Restoration of a Canadian Prairie Wetland with Agricultural and Municipal Wastewater

JAY S. WHITE*
SUZANNE E. BAYLEY
Department of Biological Sciences
University of Alberta
Edmonton, Alberta, Canada T6E 2G5

ABSTRACT / A rapid development and approval process was employed by Ducks Unlimited Canada and other stakeholders to restore a 1246-ha (3079-acre) northern prairie wetland in southern Alberta, Canada, with 3640 m^3/day (800,000 US gallons) of municipal wastewater and beef processing wastewater. A large nongovernmental organization hastened restoration with a development process that outlined restoration goals and management objectives to satisfy a dual mandate of wastewater treatment and wildlife habitat creation. In 1995, after five years of wastewater additions, the basins had been refilled and the surrounding uplands had been acquired and restored. The Frank Lake Conservation Area currently provides high-quality habitat for a variety of wildlife in a region where many of the native plants and animals species have been lost due to habitat loss and fragmentation. The success of upland and water management strategies is reflected in the increase of target species' abundance and richness: 50 shorebird species, 44 waterfowl species, 15 raptor species, and 28 other new bird species have returned to the marsh since restoration. As well, significant N and P reduction occurs as waters flow through the first basin of the marsh. The management strategies of this project that satisfied a dual mandate serve as a model to guide managers of other large-scale wetland restoration projects.

The prairie pothole region of the mid-continent has long been recognized as the principal waterfowl production area of North America (Crissey 1969, Pospahala and others 1974). Comprising 10% of the total continental waterfowl breeding area, it produces more than 50% of the fall flight of ducks (Smith and others 1964). Prairie wetland area has decreased in Canada by 71% and in America by 75% since settlement (Lands Directorate 1986), and this habitat loss and diminishing waterfowl populations are directly linked (Gollop 1965, Smith 1971, Reynolds 1987). The highly variable nature of temperature and precipitation subject prairie pothole wetlands to wide annual fluctuations, which also decreases habitat periodically. As both water and high-quality upland cover are required for the success of many species of waterfowl, permanent reestablishment of high-quality habitat in the prairie pothole region has become an important task for wildlife organizations in their efforts to restore waterfowl populations (Turner and Caswell 1989).

The establishment of more permanent waterfowl habitat at Frank Lake in southern Alberta, Canada, had been a goal of Ducks Unlimited Canada (DU) since the early 1940s. Agricultural drainage and encroachment had substantially reduced the size of Frank Lake and by the early 1980s, the wetland was dry. An opportunity arose in 1988 to restore Frank Lake with a mixture of agroindustrial wastewater from a beef processing plant, municipal wastewater, and additional fresh water from the Highwood River. DU immediately developed a project concept and outlined the goals and objectives for marsh restoration, which included management of long-term loadings of nutrient-rich wastewater into the marsh.

This paper describes the marsh management strategies that were implemented by Ducks Unlimited Canada to restore the Frank Lake prairie pothole marsh in southern Alberta, Canada. The goals of the restoration were to create and maintain high-quality waterfowl habitat in an effort to increase the biodiversity of the area, while at the same time providing wastewater treatment. The criterion for restoration included the restoration of upland vegetation and wildlife that previously occurred in the area. Five years following restoration, large increases in abundance and richness of target species attest to the success of marsh management. A strategy for the implementation of a successful environmental management project is presented with the ecological, social and economic benefits of restoration.

KEY WORDS: Frank Lake; Wetland restoration; Adaptive management; Prairie; Wastewater

*Author to whom correspondence should be addressed.

Frank Lake Site Description

The Frank Lake Conservation Area (FLCA) is located 60 km south of Calgary, Alberta (50° 33′ N; 113°

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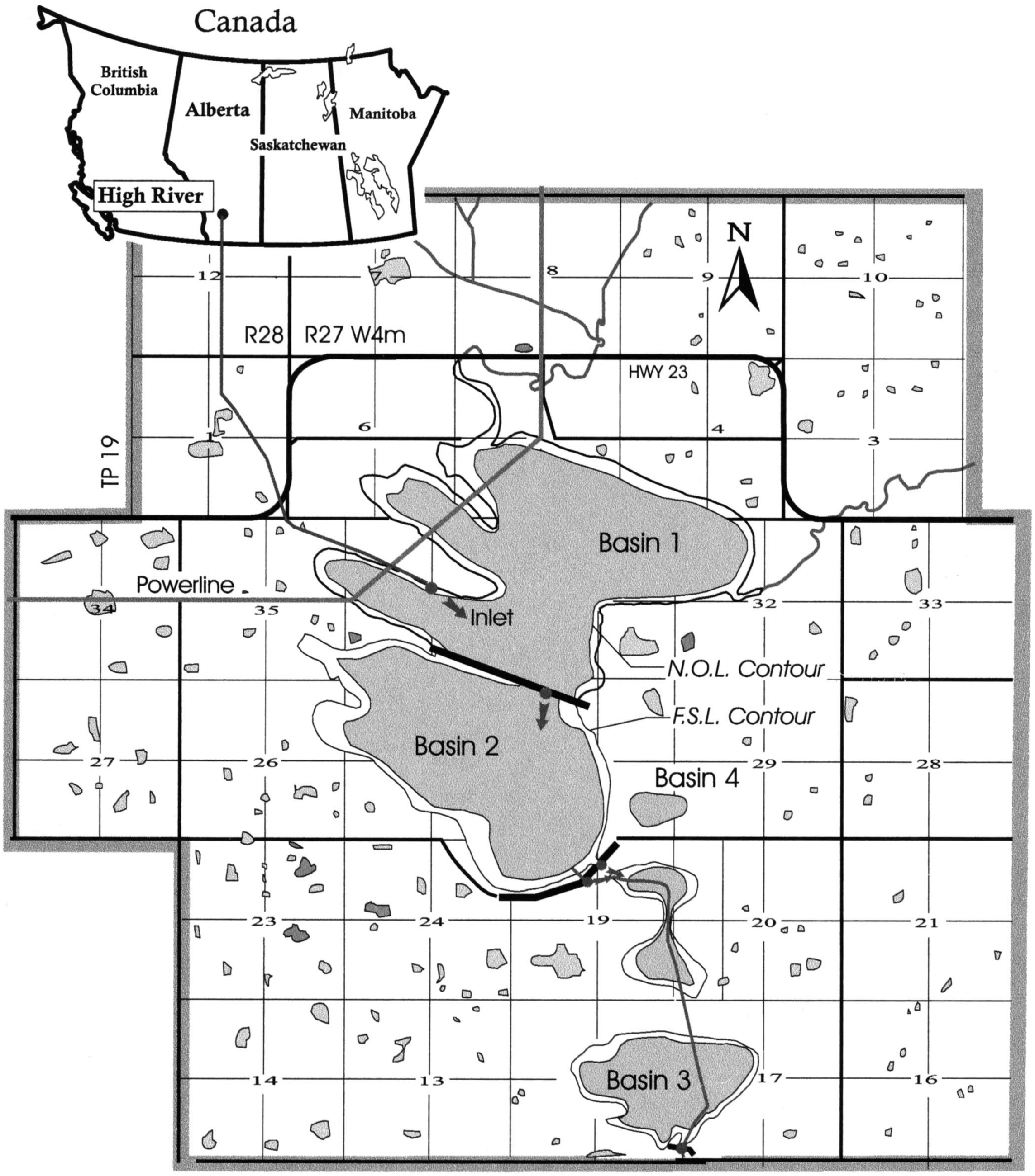

