to prevent standing water and to drain surface water to local tributaries. The width of a ditch may vary depending on the size of the road and therefore, affect the amount of vegetation present in the ditch area. Vegetation, including cattails, growing in ditches is typically mowed using commercial mowers to control growth and maintain water flow, and the debris left on site to rot.

Wetland areas on marginal agricultural lands are low-lying areas where water collects during spring runoff, high rainfall events, etc. Cattails in these areas are typically not disturbed and allowed to follow the natural cycle of growth in spring and summer, and dying off of the green vegetation during the fall and winter.

Three locations were identified for preliminary equipment setup and harvesting trials as listed below and located in Figures 1 and 2.

1) A small, man-made marsh adjacent to the Portage la Prairie (PLP) bypass was used for preliminary harvesting tests.
2) The ditches along the TransCanada Highway (Hwy 1) both east and west of Elie, Manitoba.
3) The Pelly's Lake wetland area in the La Salle Redboine Conservation District near Holland, Manitoba.

The Netley-Libau Marsh area near Libau, Manitoba was investigated and samples collected for analysis and resource assessments, but no harvesting trials were performed. A site near Winnipeg at the intersection of the Perimeter Highway and Highway 59 was also investigated and sampled but no harvesting trials were performed. Cattail samples were collected for biomass, moisture, and nutrient analysis at the Netley-Libau Marsh research site and Perimeter Highway site.

