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Bosworth Creek (NWT) Literature Review

by

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EXECUTIVE SUMMARY

Bosworth Creek originates at Hodgson (Jackfish) Lake (Latitude 65° 18′ N Longitude 126° 41′ W), Tulita District, Sahtu Settlement Area and parallels the base of Discovery Ridge before changing course to the southeast and joining the Mackenzie River (Latitude 65° 16′ N Longitude 126° 51′ W) within the municipal boundaries of the Town of Norman Wells. Bosworth Creek has played an important role in local history. Natural flow was impeded with the construction of a weir in 1960 approximately 250 metres from its confluence with the Mackenzie River. The pond created behind this weir supplied the oil refinery with water for stream driven electricity and drinking water for the Town of Norman Wells. The town abandoned this water source in 1991 and closure of the refinery in 1996 prompted channel flow reclamation as recommended by the Government of the Northwest Territories (GNWT). The weir was removed and natural flow restored in 2005 under Imperial Oil Resources NWT Limited's Reclamation and Restoration Plan (SRRB 2008).

The Bosworth Creek Monitoring Project (BCMP) was developed following concerns raised by local residents regarding the absence of Whitefish and other aquatic species. The general question was "Now that the barrier has been removed, will these animals re-inhabit the stream on their own or should they be re-introduced?"

The Sahtu Renewable Resources Board contacted the Department of Fisheries and Oceans regarding this question and possible mitigation. Since the barrier no longer exists, it was decided that re-stocking the creek was unnecessary and that natural introductions should occur following stream reorganization.

The recent restoration of Bosworth Creek presented a unique opportunity for local youth to monitor aquatic ecosystem health. A creek monitoring project enables students to learn about local fish, invertebrates, hydrodynamics, sedimentology, streambed morphology, sampling techniques, data collection and evaluation. Therefore, a primary goal of the BCMP is to provide an avenue for Mackenzie Mountain School students to learn a wide range of scientific applications and report their findings to the scientific community through public presentations and publications. Publishing original articles in science journals and working in cooperation with government and industry will give these students significant advantages over other candidates when they apply for post-secondary education.

RÉSUMÉ

Le ruisseau Bosworth prend naissance dans le lac Hodgson (Jackfish) – 65° 18′ de latitude N. et 126° 41′ de longitude O., district de Tulita, région désignée de Sahtu – et coule parallèlement au pied du col Discovery. Il bifurque vers le sud-est et plonge dans le fleuve Mackenzie – 65° 16′ de latitude N. et 126° 51′ de longitude O. – à l'intérieur des limites de la ville de Norman Wells. Le ruisseau Bosworth a occupé une place importante dans la petite histoire de cette localité. La construction d'un déversoir, en 1960, à environ 250 mètres de son point de confluence avec le fleuve Mackenzie, a créé un obstacle à son débit naturel. Le bassin de retenue permettait de produire de l'hydro-électricité pour la raffinerie de pétrole et d'alimenter Norman Wells en eau potable. La ville a abandonné cette source d'eau potable en 1991 et, en 1996, après la fermeture de la raffinerie, l'écoulement en chenal a été redirigé tel que recommandé par le gouvernement des Territoires du Nord-Ouest (GTNO). Le déversoir a été enlevé, et l'écoulement naturel rétabli, en 2005, suivant le plan de remise en état d'Imperial Oil Resources NWT Limited (SRRB 2008).

Le projet de surveillance du ruisseau Bosworth (PSRB) a été élaboré après que des résidents eurent manifesté des préoccupations au sujet de l'absence de ménominis et d'autres espèces aquatiques. On se demandait généralement si ces espèces reviendraient d'elles-mêmes dans le ruisseau après l'enlèvement du déversoir ou s'il faudrait le repeupler.

Le Sahtu Renewable Resources Board (office des ressources renouvelables du Sahtu) a communiqué avec le ministère des Pêches et des Océans à ce sujet et pour discuter des mesures d'atténuation possibles. Étant donné que le déversoir n'existe plus, il a été décidé que le repeuplement du ruisseau n'était pas nécessaire parce qu'il se produirait naturellement une fois l'écoulement naturel rétabli.

La restauration récente du ruisseau Bosworth a été une occasion unique pour la jeunesse locale d'étudier la santé de l'écosystème aquatique. Un projet de surveillance d'un ruisseau permet aux étudiants d'en savoir davantage sur les poissons, les invertébrés, l'hydrodynamique, la sédimentologie, la morphologie du lit d'un cours d'eau, les techniques d'échantillonnage ainsi que la collecte et l'évaluation de données. Un des buts premiers du projet de surveillance du ruisseau Bosworth est de permettre aux élèves de l'école Mackenzie Mountain de connaître une grande variété d'applications scientifiques et de faire connaître les résultats de leurs recherches à la communauté scientifique par le biais de présentations et de mémoires. Publier des articles inédits dans une revue scientifique et collaborer avec le gouvernement et le secteur privé procurera à ces élèves des avantages considérables par rapport aux autres candidats au moment d'entreprendre de leurs études postsecondaires.

1.0 INTRODUCTION

1.1 OBJECTIVES

The SRRB contracted SENES Consultants Ltd. to investigate work related to Bosworth Creek, comprising three main tasks:

- conduct a literature review of the existing information collected on Bosworth Creek,
- produce a summary report on the current status of reclamation and mitigation measures, identifying lessons learned and possible next steps, and
- facilitate a traditional knowledge focus session and to produce a report on the session outcome.

The present document covers the first two tasks. Task 3 was conducted and reported on separately.

1.2 STUDY APPROACH

The information presented in this report was gathered primarily from reports prepared by the SRRB relating to ongoing monitoring at Bosworth Creek and other documentation, literature related to the proposed Mackenzie Gas Project, discussions and correspondence with staff from the Department of Fisheries and Oceans Canada (DFO), some independent contractors and Imperial Oil.