Figure 1. The 9325-ha (23,040-acre) Frank Lake intensive management unit in southern Alberta, Canada. Wastewater flows underground from the town of High River and is discharged at a single point source into basin 1. N.O.L. = normal operating level, F.S.L. = full supply level.

42′ W) in the Frank Lake Plain subregion of the Fescue Prairie Ecoregion (Poston and others 1990) (Figure 1). Frank Lake is a shallow basin marsh (National Wetlands Working Group 1998). The main marsh is 1246 ha (3079 acres); other seasonal potholes in the area total 140 ha (350 acres), and an additional 698 ha (1725 acres) of uplands are managed for wildlife benefits. Mean annual rainfall and snowfall measured at the nearby Town of High River is 316.3 and 172.0 mm/yr, respectively, totaling 488.2 mm/yr (Environment Canada 1982). Mean calculated lake evaporation for the area is 522.9 mm/yr, giving a mean annual water loss of 34.7 mm/yr (Environment Canada 1984). The major habitats of Frank Lake include upland native mixed grasslands, meadows and shorelines, wetlands, and human-modified habitats (Wallis and others 1996).

Importance of Frank Lake Region to Waterfowl and Other Wildlife

DU and other wildlife groups have long recognized the geographical importance of the Frank Lake region to nesting and staging waterfowl, marsh birds, and shorebirds (Sadler and others 1995). While important as a brood marsh, Frank Lake is also the only large permanent wetland in the area and provides habitat for as many as 30,000 migrating waterfowl. As a result, the Frank Lake ecoregion is important locally, regionally, and/or provincially for breeding colonial waterbirds, migratory birds, staging geese, staging ducks, and for rare, threatened, and endangered species (Poston and others 1990, Wallis and others 1996).

Before restoration in 1990, the original Frank Lake watershed had been altered by intensive agricultural production by as much as 90%, leaving fragmented grasslands and meadows. Disturbance by cultivation, repeated heavy grazing, and fire suppression had reduced or eliminated several native plant and animal populations (Wallis and others 1996), such as the extirpation of wolf (*Canis lupus*), coyote (*Canis latrans*), badger (*Taxidea taxus*), swift fox (*Vulpes velox*), antelope (*Antilocapra americana*), sharp-tailed grouse (*Tympanuchus phasianellus*), and greater prairie chicken (*Tympanuchus cupido*) from the High River area (Fowler 1937). No data are available on extirpated plant species, but weed invasion by dandelions (*Taraxacum* spp.), bladder campion (*Silene latifolia*), toadflax (*Linaria vulgaris*), and European ox-eye daisies (*Chysanthemum leucanthemum*) were noted in Fowler (1937).

Human disturbance commonly leads to small populations with altered system dynamics. Fragmented landscapes with noncontiguous habitats and the absence of natural processes such as fire may be responsible for the low species diversity of upland wildlife previously found at Frank Lake (Wallis and others 1996). Because of the low species diversity previously found in this area, Frank Lake restoration was given high priority under the North American Waterfowl Management Plan (NAWMP) (Patriquin 1993). Within Frank Lake, Wallis and others (1996) identified several significant areas such as native grasslands, a large bulrush marsh, and four shallow wetlands that required special management.

Restoration Benefits

A system that provides effective wastewater treatment and high-quality wetland habitat provides dual benefits for society, so adaptive management strategies were used to ensure that the benefits of restoration outweighed any negative impacts. Marsh restoration provided dual benefits for both industry and the environment. For the beef-processing facility (Cargill Foods Ltd.), the creation of an industry and a wetland for wastewater treatment that could treat industrial wastewater and improve water quality in nearby watercourses was both profitable and environmentally sound. For the Town of High River and the surrounding region, the creation of an agrifood industry created other business opportunities.

Habitat and Pollution-Abatement Benefits

Restoration of Frank Lake provided a large marsh in an arid region of southern Alberta and secured a constant water supply with less variable seasonal water fluctuations for effective, long-term marsh management. Upland habitats now accommodate an estimated 4442 breeding pairs of nesting and foraging waterfowl (Sadler personal communication). In addition to creating both upland and wetland habitats, the project eliminated municipal wastewater dumping into the Highwood River, quickly improving water quality in the Highwood River (Sosiak personal communication) and reducing stress on the famous trout fishery. Results from local plant and animal inventories show that this cooperative venture has been quite successful in restoring site biodiversity (Wallis and others 1996).