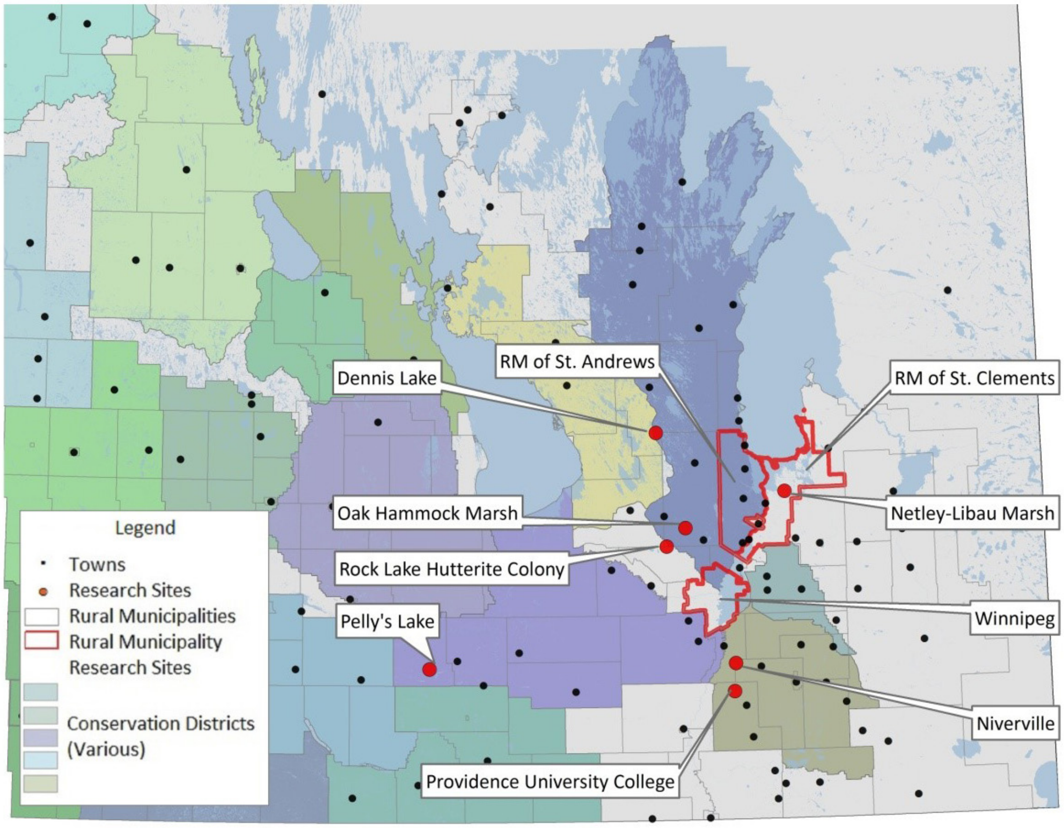


FIGURE 1. CATTAIL RESEARCH SITES

FIGURE 2. CATTAIL HARVEST RESEARCH SITES

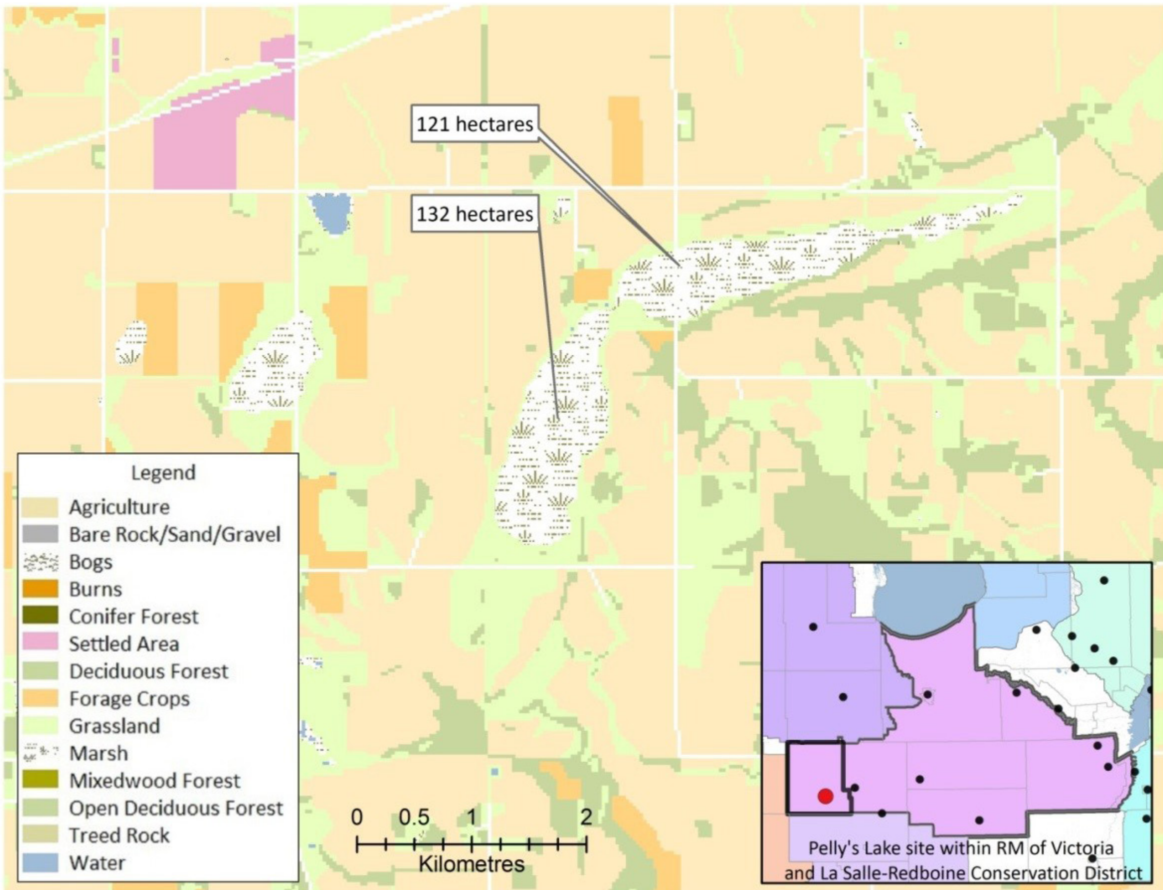


FIGURE 3. PELLY'S LAKE WETLAND AREA RESEARCH SITE

4.0 Methods and Equipment

4.1 Equipment Selection

Equipment for cutting cattails in both the ditch harvesting and wetland harvesting area was selected to minimize weight during the field operation. MacDon Industries Ltd. graciously supported the project through the use of a new windrower (commonly called a "swather"). Windrowers are capable of using interchangeable headers ranging from units specifically designed for cutting and conditioning forage crops to a wide range of widths designed for cutting grain crops.

The windrower was used to cut the standing cattails and place them in a continuous row or windrow to dry prior to collection. The windrower cuts the material with a knife, aided by the reel that feeds the knife. The cut material is fed to the centre of the windrower on belts where it is laid on the ground to dry before collection. The amount of time required before collection depends on the characteristics of the vegetation, environmental conditions and yield.

The windrower for this project came equipped with a 6.1-metre (20-foott) draper header weighing 1,484 kg (3,255 pounds), the second narrowest and lightest cutting header available for the tractor unit. Draper headers available range from 4.6 to 13.7 metres (15 to 45 feet) weighing 1,258 to 2,777 kilograms (2,780 to 6,110 pounds). Other headers specifically designed for cutting forage crops were considered but not used because of the additional weight associated with the design. The 4.9-metre (16-foot) rotary disc header for cutting forage weighs in at 1,955 kilograms (4,300 pounds), substantially heavier than the wider draper header used during this research project.

Balers were then sourced to collect and form the cut cattails into bales for storage or transportation at both harvest test sites. The use of a forage harvester to chop and collect the cattails was considered but not implemented due to the timing of the initial harvest.

4.2 Data Collection

Cattail samples from PLP bypass and Hwy 1 were collected from both the standing crop and the adjacent swaths so that comparisons could be made. The cattail samples from Pelly's Lake were collected during harvest and later extracted from bales using a 20 mm by 450 mm long core sampler. Samples from Hwy 1, Netley-Libau Marsh, and the Perimeter Hwy at Highway 59 were also collected as multiple replicate samples earlier in the season in August and September, to document loss of phosphorus over the season and from the material at harvest time.

The Hwy 1 loaded bales were weighed at Rock Lake Colony and total and average bale weight was calculated. Six representative bales from Pelly's Lake were brought to PAMI's facility in Portage la Prairie to be weighed and sampled.

Harvest areas were calculated using GPS tracking information from the windrower's movements. For the Hwy 1 trials, the areas were calculated from total travel distance multiplied by the full windrower width. This method assumes a full cut width was performed at all times. For Pelly's Lake trials, the GPS locations were mapped and then traced using computer-aided design (CAD) software to calculate the harvest area.

Bale counts were performed while they were produced for the Hwy 1 harvest trial. The bales produced at Pelly's Lake were more difficult to count due to the large area harvested. Several photographs were taken from adjacent fields at different angles. Then the photos were enlarged on a computer screen so that the bales could be counted.

5.0 Results and Discussions

5.1 PAMI - Cattail Harvesting Trials 2012

5.1.1 Preliminary Harvesting at PLP Bypass 2012

A Westward M155 windrower was obtained to perform the first step of harvest. The windrower was fitted with a 20-foot (6.1-metre) MacDon D60 draper header which has an all-purpose design for several crop varieties. The rated weight of the windrower and header system was 6,635 kg (MacDon, 2012). This is much lower than forage harvesters which are approximately 11,000–13,000 kg (John Deere, 2012, New Holland, 2011). The Westward windrower provided by MacDon Industries is shown in Figure 4.

FIGURE 4. MACDON INDUSTRIES LTD WINDROWER USED FOR CUTTING STANDING CATTAILS AT ALL TEST SITES.

The tire pressure in the wheel was reduced to distribute the weight of the windrower over a larger area. This was done to improve floatation and decrease environmental impact.

The windrower was first tested at the PLP bypass marsh on September 20 and 24, 2012. Positive results prompted the decision to continue its use at the other cattail locations.

PAMI obtained a tractor and baler to collect the cattails in a transportable form. The tractor was a Deutz-Allis 9150 with mechanical front wheel drive (MFWD). The rated operating un-ballasted weight was approximately 7,000 kg (TractorData, 2012). The baler was a CaseIH 8575 Silage Special square baler. The tractor and baler system used at the PLP bypass marsh is shown in Figure 5.

FIGURE 5. TRACTOR AND MEDIUM SQUARE BALER USED AT THE PORTAGE LA PRAIRIE OVERPASS SITE.

The soft terrain and large swaths caused difficulty in the baling process with frequent plug ups is described in greater detail later in the report. As a result, only a small portion of the marsh was baled between September 25 and October 2, 2012. A total of eight bales were produced at the PLP bypass.