1.3 REPORT FORMAT

Despite the relative lack of substantive and directly relevant information about Bosworth Creek, this report compiles what was found and presents in the following sections:

- Introduction
- Overview of Aquatic Environment
- Cumulative Effects of Oil and Gas Activity
- Lessons Learned
- Recommendations

1.4 REFERENCES

SRRB 2008. Bosworth Creek Monitoring Project. Project Summary prepared for NWT Cumulative Impact Monitoring Program: Capacity Building & Monitoring Projects 2007-2008. March 31 2008.

2.0 OVERVIEW OF AQUATIC ENVIRONMENT

2.1 BACKGROUND

The SRRB contacted DFO about whether whitefish and other species would return following removal of the weir, either naturally or be re-introduced (Guthrie 2007). It was decided that re-stocking of the creek was unnecessary and that changes in the biotic community should progress naturally. Consequently, the Bosworth Creek Monitoring Project was established and provided a unique opportunity to track the effectiveness of reclamation plans and mitigation measures in a northern ecosystem. Education is the underlying principle of this program. Using the results of the monitoring project and other available information, this section summarizes water chemistry, benthic invertebrates, fishes and parasites, and streambed morphology of Bosworth Creek.

2.2 MONITORING PROGRAM

2.2.1 WATER CHEMISTRY

There appears to be only limited information on Bosworth Creek prior to dismantling of the weir. In 1997, some preliminary water chemistry sampling was done on nine streams including Bosworth Creek as part of a winter road stream survey in the Norman Wells area during July to September (Low et al. 1997). Sampling at Bosworth Creek was conducted on June 12 and 20 and involved measurements of water and air temperature, dissolved oxygen, pH, and minimum and maximum flows. Water velocities varied from 0.55 to 0.88 m/s, pH averaged 8.3, and dissolved oxygen averaged 6.2 mg/L. Although air temperature was similar (24-25 0C), water temperatures varied significantly from 11 0C (June 11) to 200C June 20). Still, this information is rather limited.

Some water chemistry data from several dates and locations on Bosworth Creek in 1972 and 1973 were located (McCart et al.1974, Shotton 1973). Much of the data was limited to water temperature, conductivity, pH and dissolved oxygen measurements, however, analyte data was also collected for two of the samples (Table 2.2.1). One flow measurement of 0.32 m/s was taken in September 1972. Comparisons between the data are difficult to make as they were all taken at different times and mostly different locations.

TABLE 2.2.1

WATER CHEMISTRY DATA FROM BOSWORTH CREEK, 1972-73

Date	**5/9/1972**	**5/10/1972**	**12/11/1972**	**13/04/73**	**5/6/1973**	**5/6/1973**	**4/10/1973**
Location			**b**	**a**	**c**	**b**	**a**
Water Temperature (°C)			2.0	1.0	17.0	10.0	4.0
Air Temperature (°C)	2.4						
Conductivity, (μmhos/cm)			1150	650	590	605	580
pH	8.56	8.6	7.6	8.3	8.1	7.8	8.2
Flow (m/s)	0.32						
Dissolved oxygen (mg/L)	12.68	12.6	6.0	10.2	8.6	10.0	
CO2 (mg/L)	0.016						
Ca (mg/L)			124.0		140.0		
Mg (mg/L)			39.5		34.0		
Na (mg/L)			46.0		37.0		
K (mg/L)			1.6		37.0		
Fe (mg/L)			<0.05		P		
Mn (mg/L)			<0.008				
HCO3 (mg/L)	0.329	0.329	241.6		242		
SO4 (mg/L)			305.0		304		
Cl (mg/L)			45.4		69		
NO3 (mg/L)			0.2				
SiO2 (mg/L)			4.7				
Susp. Solids (ppm)	11						
Diss. Solids (ppm)	467						
P - present							

*Source: McCart et al. 1974, Shotton 1973

Water chemistry collection and analysis is continuing through a comprehensive program which is facilitated by the SRRB, and provides students from Mackenzie Mountain School with opportunities to undertake research and contribute to science. The Bosworth Creek Monitoring Project began sampling in 2006 and includes in-situ water chemistry measurements as well as collections for analyses by Taiga Environmental Laboratories and ALS Environmental Laboratories (Guthrie 2006 and 2007). Analyses include routine, nutrients, chlorophyll "A", sulfide, microbial, BTEX in water, hydrocarbons in water, metals in water, BTEX in soil, hydrocarbons in soil, and metals in soil. These samples have been collected throughout the creek system to acquire baseline data. Some sampling occurred at areas of concern (either due to climate change or human disturbance) and several locations were bi-annually sampled that now provide temporal chemistry logs. In-situ measurements were taken using professional equipment and measurements include dissolved oxygen, pH (soil and water), water flow and water temperature. Ground water was also investigated since Bosworth Creek is supplied throughout winter by numerous springs. However, new sources of groundwater that are higher in certain heavy metals are also being investigated and include sources from springs in the summers and discoloured overflow ice in the winters.