Species Benefits

A main goal of the Frank Lake project was to increase the biodiversity in the prairie pothole region. After restoration, the FLCA has 194 species of vascular plants (of which 147 are native) and 1 reptile, 2 amphibian, 168 bird, 16 mammal and 2 fish species (Wallis and others 1996). Many avian species have only recently returned to Frank Lake following marsh restoration in 1990, including 44 waterfowl species (Table 1), 15 raptor species (Table 2), 50 shorebird species (Table 3), and 28 other bird species (Table 4). Significant plant and animal species at the marsh include: 9 species considered high priority by NAWMP; 7 vulnerable, 3 threatened, and 2 endangered species (COSEWIC 1995); 8 species of concern in Alberta (COSEWIC 1995); 19 regionally or provincially rare bird species; and 1 provincially and 3 nationally rare plant species (Wallis and others 1996, Sadler personal communication 1996).

Economic Benefits

The establishment of Cargill Foods in High River provided 3280 direct and indirect jobs with an impact of $262 million annually to the provincial economy (FMP/IDEK 1995). Along with providing the local community

Table 1. Abundance list of waterfowl species using Frank Lake in the fifth year after restoration

Species	Abundance[a]
Pied-billed grebe (*Podilymbus podiceps*)	uncommon summer resident
Horned grebe (*Policeps auritus*)	uncommon migrant
Red-necked grebe (*Podiceps grisegena*)	occasional spring migrant
Eared grebe (*Podiceps nigricollis*)	abundant summer resident
Western grebe (*Aechmophorus occidentalis*)	occasional migrant and summer visitor
Clark's grebe (*Aechmophorus clarkii*)	occasional summer visitor
American white pelican (*Pelecanus erythrorhynchos*)	occasional summer visitor
Double-crested cormorant (*Phalacrocorax auritus*)	uncommon summer visitor
American bittern (*Botaurus lentiginosus*)	uncommon summer visitor
Great blue heron (*Ardea herodias*)	uncommon summer visitor
Great egret (*Casmerodius albus*)	rare vagrant
Snowy egret (*Egretta thula*)	rare vagrant
Black-crowned night-heron (*Nycticorax nycticorax*)	uncommon summer visitor
White-faced ibis (*Plegadis chihi*)	uncommon summer resident
Tundra swan (*Cygnus columbianus*)	common migrant
Trumpeter swan (*Cygnus buccinator*)	uncommon migrant
Greater white-fronted goose (*Chen albifrons*)	occasional migrant
Snow goose (*Chen caerulscens*)	uncommon migrant
Ross' goose (*Chen rossil*)	occasional migrant
Canada goose (*Branta canadensis*)	common summer resident
Green-winged teal (*Anas crecca*)	common summer resident
American black duck (*Anas rubripes*)	rare vagrant
Mallard (*Anas platyrhynchos*)	common summer resident
Nothern pintail (*Anas acutus*)	common summer resident
Blue-winged teal (*Anas discors*)	common summer resident
Cinnamon teal (*Anas cyanoptera*)	common summer resident
Northern shoveler (*Anas clypeata*)	abundant summer resident
Gadwall (*Anas strepera*)	abundant summer resident
Eurasian wigeon (*Anas penelope*)	rare vagrant
American wigeon (*Anas americana*)	uncommon summer resident
Canvasback (*Aythya valisineria*)	common summer resident
Redhead (*Aythya americana*)	common summer resident
Ring-necked duck (*Athya collaris*)	uncommon summer migrant
Greater scaup (*Athya marila*)	occasional migrant
Lesser scaup (*Aythya affinis*)	common summer resident
Surf scoter (*Melanitta perspiciliata*)	occasional migrant
White-winged scoter (*Melanitta fusca*)	occasional summer resident or visitor
Common goldeneye (*Bucephala ciangula*)	uncommon migrant
Barrow's goldeneye (*Bucephala islandica*)	occasional migrant
Bufflehead (*Bucephala albeola*)	uncommon summer visitor and migrant
Hooded merganser (*Lophodytes cuculiatus*)	occasional migrant
Common merganser (*Mergus merganser*)	occasional migrant
Red-breasted merganser (*Mergus serrator*)	migrant
Ruddy duck (*Oxyura jamaicensis*)	abundant summer resident

[a]Abundance categories from Sadler (1994).

with a secure tax base, Cargill Foods Ltd. generates revenue for associated value-added industries, adding stability and viability to the local community. Indirect economic benefits from tourism and hunting at Frank Lake generate further revenues.

Social and Scientific Benefits

Public interpretation and education opportunities are offered at the marsh and DU personnel have augmented the public school curriculum with guided field trips to the marsh. Other marsh visitors include field naturalists and business leaders from around the world who come to see this Canadian example of cooperative conservation (Anon. 1995). Ducks Unlimited Canada has been awarded the Province of Alberta's Emerald Award for Environmental Excellence at Frank Lake, which is the highest provincial honor awarded.