5.1.2 Harvesting in Hwy 1 Ditches

The Westward windrower was used to cut the ditches along Hwy 1 between Portage la Prairie and Winnipeg. For the test, it was equipped with a GPS tracking device that monitored position and time. The areas cut were: (1) a 4-kilometre section just east of Portage la Prairie, (2) a 6-kilometre section west of Elie and (3) and an 11-kilometre section east of Elie. Again, the windrower performed well in the thick crop of cattails (Figure 6).

FIGURE 6. MACDON INDUSTRIES LTD WINDROWER CUTTING CATTAILS IN THE DITCH ALONG HWY 1.

On October 4, the day after baling the cattails east of Elie, the weather turned to snow and rain. The steady precipitation throughout October and November made it impossible to complete the remainder of the harvest along Hwy 1.

Due to difficulties with the rented baling system, a local farm was contracted to bale and transport the cattails along Hwy 1. The farm used baling equipment similar to that used at the PLP bypass. The tractor was a CaseIH Magnum 245 equipped with MFWD and dual rear wheels. The baler was a CaseIH 8575 square baler as shown in Figure 7.

FIGURE 7. SQUARE BALER USED TO HARVEST CATTAILS FROM THE DITCH ALONG HWY 1.

The section of the highway east of Elie was baled on October 3, 2012. A total of 189 bales were produced in approximately 6.5 hours. The bales were collected immediately using a Caterpillar 938G loader and loaded onto a flat deck as shown in Figure 8. Bales were transported to Rock Lake Colony, Grosse Isle Manitoba, approximately 50 kilometres away from the harvest site. The loads of bales were weighed, unloaded, and stacked at Rock Lake Colony (Figure 8).

FIGURE 8. LOADER AND SEMI-TRAILER USED TO TRANSPORT BALES FROM DITCHES ALONG HWY 1, AND CATTAIL BALES STACKED AT THE ROCK LAKE COLONY.

5.1.3 Harvesting at Pelly's Lake

The Westward windrower was used to harvest cattails at Pelly's Lake. Due to high yield of cattails, the windrower was equipped with a swath roller to minimize swath height for subsequent baling (Figure 9). The windrower was equipped with a GPS tracking device data from which was used to calculate harvest area. A map of the windrower's harvest in Pelly's Lake is shown in Figure 10.

FIGURE 9. MACDON INDUSTRIES LTD WINDROWER CUTTING CATTAILS AT PELLY'S LAKE WETLAND. RIGHT IMAGE SHOWS WINDROWER IN PELLY'S LAKE WETLAND.

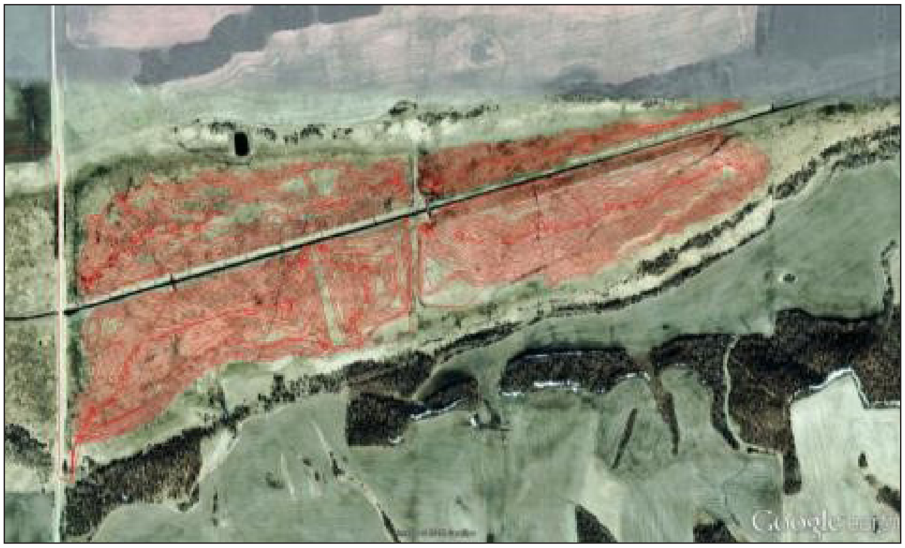


FIGURE 10. GPS TRACE OF THE WINDROWER WHILE CUTTING CATTAILS AT PELLY'S LAKE.

The first attempt to bale the cattails in Pelly's Lake was unsuccessful. A CaseIH Magnum 275 tractor with MFWD and dual rear wheels pulling a Hesston 4910 large square baler produced only a single cattail bale. The product plugged the header and throat of the baler, breaking two shear pins (Figure 11).

FIGURE 11. SQUARE BALER WITH SINGLE CATTAIL BALE STUCK IN BALER, AND PLUGGED THROAT OF BALER.

A second attempt using round balers was performed by local farm operators beginning on October 3, 2012. There were two different systems used: (1) a John Deere 4455 tractor with dual rear wheels pulling a John Deere 568 MegaWide Plus round baler, and (2) a White 100 tractor pulling a Challenger RB563A round baler. Both systems produced bales that were nearly identical in dimension and weight. The two baling systems are shown in Figure 12.

FIGURE 12. ROUND BALERS USED TO HARVEST CUT CATTAILS AT PELLY'S LAKE.

Approximately two-thirds of the lake had been baled before rain began to fall on October 4. After much precipitation, the baling of cattails resumed and was completed on October 27. Near the end of the test, it was decided that a reduced bale size would minimize sinking into the terrain due to the combined bale and baler weight. Out of the 575 round bales produced at Pelly's Lake, 412 were 1.7 metres (67 inches) in diameter and 163 were 1.5 metres (60 inches) in diameter.

5.2 Harvest Conditions

PAMI identified several factors that determined the degrees of success during cattail harvest testing. These variables are discussed in detail below.

5.2.1 Climate

The initial climate for both cattail harvesting sites was nearly ideal. The precipitation for the year ending September 30, 2012 was far below the 10-year average recorded between 1997 and 2006 for weather stations near the Hwy 1 and Pelly's Lake harvest sites. The initial harvest conditions are compared to the 10-year average in Table 1.

TABLE 1. HISTORICAL AND 2012 PRECIPITATION TO SEPTEMBER 30.