2.2.2 BENTHIC INVERTEBRATE SAMPLING

Benthic invertebrates are the most important component of an aquatic ecosystem as they support subsistence fish populations that feed on them. Benthic macroinvertebrate sampling and analysis has taken place throughout the Bosworth Creek Monitoring Project (Guthrie 2007). Preliminary analysis has identified 31 Families including Aeshnidae (Darner Dragonflies), Baetidae (Small Minnow Mayflies), Brachycentridae (Humpless Case Maker Caddisflies), Chloroperlidae (Green Stoneflies), Chironomidae (Non-Biting Midges), Corduliidae (Emerald Dragonflies), Corixidae (water boatmen), Coenagrionidae (Narrowwinged Damselflies), Dytiscidae (Predaceous Diving Beetles), Ephemerellidae (Spiny Crawler Mayflies), Heptageniidae (Flatheaded Mayflies), Hydrocarnia (Water Mites), Hydroptilidae (Microcaddisflies), Hydropsychidae (Common Netspinner Caddisflies), Leptoceridae (Longhorned Case Maker Caddisflies), Leptophlebiidae (Pronggilled Mayflies), Lestidae (Spreadwinged Damselflies), Limnephilidae (Northern Case Maker Caddisflies), Nemouridae (Nemourid Stoneflies), Notonectidae (Backswimmers), Perlidae (Common Stoneflies), Perlodidae (Perlodid Stoneflies), Phryganeidae (Giant Case Maker Caddisflies), Ptychopteridae (Phantom Crane Flies), Rhyacophilidae (Freeliving Caddisflies), Simuliidae (Black Flies), Siphlonouridae (Primitive Minnow Mayflies), Pteronarcyidae (Giant Stoneflies), Tabanidae (Horse Flies, Deer Flies), Tanyderidae (Primitive Crane Flies), and Tipulidae (Crane Flies). Further refinement to genus/species levels is currently underway by a macroinvertebrate consultant (Guthrie pers comm. 2009).

McCart et al. (1974) report the results of a benthic study on Bosworth Creek using a Surber sampler. Nine major groups were identified of which Chironomidae were the most abundant, followed by Plecoptera, and Empididae and Oligochaeta. Results are summarised in Table 2.2.2. However, this information is extremely limited and does not provide a realistic benthic macroinvertebrate inventory of Bosworth Creek.

TABLE 2.2.2

AVERAGE BENTHIC INVERTEBRATES COLLECTED BY SURBER SAMPLER FROM BOSWORTH CREEK, AUGUST 11, 1973

Taxa	Mean/ft²*	Standard Error	Mean/m²
Tricoptera	0.7	0.45	0.07
Plecoptera	9.5	4.56	0.88
Ephemeroptera	1.3	0.73	0.12
Diptera			
Simuliidae	0.2	0.15	0.02
Chironomidae	16.7	7.83	1.55
Empididae	4.8	2.65	0.45
Muscidae	0.2	0.15	0.02
Ceratopogonidae	0.2	0.15	0.02
Oligochaeta	4.8	2.15	0.45
Miscellaneous	0.2	0.15	0.02
Total	38.5	12.32	3.58

*Average of 6 samples

2.2.3 FISH SAMPLING AND PARASITES

The Mackenzie River supports 34 known species of freshwater and/or anadromous fish which exhibit primarily riverine life histories as part of a larger dynamic ecosystem. The river itself is used for spawning as well as access to spawning sites that include Bosworth Creek. Eleven species are important in the area for subsistence and sports fisheries. These include Arctic Grayling, Bull Trout, Dolly Varden, Arctic Cisco, Least Cisco, Walleye, Broad Whitefish, Lake Whitefish, Inconnu and Round Whitefish and Burbot (Stein et al. 1973).

In the 1970's, several studies were conducted on the tributaries of the Mackenzie River that would potentially be affected by the Mackenzie Gas Pipeline, three of which include data on Bosworth Creek. In 1971, seine hauls were conducted at the mouth of Bosworth Creek and collected eight species of fish (Hatfield et al. 1972). Between July and September in 1972, fish were collected from tributaries along the potential pipeline route (Shotton 1973). Fish in Bosworth Creek were collected using a 10 ft seine which yielded 38 Arctic Grayling (Thymallus arcticus), 3 Lake Chub (Couesius plumbeus) and 1 Slimy Sculpin (Cottus cognatus). Fish lengths and weights were collected for all species and the sex of the arctic grayling was determined (Table 2.2.3). The majority of the Arctic Grayling were immature. Finally, a 1974 report (McCart et al. 1974) summarised fish species in Bosworth Creek from a couple of early 1970's studies. In total, twelve species were identified in Bosworth Creek in the early 1970's (Table 2.2.4).

TABLE 2.2.3

FISH COLLECTED BY 10-FT SEINE IN BOSWORTH CREEK, 1972

		Length				Weight						
Scientific Name	Common Name	n	Mean	SD	Min	Max	Mean	SD	Min	Max	Male	Female	Immature
Thymallus arcticus	Arctic Grayling	38	16.8	6.49	9.3	29.3	56.2	69.85	8.5	226.6	11	7	20
Couesius plumbeus	Lake Chub	3	4.8	0.32	4.6	5.2	1.2	0.26	1.0	1.5			
Cottus cognatus	Slimy Sculpin	1	5	na	na	na	1.2	na	na	na			

TABLE 2.2.4

FISH SPECIES COLLECTED IN BOSWORTH CREEK, EARLY 1970'S

Scientific Name	Common Name	Fry	Other
Thymallus arcticus	Arctic Grayling	x	x
Lota lota	Burbot		x
Platygobio gracilis	Flathead Chub		x
Stenodus leucichthys	Inconnu		x
Couesius plumbeus	Lake Chub		x
Coregonus clupeaformis	Lake Whitefish		x
Rhinichthys cataractae	Longnose Dace		x
Catostomus catostomus	Longnose Sucker	x	x
Pungitius pungitius	Ninespine Stickleback		x
Esox lucius	Northern Pike		x
Cottus cognatus	Slimy Sculpin		x
Percopsis omiscomaycus	Trout-perch		x

Source: McCart et al. 1974, Shotton 1973, Hatfield et al. 1972

In 1997, a preliminary fish survey was undertaken on nine streams including Bosworth Creek as part of a winter road stream survey in the Norman Wells area (Low et al.1997). Fish were collected by a variety of methods including gillnets, seines, minnow traps, Surber samplers and an electro-shocker. However, fishing was restricted to two sampling events in June, and it is expected that species utilizing the stream (Bosworth and others) during other times of the year were likely missed. Six species of fish collected included Burbot (Lota lota), Longnose Sucker (Catostomus catostomus), Emerald Shiner (Notropsis antherinoides), sucker sp., Slimy Sculpin (Cottus cognatus), and fry sp. A summary report of 1996 reported that Jackfish Lake on Bosworth Creek (65°18'N, 126°39'W) was a popular Northern Pike (Esox lucius) fishing recreation area for local residents and Burbot (Lota lota) was harvested from the creek for subsistence during fall and winter (Stewart 1996).