As part of the adaptive management employed at Frank Lake, scientific studies and monitoring of water quality and wildlife are undertaken regularly. Water chemistry, vegetation, and sediment studies (J. S. White MSc thesis) have quantified the impacts of wastewater on the wetlands and assessed the ability of a northern prairie marsh to treat wastewater in a cold climate. Ongoing research at the marsh includes: bird banding, a breeding bird survey, habitat mapping and surveys of wildlife, vascular plants, amphibians, reptiles, mam-

Table 2. Abundance list of raptor species using Frank Lake in the fifth year after restoration

Raptor species	Abundance[a]
Bald eagle (*Haliaeetus lecucocephalus*)	occasional migrant
Nothern harrier (*Circus cyaneus*)	uncommon summer resident
Sharp-shinned hawk (*Accipiter striatus*)	occasional migrant
Cooper's hawk (*Accipiter cooperii*)	occasional migrant
Merlin (*Falco columbarius*)	uncommon summer visitor
Peregrine falcon (*Falco peregrinus*)	occasional migrant
Short-eared owl (*Asio flammeus*)	occasional summer resident
Turkey vulture (*Cathartes aura*)	scarce vagrant
Swainson's hawk (*Buteo swainsoni*)	uncommon summer visitor
Red-tailed hawk (*Buteo jamaicensis*)	uncommon summer resident
Ferruginous hawk (*Buteo regalis*)	occasional summer visitor
Rough-legged hawk (*Buteo lagopus*)	occasional migrant
Golden eagle (*Aquila chrysaetos*)	occasional migrant
American kestrel (*Falco sparverius*)	occasional migrant/summer visitor
Prairie falcon (*Falco mexicanus*)	occasional fall visitor

[a]Abundance categories from Sadler (1994).

mals, and birds (Sadler personal communication). Results of inventory and monitoring programs and scientific studies are incorporated into ongoing management decisions for Frank Lake.

Development of Frank Lake Project

The benefits of the Frank Lake project presented above were the results of timely project implementation and successful management brought about by cooperative partners and stakeholders. In 1988, Cargill Foods Ltd. required a wastewater disposal site for a proposed beef processing facility. Two nearby rivers were rejected as disposal sites for the secondarily treated wastewater produced by the slaughterhouse, as the disposal of Town of High River municipal wastewater was already causing prolific weed growth and fish kills in the Highwood River (Alberta Environment 1990). However, DU offered to use both Cargill Foods wastewater and municipal wastewater from the Town of High River to restore Frank Lake. Because DU's need for water exceeded the volumes available, additional river water from the Highwood River was added to dilute the nutrient-rich wastewater and accelerate lake restoration (Sadler and others 1995).

DU had managed Frank Lake since the 1940s and had gathered much information on the site including surveys of contours, slopes, soil stability, and water tables. These studies provided background information for the project implementation committee that was instrumental in rapid project implementation, from the initial planning in May 1988 to final approval of all components in October 1988. The primary components in the implementation process were to establish acceptable treatment options and to determine the engineering logistics of water removal from the Highwood River such as the withdrawal location, period, and volume of removal (Table 5).

Goals and Objectives of the Frank Lake Project

Frank Lake managers wanted to institute a project that would maintain the natural habitat variability and manage the full range of species that have historically and recently occurred at the site (Sadler and others 1995). The detailed project goals were broken down into immediate project goals and long-term management goals (Table 6). With the available studies on hydrologic modeling, DU was able to assure stakeholders that the wetland would not flood onto adjacent farmland or cause odor, mosquito, or groundwater contamination problems. Land purchase funds came from diverse public and private sources, including the NAWMP, Alberta Prairie CARE, and DU's Ducks and More programs. With the money secured, the land purchase around Frank Lake [1083 ha (2677 acres)] proceeded quickly, with the lands retired from pasture and cultivation.

Little public review was required in 1988 for this project, and an application for a diversion license from the Highwood River was the only legal requirement. A major concern of local trout fishery groups and farmers was mitigated with an agreement that DU would remove no water from the Highwood River during June or July when trout spawn and when other irrigation requirements are high. No other public processes or environmental impact assessments were necessary for the project. A similar project now would be reviewed by the Natural Resources Conservation Board (NRCB) and would be subject to Canadian Wildlife Service (CWS) rules on migratory and inland waterways.

Management Strategies at Frank Lake

Waterfowl management at Frank Lake focused on mitigating factors that limit waterfowl production, such as the lack of a secure water supply, diverse wetland

Table 3. Shorebird abundance list using Frank Lake in the fifth year following restoration

Shorebird species	Abundance[a]
Yellow rail (*Coturnicops novebroacensis*)	rare vagrant
Virginia rail (*Rallus limicola*)	uncommon summer resident
Sora rail (*Porzana carolina*)	common summer resident
American coot (*Fulica americana*)	abundant summer resident
Sandhill crane (*Grus canadensis*)	occasional migrant
Black-bellied plover (*Pluvialis squatarola*)	common migrant
Lesser golden-plover (*Pluvialis dominica*)	uncommon fall and occasional spring migrant
Pacific golden plover (*Pluvialis fluva*)	rare vagrant
Semipalmated plover (*Charadrius semipalmatus*)	uncommon migrant
Piping plover (*Charadrius melodus*)	summer resident
Black-necked stilt (*Himantopus mexicanus*)	occasional summer resident
American avocet (*Recurvirostra americana*)	uncommon summer resident
Greater yellowlegs (*Tringa melanoleuca*)	uncommon migrant
Lesser yellowlegs (*Tringa flavipes*)	common migrant
Solitary sandpiper (*Tringa solitaria*)	uncommon migrant
Willet (*Catoptrophorus semipalmatus*)	uncommon summer resident
Spotted sandpiper (*Actitis macularia*)	occasional migrant / summer visitor
Whimbrel (*Numenius phaeopus*)	occasional migrant
Hudsonian godwit (*Limosa haemastica*)	occasional migrant
Marbled godwit (*Limosa fedoa*)	common summer resident
Ruddy turnstone (*Arenaria interpres*)	occasional migrant
Red knot (*Calidris canutus*)	occasional migrant
Sanderling (*Calidris alba*)	occasional migrant
Semipalmated sandpiper (*Calidris pusilla*)	common migrant
Western sandpiper (*Calidris mauri*)	occasional migrant
Least sandpiper (*Calidris minutilla*)	uncommon migrant
Red-necked stint (*Calidris ruficollis*)	rare vagrant
White-rumped sandpiper (*Calidris fuscicollis*)	migrant
Baird's sandpiper (*Callidris bairdii*)	common migrant
Pectoral sandpiper (*Calidris melanotos*)	uncommon migrant
Sharp-tailed sandpiper (*Calidris acuminata*)	rare vagrant
Dunlin (*Calidris alpina*)	occasional migrant
Stilt sandpiper (*Calidris himantopus*)	uncommon migrant
Buff-breasted sandpiper (*Tryngites subruficollis*)	occasional migrant
Short-billed dowitcher (*Limnodromus griseus*)	uncommon migrant
Long-billed dowitcher (*Limnodromus scolopaceus*)	common migrant
Common snipe (*Gallinago gallinago*)	uncommon summer resident
Wilson's phalarope (*Phalaropus tricolar*)	common summer resident
Red-necked phalarope (*Phalaropus lobatus*)	common migrant
Red phalarope (*Phalaropus fulicaria*)	occasional migrant