WEATHER STATION LOCATION	10-YEAR DATA FROM 1997 TO 2006			YEAR ENDING SEPTEMBER 30, 2012	
	MAXIMUM (MM)	MINIMUM (MM)	AVERAGE (MM)	PRECIPITATION (MM)	PERCENT OF AVERAGE
Marquette, MB	789.6	328.2	547.7	401.4	73.3%
Holland, MB	655.2	335.0	513.8	304.9	59.3%

Retrieved from National Climate Data and Information Archive, 2012.

The dry conditions allowed for entry onto the marsh areas using conventional harvesting systems. In a year with average, or above-average precipitation, soil conditions may not permit easy entry into the marshes or allow for commercial equipment to readily cut and harvest the cattails. Wet field conditions are hard on equipment and slow field operations down. The downtime and costs associated with equipment stuck in the field also need to be considered when attempting harvest in wet conditions.

The months of October and November brought large amounts of precipitation and low temperatures to the harvest regions. The cattail harvest was stalled on October 4 due to a high precipitation near Hwy 1 and Pelly's Lake. The accumulated precipitation over the remaining harvest months is shown in Table 2.

TABLE 2. PRECIPITATION RECEIVED—OCTOBER AND NOVEMBER, 2012.

WEATHER STATION LOCATION	PRECIPITATION FOR LATE FALL 2012						
	OCTOBER			NOVEMBER			TOTAL (MM)
	RAIN (MM)	SNOW (CM)	TOTAL (MM)	RAIN (MM)	SNOW (CM)	TOTAL (MM)	
Marquette, MB	80	1	90	12	38	50	140
Holland, MB	82	6	88	9	38	47	135

Retrieved from National Climate Data and Information Archive, 2012.

In total, more than 130 mm (5 inches) of precipitation fell on each of the harvest regions in the months of October and November. This was far above the 10-year averages of precipitation during the same two months as shown in Table 3.

TABLE 3. HISTORICAL AND 2012 PRECIPITATION—OCTOBER AND NOVEMBER.

WEATHER STATION LOCATION	PRECIPITATION FOR OCTOBER AND NOVEMBER MONTHS COMBINED				
	10-YEAR DATA FROM 1997 TO 2006			OCTOBER-NOVEMBER, 2012	
	MAXIMUM (MM)	MINIMUM (MM)	AVERAGE (MM)	PRECIPITATION (MM)	PERCENT OF AVERAGE
Marquette, MB	129	34	67	130	194%
Holland, MB	95	21	53	135	255%

Retrieved from National Climate Data and Information Archive, 2012.

Freezing temperatures in late October provided a firm base which permitted completion of baling at Pelly's Lake. The remaining cattail swaths along Hwy 1 were not baled. A heavy snowfall of 29 cm fell in mid-November, which effectively ended further attempts to bale the remaining cattails along Hwy 1.

5.2.2 Challenges

PAMI identified several additional challenges that were encountered during the harvesting tests. Real and potential problems were noted during the test and are described in detail below.

Low Spots

Soil conditions were a major concern for cattail harvesting. The first attempt at cutting cattails at the PLP bypass resulted in the windrower being mired in soft soil. This occurred twice in the PLP bypass marsh. Each time, the windrower was extracted using a highway wrecker as shown in Figure 13.

FIGURE 13. HIGHWAY WRECKER REQUIRED TO EXTRACT STUCK WINDROWER.

The low spots were not visible to the operator since the cattails and other vegetation appeared to grow close to the soft areas. The clay soil in the low spots did not allow the windrower to drive through the wet areas. Once a low spot was encountered, the drive wheels dug down and forward progress stopped.

These were the only instances where any of the equipment became stuck. Fortunately, boggy areas were either avoided by operators at the other harvesting sites, or they didn't exist due to the dry conditions of the test year. Another year with normal precipitation may have increased the number of low spots in the wetland areas.

Baler Plugging & Pickup Height

The soft terrain caused the square balers to sink slightly and required the swath pickup to operate at a height higher than normal field operation. Even at the high pickup height, the litter and debris below the swath was picked up. Picking up the wet litter with the cattail swath caused an excess of material to be fed into the baler throat causing it to plug (Figure 14, left). A similar experience with a square baler was experienced at the Pelly's Lake wetland area. A combination of having to raise the pickup to the transport position instead of a typical field position and a wide swath caused the baler to plug at the pickup and throat as shown in Figure 14, right. After breaking the second shear pin (an overload device intended to prevent damage to other components) before producing the first bale, the use of the square baler at Pelly's Lake was discontinued.

FIGURE 14. SQUARE BALERS PICK UP (LEFT) AT THE PLP BYPASS WETLAND AND (RIGHT) PELLY'S LAKE.

The soft terrain was noticed at both the PLP bypass and Pelly's Lake harvesting sites. The baling operations that had tractors with single rear wheels appeared to be the most susceptible to the soft base. This was evident for the Duetz-Allis 9150 tractor at PLP bypass and the White 100 tractor at Pelly's Lake. The soft base caused the rear wheels of the tractor to sink into the soil. This also lowered the hitch below the stubble height and dragged the swath, making it difficult for the baler to pick up the swath properly.

Hidden Foreign Objects

There were also objects found in Pelly's Lake marsh that could damage harvest equipment. A carcass from an animal possibly trapped in the marsh and multiple pieces of driftwood were found (Figure 15).

FIGURE 15. OBJECTS FOUND IN PELLY'S LAKE THAT POSE A RISK OF EQUIPMENT DAMAGE.

Cattail Fluff

When disturbed, the cattail flower heads disperse their seeds as fluff as shown in Figure 16, below. This poses a risk for motorized equipment because it can plug radiator grills and overheat equipment. This did not occur during the harvest trials, but Figure 16 below shows a radiator grill beginning to be blocked.

FIGURE 16. CATTAIL FLOWER HEAD FLUFF.

High Biomass Yields

The enormous yield of the cattail made it difficult to harvest with conventional swathing and baling equipment. The 20-foot windrower cut less than full width in most areas to minimize swath size. Even so, the square balers used at PLP bypass and Pelly's Lake were plagued with frequent blockages. The round balers were equipped with wider pickups and were able to produce bales, but much of the swath was packed down by the tractor wheels and remained on the ground after baling. This significantly reduced bales produced, estimated biomass yields per area, and potential phosphorus capture. An example of the losses due to missed product at Pelly's Lake is shown in Figure 17.