A comprehensive study on fish species present in the Sahtu Settlement Area was conducted in 2006 as part of stream surveys associated with the proposed Mackenzie Gas Pipeline (Mochnacz and Reist 2007). Stream surveys were conducted in selected reaches of 15 streams in the Sahtu Settlement Area but did not include Bosworth Creek. Field work was conducted from July 25-30, as well as from August 28th to September 3rd. A total of 908 fish representing nine different species were captured. Slimy Sculpin (Cottus cognatus) was the dominant species comprising 67.5% of the total catch followed by Arctic Grayling (Thymallus arcticus) (27.5%), Lake Chub (Couesius plumbeus) (2.1%) and Bulltrout (Salvelinus conflentus) (1.0%). Other species such as Brook Stickleback (Culaea inconstans), Dolly Varden (Salvelinus malma), Northern Pike (Esox lucius), Mountain Whitefish (Prosopium williamsoni) and White Sucker (Catostomus commersoni) accounted for only 0.6% of the catch. Arctic Grayling was the most widespread species and was found in most streams studied.

Recent fish sampling is occurring through the Bosworth Creek Monitoring Project and includes sampling activities between July and September using minnow traps and seine nets. Seven species have been identified and are consistent with those reported earlier by Low et al. 1997. They include included Lake Chub, Slimy Sculpin, Ninespine Stickleback (Pungitius pungitius), Arctic Grayling, Longnose Sucker, Northern Pike, and Emerald Shiners.

Fish health is also part of the Bosworth Creek Monitoring Project that includes an assessment of both internal and external parasites. For example, the tapeworm Triaenophorus (based on Stewart and Bernier 1999) was indentified in several slimy sculpin. An external tumour-like growth was also observed on another sculpin, as well as fungus on ninespine sticklebacks and occasional bulbous-eyed grayling fry. Studies will continue on monitoring fish health and the potential impacts on human health will be assessed throughout the project.

In March and April of 2000, the Bandy Lake study looked at metal concentrations in fish tissue of Cisco, Northern Pike, Burbot and Lake Trout (Stewart et al. 2003). Fish were collected using single mesh, bottom set gillnets, which were 91.4m long and 3.66 m deep. Three mesh sizes of 89, 114 and 140 mm (stretched measure) were used. Mercury, arsenic, and selenium concentrations were examined for Cisco and Northern Pike, while mercury alone was examined for Burbot and Lake Trout. The results are summarized in Table 2.2.5.

TABLE 2.2.5

SUMMARY OF TOTAL METAL CONCENTRATIONS IN FISH FLESH IN BANDY LAKE - MARCH AND APRIL 2000

Species	n	Total Metal Concentration in Flesh (ug/g wet wt)					
		As		Hg		Se	
		Mean	SD	Mean	SD	Mean	SD
Cisco	19	0.04	0.02	0.23	0.15	0.25	0.04
Northern Pike	22	0.09	0.15	0.32	0.19	0.25	0.04
Burbot	6			0.13	0.04		
Lake Trout	54			0.21	0.08		

In summary, there appears to be limited information on the Bosworth Creek fisheries prior to weir removal. To date, Whitefish have not been observed in Bosworth Creek.

2.2.4 STREAM MORPHOLOGY AND HABITAT ASSESSMENT

A fish habitat study was undertaken in the Sahtu Settlement Area by DFO in 2006 to acquire baseline information on stream crossings associated with the proposed Mackenzie Gas Pipeline Project (Mochnacz and Reist 2007). Stream surveys were conducted in selected reaches of 15 streams in the Sahtu Settlement Area but did not include Bosworth Creek. Habitat information was collected on 7 of the 15 streams. These data were quantified at both macro-habitat and micro-habitat levels. Macro-habitat represents general physical features such as depth, velocity, substrate and wetted width of a stream. In contrast, micro-habitat represents the physical features of the stream at specific positions where fish are captured. Mean water depth for the 7 streams ranged from 7.1 to 42.5 cm and water velocities ranged from 0.04 to 0.34 m/s. Mean water temperatures during July and August averages over all streams ranged between 6.7 and 16.6 0C. Classifications of substrate types were done by size, and included boulders, cobbles, pebbles, gravel, sands and silts. Cobbles (64-255 mm) and pebbles (16-63 mm) were the dominant substrate types found.

McCart et al. (1974) reported a minor spawning and rearing area for arctic grayling and suckers at the mouth of Bosworth Creek and surmised the creek provided summer feeding habitat for the fish present. The creek has flowing water year-round and provides a probable over-wintering habitat. During the winter Bosworth Creek had a water depth of 0.32 m, discharge rate of 1.01 m3/s, temperature of 1.0 °C and dissolved oxygen of 10.2 mg/L.

McCart et al. (1974) described Bosworth Creek as having gravel and cobble substrate and stable banks. Shotton (1973) reported the results of a sediment analysis of Bosworth Creek from September of 1972 (Table 2.2.6). Sediment was dominated by larger sized particles (26.26 mm and 13.33 mm) with particles of 0.417 mm and 0.833 mm also composing a sizable fraction of the sample (27%).