[a]Abundance categories from Sadler (1994).

habitat, and/or the shortage of upland nesting cover. Several upland and water management initiatives were employed to overcome these problems, including reclamation of cultivated lands to native grasses, weed eradication, grazing, backflood irrigation, and drawdowns. Other management strategies following marsh restoration dealt with the management of plant and animal wildlife, sewage water and visitors.

Upland Management Strategies

Properly managed upland habitats are critical for waterfowl production. Up to three times as much properly managed upland area may be required per unit area of wetland to support the wetland inhabitants (Haworth-Brockman and Smallwood 1989). Managers of Frank Lake have reclaimed cultivated lands to create cover for breeding waterfowl, birds, and mammals. Almost 800 ha of upland cover have already been restored to native grasses and shrubs by seeding (Sadler and others 1995). Grassland areas are managed by selective grazing or mowing and fire strategies to encourage growth of prairie species in an effort to mimic the natural system and help control nonnative species (Sadler and others 1995). Burning has not been employed at Frank Lake, but may be used in the future to maintain and restore productive wildlife habitat.

Water Management Techniques

An important wetland restoration technique is to restore water levels and appropriate seasonal depth variations (Jordan and others 1988). A variety of techniques can be employed to manage water levels in wetlands such as the construction of dams and weirs,

Table 4. Species list and abundance of other birds returning to restored Frank Lake wetlands complex five years after restoration

Species	Abundance[a]
Franklin's gull (*Larus pipixcan*)	abundant summer resident
Bonaparte's gull (*Larus philadelphia*)	uncommon migrant
Mew gull (*Larus canus*)	rare vagrant
Ring-billed gull (*Larus delawarensis*)	uncommon summer resident
California gull (*Larus californicus*)	abundance summer resident
Herring gull (*Larus argentatus*)	occasional migrant
Common tern (*Sterna hirundo*)	uncommon summer resident
Forster's tern (*Sterna forsteri*)	uncommon summer resident
Black tern (*Childonias niger*)	uncommon summer resident
Tree swallow (*Tachycineta bicolor*)	uncommon migrant/summer resident
Bank swallow (*Riparia riparia*)	occasional migrant/summer visitor
Cliff swallow (*Hirundo pyrrhonota*)	uncommon migrant/summer visitor
Barn swallow (*Hirundo rustica*)	uncommon summer resident
Sedge wren (*Cistothorus platensis*)	occasional migrant
Marsh wren (*Cistothorus palustris*)	common summer resident
American pipit (*Anthus rubescens*)	uncommon migrant
Yellow warbler (*Dendroica petechia*)	occasional migrant
Palm warbler (*Dendroica palmarum*)	occasional migrant
Northern waterthrush (*Selurus noveboracensis*)	occasional migrant
Common yellowthroat (*Geothlypis trichas*)	uncommon summer resident
American tree sparrow (*Spizella arborea*)	uncommon fall and rare spring migrant
Grasshopper sparrow (*Ammodramus savannarum*)	occasional summer resident
Le Conte's sparrow (*Ammodramus leconteii*)	common summer resident
Sharp-tailed sparrow (*Ammodramus caudacutus*)	uncommon summer resident
Lincoln's sparrow (*Melospiza lincolnii*)	occasional migrant
Swamp sparrow (*Melospiza georgiana*)	occasional migrant
Red-winged blackbird (*Agelalus phoeniceus*)	common summer resident
Yellow-headed blackbird (*Xanthocephalus xanthocephalus*)	abundant summer resident

[a]Abundance categories from Sadler (1994).

backflooding, and the addition of wastewater such as municipal effluent. Water began to flow in the spring of 1989 and by July of 1993, basin 1 had been filled to its normal operating level. The volumes of water piped into Frank Lake were approximately: (1) 910 m^3 (200,000 US gallons) per day of secondarily treated municipal wastewater from the Town of High River, (2) 2275 m^3 (500,000 US gallons) per day of secondarily treated wastewater from the Cargill beef processing plant, and (3) approximately 455 m^3 (100,000 US gallons) per day of water from the Highwood River (Table 7).

Backflood irrigation and drawdowns. Backflooding is a technique that involves flooding an area during the spring, then allowing the collected water to recede at a controlled rate throughout the summer. This procedure attracts several species of breeding birds by providing shallow water and exposed mudflat habitat. An additional 283 ha (700 acres) of marsh is added to the existing basin every spring at Frank Lake with backflood irrigation (Haworth-Brockman and Smallwood 1989). Backflooding is alternated with drawdowns, the intentional lowering of the water level from an area thorough the use of a weir or water-control structure. Gradual drawdowns are used in Frank Lake to expose mudflats to maintain the full range of marsh vegetation and to create feeding habitat for waterbirds, marsh birds, and shorebirds.