FIGURE 17. CUT CATTAILS UNABLE TO BE PICKED UP DURING BALING.

A different selection of cutting equipment may reduce losses during harvest. Smaller swaths and lower cut heights may improve ability to harvest more of the available crop.

Safety Along Highways

Harvesting safety along Hwy 1 was a concern. PAMI complied with traffic safety regulations by erecting signs during all harvest testing along the highway. As well, beacons were installed on all equipment used for the Hwy 1 tests. Since signs had to be moved frequently during the Hwy 1 harvest tests, the moving of signs became as much of a safety concern as the harvesting itself because of the heavy traffic. The placement and moving of signs required an additional part-time person during the cutting portion of the harvest. Since the baling and bale-picking processes spanned a large distance over a short period of time, an additional person was required to move signs to appropriate positions along the highway depending on where the work was being performed.

Bale Transportation

A load of round bales harvested at the Pelly's Lake wetlands was shipped to Saskatchewan for conversion to biocarbon. The bales were transported on a standard flat-deck semi-trailer. During the initial transport, the bales shifted slightly, grounding the truck and trailer. The bales were reloaded onto a specialty trailer with cradles that held the bales in position on the trailer. The transport company believed the bale moisture content and nature of the cattails affected the bale shipping. Because of these two factors the straps used to secure the bales tended to slide off the outer surface of the bales. Typical straw or forage round bales have a lower moisture content and straps dig into the outer surface of the bales more easily compared to the much denser cattail bales.

5.3 Harvest Yields

Total harvested weight of cattails was determined from collected bales. The total weight of bales from Hwy 1 was measured during transportation to the final storage location. The total weight of bales at Pelly's Lake was calculated based on a bale count and a three-bale average mass from the two balers used. Yield by bale count was also determined so that handling and storage costs and methods can be determined. The results of the harvest in terms of yield are given in Table 4.

TABLE 4. CATTAIL HARVESTED YIELDS.

SITE	BALES	AREA		*TOTAL WEIGHT		AVERAGE HARVESTED PER AREA	
		(HA)	(ACRE)	(KG)	(LB)	(KG/HA)	(LB/ACRE)
PLP Bypass	8	n/a	n/a	n/a	n/a	n/a	n/a
Hwy 1	189	17.1	42.3	50,641	111,645	2,961	2,641
Pelly's Lake	575	54.1	133.7	329,431	726,270	6,089	5,433
Total	772	71.2	176.0	380,072	837,915	n/a	n/a

Total potential cattail biomass yields for each site were also calculated based on averages from collected biomass samples and cattail densities at each site (six 1 metre x 1 metre sampling quadrats at each site). Cattail biomass samples were not collected for Pelly's Lake due to harvest schedules and weather issues, so the average potential yields were calculated from harvested material plus 30 per cent estimated biomass material left on site for Pelly's Lake (Table 5).

TABLE 5. CATTAIL BIOMASS YIELDS.

SITE	SAMPLE DATE	CATTAIL DENSITIES (#/M2)	AVERAGE DRY WEIGHT PER AREA		
			(KG/HA)	(T/HA)	(LB/ACRE)
Netley-Libau 1	August 20	57	21,843	22	19,484
Netley-Libau 2	Sept 10	45	12,766	13	11,387
Hwy 1	August 9	50	14,000	14	12,488
Hwy 1	Sept 4	50	11,500	12	10,258
Perimeter south	Aug 1	51	11,816	12	10,539
Pelly's Lake*	Sept 25	54	8,000 to 13,000*	8 to 13*	7,137*

*Calculated from harvested material, 30 per cent estimated biomass material left on site, cutting height, and plant densities for Pelly's Lake.

The harvested yield from Pelly's Lake in terms of weight per hectare was approximately double the yield of Hwy 1 (Table 4). This may explain the ease of harvest along Hwy 1 using the same type of equipment that was unsuccessful in Pelly's Lake. The potential yields at each site (Table 5) compared to actual harvested biomass (Table 4) are much higher, due to cut heights being higher to avoid debris pick up. It should also be noted that cut heights and material losses were much greater in Pelly's Lake than Hwy 1, which explains the much lower biomass yields. Also, cattail biomass samples were not collected at Pelly's Lake to be able to more accurately calculate dry weight per given area (Table 5), so cattail biomass yields would potential be even greater at Pelly's Lake.

Wetland areas are especially productive and could produce significant quantities of cattails, if the water table could be successfully managed to account for seasonal variation in precipitation. A managed wetland would maintain high soil moisture during the growing season to maximize cattail growth and phosphorus uptake, followed by controlled drainage to reduce the soil moisture content. The ability to dry out the soil near the end of the growing season would allow commercially available agricultural equipment to harvest the cattails.

5.4 Cattail Nutrient Analysis and Phosphorus Capture and Recovery

The cattail biomass harvesting project is part of a larger research program at IISD that explore the use of ecological biomass for multiple environmental and economic benefits, including nutrient capture and removal from water bodies in Manitoba. The nutrient of concern is primarily phosphorus (P), which causes the nutrient loading and algae blooms in Lake Winnipeg, but also of interest are nitrogen (N) and potassium (K). Samples of cattails were sent to third-party labs for analysis of chemical properties.

Cattail nutrient values are given as a percentage of dry matter in Table 6 from multiple replicate samples at each site for different time periods. The table also provides nutrient profiles at time of harvest later in the season.

TABLE 6. CATTAIL NUTRIENT PROFILE—AVERAGE DRY BASIS.

SAMPLE SITE	SAMPLING DATE	SAMPLE DESCRIPTION	MOISTURE CONTENT (%)	PHOSPHORUS (% DRY WEIGHT)	NITROGEN (% DRY WEIGHT)	POTASSIUM (% DRY WEIGHT)
Netley-Libau 1	August 20	Green	72	0.13	0.84	1.33
Netley-Libau 1	September 2	Drying	70	0.12	0.99	0.90
Netley-Libau 2	September 10	Drying	70	0.07	0.82	0.86
Hwy 1	August 9	Green	72	0.11	1.01	1.42
Hwy 1	September 4	Drying	68	0.04	0.98	0.56
Perimeter south	August 1	Dead	17	0.02	0.41	0.25
Pelly's Lake	September	Dead	32	0.10	1.3	0.62

TABLE 7. CATTAIL NUTRIENT PROFILE—AVERAGE DRY BASIS.