TABLE 2.2.6

BOSWORTH CREEK SEDIMENT ANALYSIS, SEPTEMBER 5, 1972

Particle Size	% Composition
26.26 mm	30.2
13.33 mm	10.6
6.68 mm	8.4
3.33 mm	9.3
1.65 mm	8.1
0.833 mm	15.7
0.417 mm	11.5
0.208 mm	2.1
0.104 mm	1.5
Silt	2.6

*Shotton 1972

The Bosworth Creek Monitoring Project is recording the morphological changes to a 360 square metre area of creek substrate over time that is impacted by ice and all terrain vehicles (ATVs). Some local residents are driving their ATVs up and down the length of the creek (Guthrie 2006, 2007). While ATV crossings typically limit damage to the creek at localized areas, in-stream driving causes damage to downstream fish spawning habitats and increases erosion of the banks by re-directing water flow through tire-induced channel alteration.

Weir Removal and Fish Habitat Assessment

Dismantling of the weir was initiated in the fall of 2004 and completed in 2005. Following removal, a project was initiated to re-contour the bed and banks of Bosworth Creek to allow fish (specifically arctic grayling) access to traditional spawning areas upstream of the lower Bosworth bridge (Imperial Oil Resources 2005). An engineering design was developed to facilitate fish movement by re-contouring the creek bed to a slope of approximately 3o. This 3o grade represented a lower-angled creek-bed than the historic grade based on earlier engineering diagrams (Imperial Oil 2005). Hydraulic analysis of the rehabilitated stream was conducted to determine the capacity of the creek and the flow velocities during high flow. Flow velocity below the bridge was calculated to be on the order of 2.3 m/s. Flow velocities in the pool area ranged from approximately 2.6 to 2.8 m/s depending on proximity to rocky outcrops. Flow velocities in these areas were approximately 3.1 m/s. Further details of the water management techniques, design modifications, construction work, final survey and hydraulic analysis are given in Komex 2005. At the request of DFO, Streamworks Unlimited was asked to provide advice on the channel and bank stabilization with respect to long term fish habitat and passage (Bates 2005). There were some initial concerns such as the placement of large boulders at 5-m spacing along each bank as potential resting places for fish. It was felt that these boulders may not be adequate at higher flow conditions for fish spawning. Modifications were suggested to the earlier surface design, and included the construction of three riffles and pools along the channel which would improve stability by dissipating energy, and provide areas for fish resting and holding. The three riffles were placed approximately 30-m apart and constructed to be about 0.9-m in height, allowing each rifle to backwater the toe of the next riffle upstream.

In summary, a relatively stable bank section with good opportunities for fish passage at a range of flows was created downstream of the bridge over Bosworth Creek. Still, it remains unclear whether the channel has been monitored for fish passage successes or spawning activities (Bates 2009). A report was prepared for DFO on the weir removal which included a summary of proposed engineering activities; however, there were no biological studies proposed (Imperial Oil 2004).

Several pictures of works around the weir area on Bosworth Creek were located and are shown in Figure 2-1 through Figure 2-7 (Precision Gradall 2008). These pictures document the re-contouring of Bosworth Creek and show that efforts were made to stabilize the banks and mitigate erosion through placement of rip-rap and gravel along the shore, either during re-contouring, or as part of the weir construction and/or decommissioning. From Figures 2-6 and 2-7, it appears that during re-contouring, the creek was modified including the creation of several riffles.

FIGURES 2-1 THROUGH 2-7

PRECISION GRADALL WORK ON BOSWORTH CREEK

2.1

2.2

2.3

2.4

2.5

2.6

2.7

DFO has developed a Watercourse Resource Database and a Risk Assessment Tool (Rempel 2006) which could be of benefit to assess the sedimentation impacts from the removal of the weir. The database compiles information on geomorphology, fish presence, fish risk scores, hydrology, sediment, invertebrates and water quality. The Risk Assessment Tool combines this information to "1) quantify the likelihood for sedimentation impacts to streams, 2) quantify the consequence of sedimentation impacts to fish and fish habitat, 3) identify sites where sedimentation risk is highest, and 4) provide a defensible rationale for site prioritization in baseline data collection, monitoring and regulatory permitting." (Rempel 2006).

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3.0 CUMULATIVE EFFECTS

3.1 GENERAL EFFECTS OF OIL AND GAS ACTIVITIES ON THE ENVIRONMENT

3.1.1 PHYSICAL DISTURBANCE

The water quality and drainage of Bosworth Creek depends on natural sources of surface and groundwater within its watershed, but also may be affected by local industrial activities, most of which are associated with oil and gas activities. The region contains large deposits of oil and gas and the community of Norman Wells was established to extract oil, refine and transport the resource to southern markets. Although oil seeps were well known by indigenous people in the area, production of oil started in the 1920s and a refinery was built and then closed in 1925 due to a lack of markets. Mines in Yellowknife and Port Radium in the 1930s resulted in the refinery being reactivated in 1932. A new refinery was constructed in 1939 to produce aviation and diesel fuels (Bone and Mahnic 1984). In 2007, Imperial Oil facilities in Norman Wells produced 964.3 thousand m3 oil and 103.7 million m3 of gas, although the amount of oil produced has declined substantially over the years (INAC 2007). In addition, natural oil seeps are common in the area and can have significant impacts on local water quality. Although the location and discharge rates of the seeps are not well known, their abundance in the Norman Wells area suggests that individual chemical compounds that are present in the oil, might be present in surface waters. Concentrations of the compounds may vary locally and seasonally.