Control structures at Frank Lake. Physical modifications of the purchased lands around the Frank Lake marsh (berms, ditches, and dikes) were made to control water levels and maintain productive waterfowl habitat. The original large basin was divided in two by a berm, and as lands were acquired, two smaller basins were created. This design allowed Ducks Unlimited to manage each basin separately based on the different morphology and conditions within each basin. This tactic also allowed DU to focus on restoring the basins sequentially, as water availability permitted.

Management of the four subbasins of Frank Lake. Basin 1 (502 ha) receives all of the sewage and agricultural wastewater as a single point discharge. A persistent zone of poor water quality has been identified in the immediate inflow plume, characterized by high turbidity and high nutrient concentrations (White and Bayley unpublished data). Basin 1 has advanced vegetative development with extensive shallows and lush emergent vegetation, and it provides the highest quality marsh habitat at Frank Lake. Presently, it is managed at a depth of 1.0 m and floods 501.8 ha (1240 acres). This encourages continued growth and development of hemimarsh conditions (50% open water, 50% emergent vegeta-

Table 5. Project implementation schedule for Frank Lake, created by Frank Lake Wetlands Project Implementation Committee in June 1988[a]

Project components	Parties involved	Key components	Implementation schedule
Establish the Frank Lake Implementation Committee	Cargill Foods, Town of High River, M.D. of Foothills, Alberta Environment, Transportation and Utilities, Alberta Fish & Wildlife	Oversee project	June 1988
Evaluate tertiary treatment options	Cargill, town of High River, Alberta Environment, transportation and utilities	Joint vs separate system, sizing, cost sharing, Ownership / operation, Government Approvals	Evaluations (June), predesign / design (July), government approvals (August / September), construction (Fall 1988)
Determine Frank Lake wetland development options and associated water needs	Ducks Unlimited, Alberta Fish and Wildlife, Environment Canada	Existing vs future flows, flooding of deeded land	Surveying (June), options (July), water needs (July), final option (August), design (August / September), government approval (October), construction (1989)
Define acceptable Highwood River withdrawal period	Alberta Environment, Alberta Fish and Wildlife, Ducks Unlimited	Evaluate period, fishery requirements, and withdrawal needs; withdrawal approvals	Define withdrawal window (June), finalize withdrawal period and water needs (July / August)
Evaluate locations for withdrawal of water from Highwood	Alberta Environment, Alberta Fish and Wildlife, Ducks Unlimited, M.D. of Foothills	Fishery requirements, water resource approvals	Preliminary evaluations (June), site selection (August), government approvals (October)
Evaluate pump station, pipeline and discharge options	Entire implementation committee	Pipeline sizing, rights of way / access, discharge location / design, cost sharing, ownership / operating agreement government approvals	Select pipeline size (July / August), pump station location (August), predesign / design (August / September), government approval (October), construction (1988–1989)

[a]This document outlines the parties involved, key components of project development and the implementation schedule. MD = Municipal district.

tion) and can be raised 0.6 m (2 ft) to kill excessive vegetation.

Basin 2 covers 360.2 ha (890 acres) at a depth of about 1 m (3 ft). Basin 2 has much less emergent vegetation than basin 1 because basin 2 was historically too deep for emergent macrophyte growth. Ducks Unlimited has changed the management of basin 2 and now keeps it shallow to encourage emergent vegetation growth. Future management of this basin is to develop and maintain hemimarsh conditions.

Basin 3 lies south of the first two basins and can be flooded to cover 138.8 ha (343 acres). This ephemeral marsh is valuable for staging waterfowl and breeding bird habitat but is too shallow for waterfowl habitat. This basin collects runoff in the spring and slowly drains through July to expose mudflats and shallow flooded areas, and provide habitat for migrant shorebirds. Future management of basin 3 includes seeding with whitetop (spangletop) grass (*Scolochloa festucacea*) to provide habitat for waterfowl and other birds. DU recommends growing whitetop for waterfowl cover in wetlands and as forage for livestock, as whitetop offers superior nutritive qualities and high productivity compared to other native grasses (Neill 1993). This basin is also used to backflood basin 4 that lies northeast of basin 3 at a similar elevation. Basin 4 became available to Ducks Unlimited for management in the summer of 1995. It is a small ephemeral pool (12–16 ha; 30–40 acres) that forms each spring and can be managed as a shallow seasonal wetland suitable for the establishment of whitetop grass.

Other Wildlife Management

Artificial structures around Frank Lake have been built to create habitat for breeding animals. Amphibian scrapes, nesting boxes for burrowing owls and mountain bluebirds, nesting structures such as flax bales and rock islands for Canada geese and nesting waterfowl,

Table 6. Frank Lake wetlands project and management goals

Project goals
1. Provide a sink for secondarily treated sewage from Cargill
2. Create permanent marsh habitat in Frank Lake by providing a reliable source of water to the area
3. Provide a sink for secondarily treated wastewater from the Town of High River
4. Cease wastewater inputs into the Highwood River to improve water quality
5. Maintain the trout fishery in the Highwood River

Management goals
1. Maintain and increase the existing vegetation and wildlife in the marsh
2. Stimulate the growth of new vegetation for habitat
3. Provide additional habitat (i.e. nesting sites) for waterfowl and other birds
4. Provide additional habitat (i.e. nesting sites) for other wildlife
5. Restore the biodiversity of upland vegetation and wildlife
6. Treat the nutrients from the wastewater as waters flow through the marsh
7. Maintain the marsh as a hemi-marsh over a long time period
8. Create a wildlife conservation area for public enjoyment and education

Table 7. Typical flow volumes (cubic meters) to Frank Lake[a]

	Area (ha)	Depth (m)	Cargill waste-water	Municipal waste-water	Highwood River - water	Total
Basin 1	502	1.0	850,124	719,612	1,076,216	2,645,952
Basin 2	360	1.0	N/A	N/A	N/A	N/A
Basin 3	139	0.3	N/A	N/A	N/A	N/A

[a]The amount of water removed from the Highwood River in the spring for dilution was determined by Alberta Environment and varied yearly from 1990 to 1994. At the time of writing, no water from the Highwood River had been pumped into Frank Lake since the summer of 1994.

nesting platforms for hawks, and rock piles for garter snakes have been constructed (Sadler and others 1995, Alberta NAWMP Centre 1992). The success of the nesting structures is reflected in the large number of immature birds banded at Frank Lake from 1993 to 1996 (Table 8).