SAMPLE SITE	SAMPLING DATE	SAMPLE DESCRIPTION	MOISTURE CONTENT (%)	PHOSPHORUS (% DRY WEIGHT)	NITROGEN (% DRY WEIGHT)
PLP Bypass	PLP1 Standing	19.31	0.049	0.536	0.727
	PLP1 Cut	9.99	0.070	0.698	1.915
Hwy 1	Road 7W Standing	25.35	0.097	0.821	1.146
	Road 7W Cut	18.22	0.097	0.707	1.127
Pelly's Lake	Bale Pelly I	37.24	0.092	1.325	0.337
	Bale Pelly II	32.85	0.086	1.267	0.325
	Bale Pelly III	29.49	0.083	1.099	0.624
Winnipeg Bypass (no harvesting performed)	59/PER/BEF1	4.4	0.024	0.479	0.431
	59/PER/DEF2	25.8	0.048	0.781	0.697

At the time of harvest at Pelly's Lake at the end of September, average phosphorus content (dry weight) was 0.087 per cent. Average moisture content of the bales was 33.19 per cent, giving a total weight of cattails harvested from Pelly's Lake of 329,431 kilograms, and a total dry weight of 220,092 kilograms. The total phosphorus removed in the harvested material from this 54.1 hectare area was 191 kilograms of phosphorus, or 3.5 kg/ha (3.1lb/acre).

It should be noted that due to the late timing of harvest and the fact the cattail biomass was dead and drying out on the stalk, the phosphorus levels found in these samples are much lower than potential P capture and removal. Previous research from IISD and the University of Manitoba has shown that cattails lose phosphorus later in the season as plant begin to die and senesce, and will actually lose nutrients and material as cell structure breaks down from drying. Additionally, a lot of material was left on the site during harvest, so the potential phosphorus available for capture could be much greater. An estimate of phosphorus captured in harvested material and total potential phosphorus capture is given in Table 8.

TABLE 8. ESTIMATE OF PHOSPHORUS CAPTURED IN HARVESTED MATERIAL (1 TONNE = 1,000 KG).

	UNIT	HWY 1 DITCHES	PELLY'S LAKE
Total weight of harvested cattails - dry basis	tonne	41.41	220.09
Average total phosphorus (TP) in harvested cattails	%	0.097	0.087
Total phosphorus in harvested material	kg	40.35	191.48
Total harvested area	ha	17.1	54.1
Calculated biomass yield per area	tonne/ha	13	13
Total calculated biomass yield at site – dry basis	tonne	222	703
Average total phosphorus (August peak growth)	%	.11	.10
Total phosphorus in cattail biomass	kg	244	703
Total average phosphorus per area	kg/ha	14.3	12.99

For the purpose of this project, the harvest of cattails took place in late September through early October, and demonstrated that late-season cattails can be successfully harvested using commercially available equipment. Harvesting cattails earlier in the growing season would increase the amount of phosphorus contained in the cattail, but may also change the harvest conditions and the ability of commercially available equipment to cut and bale the cattails. An earlier harvest would also mean that the cattails would be green, which would require swathing and giving time to dry before baling. Further timing of harvest, field conditions, and nutrient changes requires further study towards commercialization.

5.5 Economic Analysis

5.5.1 Cost of cattail biomass harvesting

Harvesting cattails with commercially available agricultural equipment is possible if the environment and conditions are suitable. Two different types of evaluation sites were harvested during this project with varying costs. Costs were incurred during each field operation (cutting, harvesting, moving bales, etc.) and depended on the conditions at the time.

Agricultural field operations are priced based on the capital cost of the equipment, repair and maintenance costs, fuel and labour for normal field conditions. Agricultural equipment is capital-intensive, and owners are protective of their equipment investment. During the course of this project, custom operators of equipment were contacted to perform field operations, but many declined due to the increased risk that harvesting in atypical conditions posed to their equipment. The risk of equipment damage due to rocks or other foreign objects hidden in ditch areas or wetlands was a deterrent. The risk of equipment getting stuck and the potential for subsequent damage during extraction is also a factor that needs to be considered.

The cost for a specific piece of equipment (i.e., for baling) is also based the on field efficiency. Decreasing field efficiencies increases the cost of each operation. Decreased field efficiencies with the baling of the cattails were encountered during both the ditch harvest site and wetland harvesting and are described in further detail in the following sections.

MAFRI publishes a guide (the Farm Machinery Custom and Rental Rate Guide) that can be used to estimate the cost of each field operation. It provides typical costs for equipment operation in normal field conditions. Conditions outside of the norm require a premium to account for additional expenses or risk of equipment damage. Both the highway ditch and wetland sites had increased risk of damage compared to normal field conditions.

The cattail harvesting performed along the ditches of Hwy 1 was readily accessible for equipment due to the size of the ditches and the dry summer/fall period when the cattails were cut. A year with increased precipitation would be more challenging to operate in, similar to the conditions that were experienced at the PLP bypass.

Temporary traffic signs will need to be used when harvesting in ditches, and moved at additional expense compared to normal field operations. The number of signs and frequency of movement will depend on the conditions at the time of cutting or harvest. This will reduce the efficiency of any field operation and add additional expense.

Each segment of ditch where cutting or harvesting is performed can be considered a small field. Multiple small fields will have an inherently lower field efficiency as compared to one larger field. The time to travel between fields, the need to wait for traffic when moving between fields, and the reduced cutting width when windrowing along the outer edge if the field is not a perfect multiple width of the cutting tool, all contribute to decreased field efficiency.

The wetland harvesting at Pelly's Lake presented its own set of challenges. The hidden objects in the field due to flooding, unknown terrain, the time of year for baling and moving, also contributed to increased risk and cost.

An estimate of the costs of harvesting according to field operation for both harvest sites is presented in Table 9 and 10. Hours presented are actual hours incurred to perform the field operations where available. In order to provide a fair comparison between different equipment types, the costs were based on the MAFRI Farm Machinery Custom and Rental Rate Guide. An estimate of additional premiums during the pilot harvest to contract custom operators is also provided, based on contractor pricing during specific field operations encountered during this project. A range is provided from normal field conditions to a premium that may be required for harvesting cattails to compensate custom operators for wet or difficult field conditions.