A number of assessments have been conducted on the environmental effects of oil and gas activities under arctic conditions. Major reviews have been published by Walker et al. (1987 a,b), Walker and Walker (1991), Forbes (2005) and the U.S. National Academy of Science (NAS 2004). The most recent assessment of the environmental and human health effects of oil and gas activities in the Arctic has been completed by the Arctic Monitoring and Assessment Program (AMAP 2007; www.amap.no). The assessment relied on the input of several dozen experts from eight arctic countries to evaluate past and present activities within the Arctic, and project those activities ten years into the future.

Each of these reviews documents the extensive changes in the northern landscape that can occur from large-scale oil and gas development. Forbes (2005) describes several categories of impacts including direct effects, transportation corridors, off-road vehicle use, oil spills and contaminants, quarrying, trampling by humans and animals, and indirect and cumulative impacts. However, only those that might impact Bosworth Creek are discussed here.

These reviews provide a consistent view that the major impact from oil and gas exploration, production and transportation is the physical disturbance of arctic terrain that can cause erosion of permafrost, changes in surface water drainage that can cause pooling of water and large changes in plant communities, including the presence of non-native species. Arctic soil horizons consist of a top organic layer lying on top of an active layer that thaws during summer. Where it is present, permafrost forms the base for the soil. Removal of the upper plant and organic layer causes a loss of insulation that result in changes in hydrological conditions and the erosion of the permafrost. Disturbance of the top soil layer can occur by off-road vehicles or during seismic exploration or, more severely, during the construction of roads and buildings. Several examples of impacts from physical disturbance remain in the NWT several decades after the damage and are still evident from the construction of roads, airstrips, buildings and gravel pads for oil and gas facilities. Single passes of off-road vehicles in some areas have resulted in loss of the plant cover, the formation of ruts and pooling of water that further the erosion (Walker et al. 1987a). Similar effects from the construction of buildings and roads in the Bosworth Creek watershed may have changed the drainage of surface waters that ultimately affect the hydrology and water chemistry of the creek.

There are also a number of impacts to the local environment that have been termed "indirect" effects because they follow from larger direct effects. Road dust had been shown to change the chemistry of the surface layer of soils and cause major changes in the resident plant community (Walker et al. 1987 a,b, Walker and Everett 1987, Myers-Smith et al. 2006). Dust has been shown to directly affect vegetation by covering leaves, or by changing pH of the soils which ultimately becomes toxic to some plant species. Although dust is certainly being deposited on roadside vegetation and into Bosworth Creek at the upper bridge (Latitude 65° 17.432 N Longitude 125° 52.507 W), it does not appear to significantly impact native plant species.

3.2 CLIMATE CHANGE

Climate change is a major cumulative effects component in northern Canada. Various studies predict overall lower water levels in the NWT, thawing permafrost, a rise in the number of forest fires and increasing occurrences of landslides (e.g., Cohen 1997; ACIA 2005). The Geological Survey of Canada also conducted an assessment of the effects of climate change on infrastructure in the NWT and used Norman Wells as a model because of the higher proportion of large-scale infrastructure relative to the size of the community. Modelling by one of the authors suggests that thaw depths will increase dramatically around Norman Wells and permafrost may disappear entirely in the Norman Wells area. This is expected to have a significant impact on the stability of buildings in the Norman Wells area that rely on stable permafrost for stable footing (Couture et al. 2000). These changes are becoming apparent in the Bosworth Creek watershed and include significant chemistry changes in Edie Lake, increasing volumes of overflow and the formation of new groundwater sources in the creek.

Edie Lake is the second largest waterbody in the Bosworth Creek watershed. Both traditional knowledge (TK) and scientific sampling of Edie Lake by the GNWT in 1993 suggest that increased subsurface water has led to significant habitat change over time. This lake was considered to be an unpleasant body of water twenty years ago because of a bad odour and lack of fish. The GNWT study indicates that Edie Lake was a fish unfriendly environment with a very basic chemistry of pH 10.2; compared to its current pH value of 7.8. Edie Lake currently sustains a juvenile (15-20cm long) jackfish population in the summer, as well as lake chub, sticklebacks and a healthy benthic macroinvertebrate community. While there is still an odour present when sampled through ice, the water does not produce an obnoxious smell during the summer today. This could be the result of an increase in groundwater that flushes the system of alkaline and gaseous chemistry.

Another example of change in the distribution of groundwater is evident between the two permanent bridges. Overflow beneath both bridges has increased by approximately ½ metre/year for the last three years (measured annually on April 23rd). This additional overflow equals a significant amount of water given the one kilometre distance between these two structures.

Finally, six new subterranean water sources have been identified between the two bridges in the last two years. All of these sources produce cold water ranging between 1.4 °C - 3.7 °C, implying that they either originate directly from melting permafrost, or are the result of subsurface water filtering through permafrost. This water has very low dissolved oxygen (0.7 □S - 1.2 □S) and produces a strong sulphur smell (Guthrie pers comm.).

The International Panel on Climate Change (IPCC 2001) made several predictions regarding change in the Mackenzie Delta which may impact surface waters in the Norman Wells area. These changes are supported by assessment of the effects of climate change in Alaska and other northern areas (Hinzman et al. 2005). Declines in runoff and lake levels due to warming air temperatures have been observed throughout the NWT and these effects are expected to increase over the next decades. Other threats to the Mackenzie landscape are increasing levels of erosion and landslides caused by permafrost thaw and extreme events, such as forest fires. Freshwater ecosystem impacts include the loss or decline of some lakes, increased surface water temperatures and increased sedimentation of rivers. Monitoring physical, chemical and biological conditions in Bosworth Creek will help to detect change and assist with fisheries management.