Wastewater Treatment

At the time of marsh restoration, little was known about the short-term or long-term capacity of a prairie marsh to provide sewage treatment, and marsh manag-

Table 8. Bird banding count[a] data and percentage immature birds (in parentheses) 1993–1996 for restored Frank Lake wetlands complex[b]

Species	1993	1994	1995	1996
Mallard	1344 (35)	1393 (21)	2002 (10)	1834 (24)
Black duck	1 (0)	0 (0)	0 (0)	0 (NR)[c]
Gadwall	55 (80)	32 (38)	13 (38)	76 (NR)
American wigeon	86 (76)	6 (17)	1 (0)	28 (NR)
Green-winged teal	56 (86)	281 (57)	27 (48)	34 (NR)
Blue-winged teal	2340 (40)	1700 (47)	736 (29)	1413 (NR)
Cinnamon teal	17 (18)	17 (24)	19 (37)	9 (NR)
Shoveler	4 (100)	2 (100)	1 (0)	37 (NR)
Pintail	504 (60)	617 (31)	114 (27)	296 (NR)
Redhead	153 (20)	241 (75)	49 (69)	192 (68)
Canvasback	9 (78)	1 (100)	2 (0)	9 (NR)
Lesser scaup	7 (71)	0 (0)	1 (100)	10 (NR)
Ring-necked duck	2 (0)	0 (0)	0 (0)	0 (NR)
Ruddy duck	2 (0)	2 (0)	0 (0)	8 (NR)
American coot	185 (NR)	520 (NR)	33 (NR)	288 (NR)

[a]Data from Environmental Conservation Branch, Canadian Wildlife Service, Prairie and Northern Region, Edmonton, Alberta.

[b]Numbers do not reflect true figures of relative abundance due to trapping methods used and differential capture rates. However, the percentage of immature birds present is an important indicator of local production.

[c]NR = no record of data.

ers assumed that Highwood River water dilution would ensure that wastewater would not threaten the integrity of the Frank Lake ecosystem. The only physical modification made within the marsh was a deep channel dug from the inflow canal to the outflow of basin 1 to keep basin 1 dry during construction. Unfortunately, this ditch short-circuits water flow through basin 1. Despite the short-circuiting of marsh water, preliminary findings of nutrient treatment by the marsh showed total phosphorus retention of 64% and NH_3 retention of 87% during 1994–1995 (White and Bayley unpublished). During the summer period, over 90% of the phosphorus and nitrogen put into the marsh were removed in basin 1. Approximately 79,662 kg of phosphorus has accumulated in Frank Lake sediments from the total 1990–1995 input load of 141,760 kg (White and others unpublished). Basin 1 sediments have retained 51% and basin 2 sediments have retained 6% of the total point source P load that has been added to Frank Lake from 1990 to 1995. In the areas receiving the greatest nutrient loading (near the inflow pipe), approximately 38.5 g P/m^2/yr (105.4 mg P/m^2/day) have been deposited, with 24 g P/m^2/yr (65.7 mg P/m^2/day) elsewhere in basin 1, and 0.43 g

P/m^2/yr accumulated in basin 2 since 1990 (J. S. White MSc thesis).

Visitor Management

The goal of visitor management is to promote use of the site with self-guided tours and to provide enjoyment and education for visitors while maintaining the integrity and productivity of the area. Controlled and planned access to Frank Lake separates visitors from wildlife activities both spatially and temporally. Management and recreation activities, such as hunting and bird-watching are minimized at Frank Lake during critical periods to reduce impacts on wildlife, and trail creation has been curbed in sensitive and productive areas. For example, DU restricts management such as hay cutting until 15 July each year to reduce the effects on nesting waterfowl. Similar time constraints are placed on other management activities such as grazing and burning.

Future Concerns

While the marsh presently treats wastewater adequately, there is some debate about the long-term ability of the marsh to continue providing wastewater treatment. High nutrient loadings could lead to eutrophication of the system and change the species composition of the marsh. High phosphorus loadings could saturate the sediments with phosphorus and result in poor phosphorus treatment. Poor treatment in the marsh could result in seasonal phosphorus export from the marsh and downstream leakage of nutrient rich water into the Little Bow River. Flooding of some surrounding lands, groundwater recharge by nutrient rich water (especially near the inflow canal) and bioaccumulation of metals may be a concern in the future and should be addressed by future management.

Implementing Wetland Restoration Projects

The social desire for ecological restoration in the United States is reflected in numerous regulations such as NEPA and Section 404 of the Clean Water Act. These regulations contain provisions for mitigation, rehabilitation, enhancement, and restoration of natural wetland systems (Tripp and Herz 1988). Canada has few statutes to protect wetlands, and without legislation, Canadians rely heavily on resource management agencies and private landowners for ecological restoration of wetlands. Unfortunately, many private landowners and resource management agencies suffer from a lack of technical expertise to support wetland management and protection (Jones and others 1995). As Canadian wetlands become degraded, wetland restoration efforts become increasingly important as is information on successful wetland restoration techniques (Davis 1994). The success of the Frank Lake project and the speed at which the marsh was restored are testimony that the techniques used at Frank Lake can be used on other restoration projects.