TABLE 9. ESTIMATE OF FIELD OPERATION COSTS – PELLY'S LAKE.*

UNIT OPERATION	MAFRI CUSTOM RATE ($/HR)	PILOT RESEARCH RATE ($/HR)	HOURS	MAFRI CUSTOM RATE TOTAL	PILOT RESEARCH RATE TOTAL
Windrower: Self-propelled, 18–24' draper header (includes $2.25/hr swath roller)	$117.47	$174.90	14	$1,644.58	$2,448.59
Baling : 5' x 6' round bale, 80 hp tractor	$94.03	$140.00	56	$5,265.68	$7,840.00
Bale Mover: Pull type, 7–12 round bale, 120 hp tractor	$113.07	$168.47	*41	$4,635.87	$6,907.45
Total Estimated Cost				$11,546.13	$17,196.04
Total Estimated Cost Per Bale (575 round bales):				$20.08	$29.91
Total Estimated Cost Per Dry Mass (220.09 tonnes):				$52.46	$78.13

Note: Bale moving hours are an estimate only, calculated from the MAFRI Farm Machinery Custom and Rental Rate Guide Appendix A. A 2-mile haul distance and 7-bale/load capacity was used for the estimate assuming that bale moving operations can be performed with typical hay harvesting equipment before snow fall. Actual bale moving was performed with skid steers and bale in snow conditions.

** All figures in Canadian dollars.*

TABLE 10. ESTIMATE OF FIELD OPERATION COSTS – HWY 1 DITCH TEST SITE.

UNIT OPERATION	MAFRI CUSTOM RATE ($/HR)	PILOT RESEARCH RATE ($/HR)	HOURS	MAFRI CUSTOM RATE TOTAL	PILOT RESEARCH RATE TOTAL
Windrower: Self-propelled, 18–24′ draper header	$115.22	$171.68	*9.5	$1,094.59	$1,630.94
Baling : 35″ x 31″ square bale, 125 hp tractor	$175.63	$261.69	6.5	$1,141.60	$1,700.98
Bale Mover: Pull type, 6–12 square bales, 125 hp tractor	$145.79	$217.23	**8	$1,166.32	$1,737.82
Total Estimated Cost				$3,402.51	$5,069.74
Total Estimated Cost Per Bale (189 square bales):				$18.00	$26.82
Total Estimated Cost Per Dry Mass (41.41 tonnes):				$82.16	$122.41

**The windrower operation includes driving time from yard west of Elie where the windrower was stored overnight.*

***Bale moving hours are an estimate only, calculated from the MAFRI Farm Machinery Custom and Rental Rate Guide Appendix A. A 6-mile haul distance and 12-bale/load capacity was used for the estimate, assuming that bale moving operations can be performed with typical hay harvesting equipment before snowfall. Actual bale moving was performed with a frontend loader and semi-trailer due to the distance of the bale hauling.*

Total cattail harvest costs to cut, harvest and store bales at a site near the harvest area are estimated to range between $20–$30 per round bale or $52–$78 per dry tonne at a wetland site using round bales. The price for a ditch harvesting site ranged from $18–$27 per square bale or $82–$122 per dry tonne of cattails. Moisture content can significantly influence the cost per dry tonne and needs to be monitored during harvest operations. The cattails harvested at Pelly's Lake had a higher moisture content and therefore lower mass on a dry basis.

5.5.2 Cost of Phosphorus Capture and Recovery

The quantity of P captured in the actual harvested cattail from both test sites was based on the total mass of dry material and concentration of the specific nutrient in the cattails collected. A dry mass basis is used to exclude the effect water may play on the nutrient concentration. A cost comparison based on the field operations and quantity of total phosphorus (TP) harvested is presented for the two test sites (Hwy 1 ditches and Pelly's Lake wetland) in Table 11.

Total phosphorus in the biomass at each site and potential phosphorus capture is also given, based on if the timing of harvest occurred earlier in the season to capture stored phosphorus, as well as potential biomass with more efficient harvesting and baling in Table 12.

TABLE 11. ESTIMATE OF PHOSPHORUS CAPTURED IN HARVESTED MATERIAL (1 TONNE = 1 000 KG).

	UNIT	HWY 1 DITCHES	PELLY'S LAKE
Total weight of harvested cattails—dry basis	tonne	41.41	220.09
Average total phosphorus (TP) in harvested cattails	%	0.097	0.087
Total phosphorus in harvested material	kg	40.35	191.48
Total calculated biomass yield	tonne	222	703
Average total phosphorus (August peak growth)	%	0.11	0.10
Total phosphorus in cattail biomass	kg	244	703

TABLE 12. ESTIMATE OF COST OF PHOSPHORUS CAPTURED IN HARVESTED MATERIAL BASED ON FIELD OPERATION TOTALS (1 TONNE = 1,000 KG).

	UNIT	HWY 1 DITCHES	PELLY'S LAKE
Estimated cost to harvest TP - MAFRI custom rates	$/kg	84.32	60.30
Estimated cost to harvest TP - MAFRI custom rates	$/tonne	84,320	60,300
Estimated cost to harvest TP – pilot harvest rates	$/kg	125.63	89.81
Estimated cost to harvest TP – pilot harvest rates	$/tonne	125,630	89,810

TABLE 13. ESTIMATE OF COST TO CAPTURE PHOSPHORUS IN HARVESTED MATERIAL BASED ON AVERAGE OF MULTIPLE REPLICATE SAMPLES FROM SITES (1 TONNE = 1 000 KG).