One potential benefit of climate change would occur from the reduction in ice cover seen with rising temperatures. Burbot fish livers in the Norman Wells area were found to contain lower levels of light aromatic hydrocarbons during ice free periods on the Mackenzie River (Lockhart et al. 1987). When the river is encased in ice, hydrocarbons are prevented from being released from the water into the air, increasing the exposure of fish to these pollutants. Lonergan et al. reported in 1993 that the Mackenzie River at Norman Wells was ice free for approximately 164 days per year. Through modelling, Lonergan et al. found ice free days would increase to between approximately 183 to 206 days per year over the next hundred years. This would reduce the amount of exposure that fish would have to several types of hydrocarbons. However, the increase in ice free days will reduce the length of time that ice roads and trucking will be a viable transport option in the Norman Wells area (Lonergan et al. 1993).

3.3 CUMULATIVE IMPACTS

The National Academy of Sciences (2004) conducted a review of the cumulative effects of oil and gas activities in Alaska. The range of effects included contamination of fish and wildlife by toxic materials, the effects of oil spills and construction activities and are described in Table 3.3-1. This assessment may be useful for Bosworth Creek because it considers the types of activities currently conducted by industry.

The underlying principle of cumulative effects is that a number of small changes may ultimately result in unexpected changes to a component of an ecosystem. In their assessment of known effects of oil and gas, the NAS recognizes effects from roads and damage to the tundra from seismic and off-road vehicles, spills and refined products and abandoned infrastructure and unrestored landscapes. However, some of these activities are not presently occurring the remainder fall within two separate categories including oil and gas activities and other activities. Potential cumulative effects by oil and gas activities on Bosworth Creek are limited to spills, concerns over buried materials, road dust from the two permanent bridges that service the facilities, and the proposed Mackenzie Gas Pipeline crossing. Other activities include recreational use of Bosworth Creek by local residents, the current winter road crossing, and the proposed construction of a permanent winter road crossing. Of these, recreational use of All-terrene vehicles (ATVs) by local residents is creating the most observable damage.

The Bosworth Creek Monitoring Project has identified four kinds of damage resulting from these activities that are negatively impacting subsistence fish species that have strong traditional ties to local Dene and Metis residents. First, some enthusiasts drive their vehicles up and down the banks rather than using one of the many minor crossings that currently exist. These actions result in bank collapses that release car-sized volumes of mud into the creek at a time. Second, tires crush and destroy spawning habitat and kill the benthic macroinvertebrates that feed fish. Third, large volumes of fine silty mud are continually released while the vehicles are in the creek. These sediments drift downstream and suffocate fish spawning habitat. Fourth, tire tracks alter the streambed by creating sub-channels that redirect water flow. This is resulting in accelerated erosion of the creek's banks at several locations.

3.4 LOCAL SOURCES OF CHEMICALS

Oil and gas facilities can also release chemicals from production and refining, either intentionally, as part of a production process, or unintentionally, as in a spill. Chemicals released from oil and gas facilities can affect the water quality in surface waters by deposition of contaminants and particulates into watersheds, or releases into groundwater that discharges to the stream.

One consequence of oil and gas activity is the spilling of crude oil and brine from areas of production and transportation. Long-term monitoring of larger pipelines shows that large oil spills are relatively rare and that most spills cover only a few square meters of land. Oil spill experiments near Norman Wells during the 1970s helped to show the long term fate of spills under northern conditions (Hutchison and Freedman 1978). Release of oil on the tundra caused immediate death of lichens and mosses and, after a lag period, the loss of higher plants such as pine. Some plants were able to regenerate from underground rhizomes that were not affected by the original spill (Hutchinson and Freedman 1978). Other studies have shown that oil spilled in summer can move through the upper active layer of soil, move along the permafrost and keep the toxic components of the oil for several years (McCarthy et al. 2004). These studies show that spills within the Bosworth Creek watershed may remain toxic for long periods of time and may continue to release toxic compounds to surface waters.

There are several known local sources of hydrocarbons that may impact water quality in the Bosworth Creek system. One major source of hydrocarbons is natural seeps that are defined as areas where fluids, like oil, or gases, like natural gas, emanate onto the surface of the earth. Although oil seeps are known to be common around Norman Wells and are well known as sources of hydrocarbons in the Mackenzie River, no map of known seeps around Norman Wells was available for this review. Morgan et al. (1987) made note of a naturally occurring oil seep near the mouth of Bosworth Creek. A recent assessment of hydrocarbon sources to the Arctic Ocean by the Arctic Monitoring and Assessment Program (AMAP 2007, draft Chapter 4 of the Science Document) identified the Mackenzie River as a major source of hydrocarbons to the Arctic Ocean because of a number of seeps in the Valley. Seeps are known to be major sources of hydrocarbons, including the toxic group of compounds known as polycyclic aromatic hydrocarbons (PAH).

The amount of oil, or its products, that have spilled within the Bosworth Creek drainage area is unclear from spill databases maintained by the GNWT Hazardous Materials Spill Database or the National Energy Board. A major spill of 397,000 litres of oil was reported to occur in 1997 in Norman Wells when a transfer line from a central processing facility to a storage tank ruptured (AMAP 2007, draft version of Chapter 2 of Science Document). A search for spills in the GNWT database reports a number of crude oil and processed water spills from various facilities around Norman Wells. The GNWT database lists a total of 88 spills of hazardous materials between 1971 and 2006, but most spills are of sewage, or fuel at the airport. Large amounts (>10,000 litres) of hydrochloric acid and sewage were spilled at various times during the 1990s but well away from Bosworth Creek. No information is available on any monitoring or clean-up that took place or the current levels of contamination.

The second facility is the Norman Wells Crude Production Facility operated by Imperial Oil. The plant releases a number of volatile compounds and particulates, some of which are regulated due to their toxicity. Amounts of some of the volatile compounds released annually are listed in Table 3.4-2. The database also lists several off-site releases of many of the chemicals, although the amounts released are relatively small. A third facility, a compressor station, has been proposed for Norman Wells as part of the Mackenzie Gas Project but did not have any chemical releases as of 2007.