To ensure the success of large-scale environmental projects, two conditions must be met. The project must be ecologically feasible given local constraints, and it must be socially desirable given local values (Wyant and others 1995). The cooperation of dozens of individuals at several levels of organization was instrumental in making the Frank Lake project ecologically feasible and socially desirable. Their actions assured that implementation, permitting, and orchestration of the project was executed in a very small time frame. Most DU projects take at least three years of preparation, with larger projects taking more than 10 years to complete. The Frank Lake project was DU's largest in Canada and was instituted in less than one year.

Leadership provided by a large nongovernmental organization was an important factor contributing to the success of the Frank Lake project. DU played a key role in the quick development of the project with their background information and experience in prairie wetland restoration. By assuming future marsh stewardship responsibilities, DU left stakeholders with no further obligations after project completion, so stakeholders had no long-term commitment but were ensured that management and ongoing environmental monitoring would continue to address their interests.

While the political will behind the Frank Lake project was a major factor in the speed of project implementation, several other factors helped to secure stakeholders' interests. The short-term and long-term benefits for this project were shown to the landowners, stakeholders, and community in general, which secured their enthusiasm and support for the project. Development strategies that alleviated concerns from opposing interests also ensured the success of this project. The combined benefits of job creation and establishment of an environmentally sound product has produced one of the best examples of cooperative conservation and sustainable development in Alberta. For the Highwood River, the benefits were twofold: the sewage wastewater from the Town of High River was removed from the watercourse and it was spared additional nutrient loadings.

Components of Successful Wetland Projects

The Frank Lake project provides a decision-making framework that can be used to institute other large-scale wetland rehabilitation projects. Some projects fail due to poor planning or the omission of key stakeholder or landowner involvement, but these pitfalls were avoided in the Frank Lake project by employing flexibility in the implementation phase (Wyant and others 1995). Specifically, marsh managers advocated policies that promoted the development of shared understanding among the diverse range of stakeholders, an approach that McLain and Lee (1996) found to be essential for successful projects. Wyant and others (1995) stressed that the goals of restoration must have a meaning to society. The following five steps can help resource managers to succeed at implementing large scale wetland management projects:

1. Stakeholder identification. The support of these groups is an important variable to ensure project completion. Stakeholders include local residents, employees, consumptive and nonconsumptive recreational users, landowners, environmental groups, businesses, and industries that depend on local natural resources. Resource managers must consult these project partners to understand their opinions and concerns (Haney and Power 1996). Educated stakeholders will have greater understanding and enlightened opinions and attitudes towards the project and will usually be more supportive.

2. Clear, well-defined goals. The project goals and objectives, benefits, and possible negative impacts should be effectively communicated to the stakeholders and other partners. Goals and objectives should reflect information gathered during exchanges with stakeholders such as the environmental, socioeconomic, and cultural considerations (Haney and Power 1996). Haney and Power (1996) feel that these goals and objectives must be communicated in writing so that the stakeholders will have a common understanding of the issues and underlying assumptions. Uncertainty and complexity can frustrate both science and management (Haney and Boyce 1996).

3. Anticipation. Clearly understanding stakeholder concerns is essential to effectively minimize or mitigate any negative effects. Working as closely as possible with these groups is important to understanding their concerns. In most instances consensus building can lead to a compromise. Hilborn and Walters (1977) found that forcing both managers and stakeholders to quantify their objectives was useful in identifying conflicting objectives. An ongoing part of the adaptive management process is risk abatement, and the abatement of risk has been found to be an indicator of restoration success (Wyant and others 1995).

4. Resourceful stakeholders (in projects where capital is required). Participation of an organization with funds for land purchase is an essential partner in a wetland restoration project. The ideal partner has links to programs and funding agencies that permit the land purchase required for successful restoration.

5. Environmental monitoring and adaptive management. The participation of an experienced organization to provide site management is essential following project completion. Restoration projects undertaken for environmental and economic reasons may require frequent adjustments in management after implementation to maintain a viable, healthy ecosystem (Wyant and others 1995). It has been suggested that adaptive management of a site should involve site monitoring relative to project objectives, analysis of the monitoring data to determine the effectiveness of specific restoration techniques, and incorporation of experimental results in further site manipulation. We further recommend that long-term management be delegated to a reputable management partner.

Conclusions

The Frank Lake project can serve as a model to guide managers of other large-scale wetland projects because the project was successful in reaching all mandated goals. Project and management goals were quickly met and the dual mandate of wildlife production and wastewater treatment was satisfied. The partner's state of readiness and stakeholder support insured quick project development. Within five years of wastewater addition to the marsh, over 130 bird species had been reintroduced, several other species of flora and fauna had reestablished, and the marsh had demonstrated a significant capacity for wastewater nutrient reduction. Not only had marsh disposal of wastewater created much needed waterfowl habitat in southern Alberta, but it had provided an environmentally friendly alternative to river discharging of wastewaters.

The process of Frank Lake marsh reestablishment is a model of cooperative conservation for a project with dual mandates and serves as an example of adaptive management in southern Alberta. Implementation of large-scale wetland restoration projects generally involves the cooperation of several agencies and proper communication of the agencies with stakeholders, landowners, and the local community. When the benefits of the project and the mitigation of negative impacts can be demonstrated, then the project development sequence can be hastened. Because the benefits of the Frank Lake project were demonstrated to participants and the project managers were shown to mitigate any negative impacts, the project proceeded rapidly.

Acknowledgments

We extend thanks to Ducks Unlimited Canada, NAWMP, CAESA, and NSERC for funding and to Tom Sadler and Gary Stewart of Ducks Unlimited Canada for providing comments. We also gratefully acknowledge the technical assistance of Jane Horb, Gary Larsen, and Jim Wohl at the Ducks Unlimited office in Edmonton; Debra Paton at Cargill Foods in High River; and Mark Rigby and Shannon Keehn at the University of Alberta.

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