	UNIT	HWY 1 DITCHES	PELLY'S LAKE
Estimated cost to harvest TP — MAFRI custom rates	$/kg	13.94	16.42
Estimated cost to harvest TP — MAFRI custom rates	$/tonne	13,940	16,420
Estimated cost to harvest TP — pilot harvest rates	$/kg	22.84	24.5
Estimated cost to harvest TP — pilot harvest rates	$/tonne	22,840	24,500

6.0 Recommendations

This pilot-scale harvest demonstrated that cattail can be harvested on a large-scale with commercially available agricultural equipment if the field conditions are suitable. Much valuable experience was gained during the course of this research project. Several key findings and recommendations include:

1. **Maximize the phosphorus capture by timing of harvest**. It is expected that the late harvest contributed to the reduced P concentrations in the cattail samples collected. An earlier harvest time would increase the amount of P captured and removed from the watershed. Additional research to determine the P concentration, soil conditions at the time, and dry down required before baling is needed to quantify the effect of harvest season.
2. **Investigate opportunity to maximize the quantity of biomass and P through managed wetlands**. The Pelly's Lake wetland trial produced a significantly higher biomass yield compared to the harvest of cattails in the ditches along Hwy 1. Because total P capture is related to the quantity of cattails harvested, a higher yield per unit area will ultimately provide the most efficient and cost-effective harvest. A managed wetland could provide optimum growing and harvest conditions.
3. **Investigate alternative methods of harvesting**. Harvesting earlier in the growing season when more P is contained in the plant tissue will also result in a higher moisture content of the cattails. For a green manure application, a higher moisture content will be beneficial if land applied soon after harvest.
    a. A forage harvester that cuts and chops the cattails in one pass may provide a more efficient means of harvesting provided the soil conditions are suitable.
    b. A smaller swath would provide fewer difficulties for baling equipment.
    c. Suitable baling equipment needs to be utilized to maximize biomass collection.
    d. Investigate and test specialized harvesting equipment suitable for wet conditions, such as low-weight ratio tracked harvesters that are used in Europe for wet agricultural conditions.

References

Government of Canada. (2012). National Climate Data and Information Archive. Retrieved from http://climate.weather.gc.ca/

MacDon. (2012). MacDon self-propelled windrowers and headers full line (Brochure). Retrieved from http://www.macdon.com/products/m-series-sp-windrowers

TractorData. (2012). Deutz-Allis 9150. Retrieved from http://www.tractordata.com/farm-tractors/003/1/7/3174-deutz-allis-9150.html

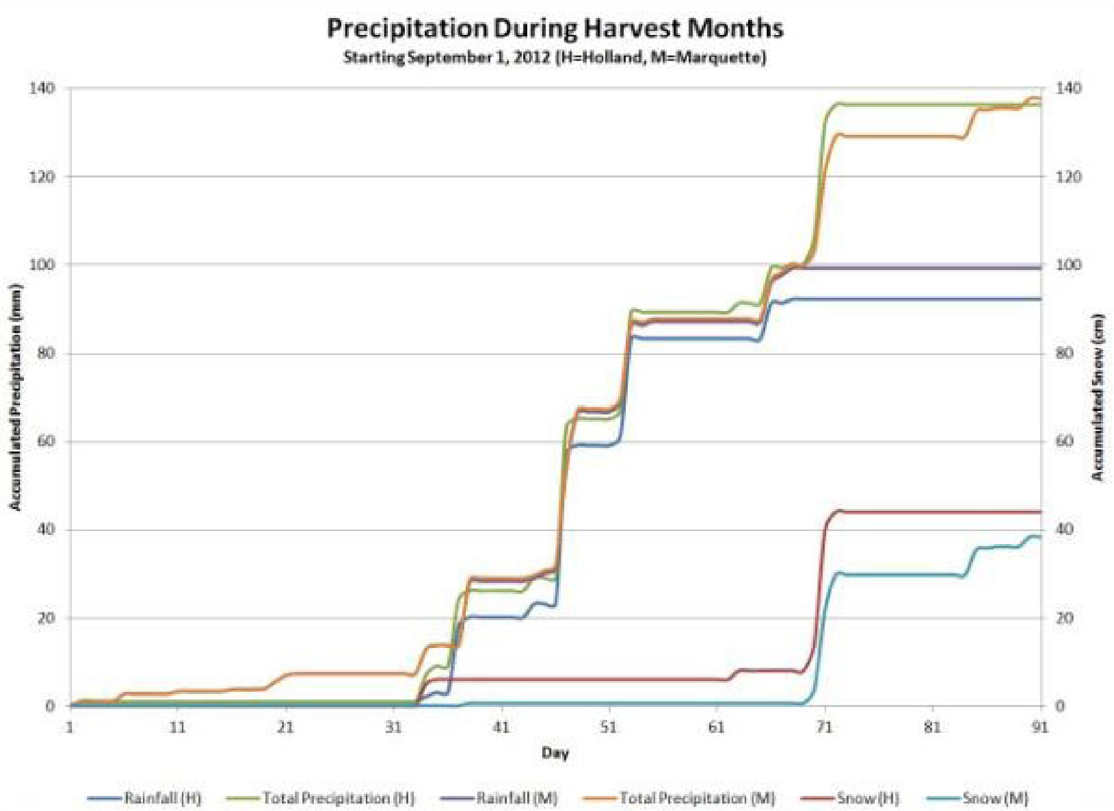
Appendix I

List of Equipment Used During Harvesting

TYPE	MAKE	MODEL	RELEVANT FEATURES	TEST LOCATION
Windrower	Westward	M155	6.1-m MacDon D60 Draper Header	All
Tractor	Deutz-Allis	9150	MFWD	PLP Bypass
Tractor	CaseIH	Magnum 275	MFWD w/duals	Pelly's Lake
Tractor	John Deere	4455	RWD w/duals	Pelly's Lake
Tractor	White	100	RWD	Pelly's Lake
Tractor	CaseIH	Magnum 245	MFWD w/duals	Hwy 1
Baler	CaseIH	8575 Silage Special	0.8 m x 0.9 m Square	PLP Bypass
Baler	Hesston	4910	1.2 m x 1.3 m Square	Pelly's Lake
Baler	John Deere	568 MegaWide Plus	1.6 m Round	Pelly's Lake
Baler	Challenger	RB563A	1.6 m Round	Pelly's Lake
Baler	CaseIH	8575	0.8 m x 0.9 m Square	Hwy 1
Loader	Caterpillar	928G		Hwy 1

Appendix II

Accumulated Precipitation at Harvest Sites



International Institute for Sustainable Development
Institut international du développement durable

Published by the International Institute for Sustainable Development.

International Institute for Sustainable Development
Head Office
161 Portage Avenue East, 6th Floor, Winnipeg, Manitoba, Canada R3B 0Y4
Tel: +1 (204) 958-7700 | Fax: +1 (204) 958-7710 | Website: www.iisd.org