TABLE 3.4-1

RELEASES OF AIR POLLUTANTS FROM THE NORMAN WELLS CRUDE PRODUCTION FACILITY OPERATED BY IMPERIAL OIL

Data are for the releases to air for some compounds for which air quality criteria exist. Other substances released but for which there are no air quality criteria are n-hexane, toluene, methanol and ethylene glycol. Units are in tonnes (=1000 kg)

Year	Benzene	Hydrogen Sulphide	Oxides of nitrogen	PM10[1] and PM2.5	Toluene	Volatile Organic Compounds[2]
1994	1.7	-	-	-	5.2	-
1995	1.7	-	-	-	5.2	-
1996	0.8	-	-	-	2.6	-
1997	4.3	-	-	-	1.4	-
1998	0.16	-	-	-	0.44	-
1999	0.16	0.09	-	-	0.40	-
2000	0.174	-	-	-	0.622	-
2001	0.16	-	-	-	0.574	-
2002	0.21	-	167	0.739	0.577	31
2003	0.263	-	210	7.5	0.498	249
2004	-	-	226	7.4	2.7	212
2005	-	-	209	8.0	2.4	188
2006	-	-	214	7.5	2.4	182
2007	-	-	217	14	2.1	185

1 – PM10 – particulate matter <10 microns; PM2.5- particulate matter<2.5 microns

2 – volatile organic compounds are gases that contain carbon and usually include up to 150 different compounds, some of which are toxic to humans and the environment (National Pollutant Release Inventory;
http://www.enr.gov.nt.ca/epd_spills/
http://www.ec.gc.ca/pdb/npri/npri_home_e.cfm)

The Federal Contaminated Sites Inventory lists seven contaminated sites within the community of Norman Wells, most of them operated by DFO or the Department of Transport, but none of them are near Bosworth Creek. Dominant contaminants at the sites are petroleum hydrocarbons and polycyclic hydrocarbons (PAHs).

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4.0 LESSONS LEARNED

Based upon our review we note the following lessons learned:

- Follow-up monitoring of fisheries habitat may have provided a finer scale to judge the success of the weir removal project than is currently available. However, since the weir was removed only three years prior to the writing of this report, there is ample time to begin a fisheries habitat monitoring program to track the degree of success or failure of the restoration plan. Data collected by the Bosworth Creek Monitoring Project would assist with establishing a comprehensive baseline that could be used in a fisheries habitat monitoring project.

- The unfortunate lack of fisheries habitat data prior to removal of the weir seriously impacts any comparison that can be made pre and post weir removal. However, Traditional Knowledge could potentially alleviate this by providing invaluable personal observations of subsistence species distributions, abundances and health, and their relative importance to local people in the past. Investigators could then make general statements about the health of Bosworth Creek before the weir was removed based on known associations of subsistence species, and other chemical and biological parameters.

5.0 RECOMMENDATIONS

There are several recommendations following our evaluation of the weir removal project.

5.1 BASELINE AND FOLLOW-UP FIELD STUDIES (INCLUDING MITIGATION)

Any future major project in the North should follow a model that includes exhaustive baseline data collection prior to alteration, followed by bi-annual collections for the following 10 years. This type of monitoring plan provides a solid foundation to monitor on-going change expected following any significant assault to an ecosystem; regardless of whether the actions were a result of development or mitigation. A similar model can be adopted for Bosworth Creek. Long-term biological and chemical sampling and analyses that builds on previous studies could demonstrate the success of this restoration plan. Standard collection techniques for water, soil and invertebrates should follow established protocols and efforts should be made to collect at geographically important sites, as well as repetitive site-specific sampling over time. Traditional Knowledge seminars would also add considerably to the basic concepts of past ecosystem geography and health. Many aspects of day to day observations in the past can help shed light on present day phenomena. For example, the current confluence of Bosworth Creek and the Mackenzie River is more than 200 metres farther from shore than during the 1940's (Hodgson and Oudzi pers comm.). This is likely due to human alteration of the shoreline and creation of the artificial islands. Traditional Knowledge identified this alteration that impacts the energy requirements of spawning fish as they now have to navigate an additional 200 metres of creek to get to spawning grounds. What impact this has on the natural re-introduction of certain species is unknown, but it may account for the current confirmed absence of whitefish on Bosworth Creek.

5.2 FISHERIES RELATED STUDIES AT BOSWORTH CREEK

As mentioned above, the SRRB has an excellent field program dedicated to a better scientific understanding of Bosworth Creek as well as providing excellent educational opportunities for students from Mackenzie Mountain School to undertake research and contribute to science. Since the program is ongoing, it may be possible to incorporate additional fish related studies. Two suggested areas to concentrate on are as follows: basic fish abundance studies at pre-determined sections of the Creek (including the weir removal area), and fish spawning and habitat studies.

5.2.1 FISH ABUNDANCE AND DISTRIBUTION STUDIES

This work may involve electro-shock methods, gill-nets, minnow traps, seine nets and other standard equipment. Information on fish collected should include species, size, weight, sex, reproductive status and age. Benthic and water chemistry sampling would be very supportive monitoring tools at the same locations as the fish collections. This sampling program would occur bi-annually over a ten-year period to complement benthic collections and analyses.

5.2.2 FISH HABITAT AND FISH SPAWNING STUDIES

Fish habitat types can be differentiated by physical attributes such as channel geometry, riparian community, substrate characteristics and watercourse velocity. It is suggested that sampling in Bosworth Creek consist of 7 or 8 different segments with generally similar hydrological, topographical and aquatic habitat characteristics. As stated above, one of these could include the bridge at Bosworth Creek where improvements to the stream bed were previously made to facilitate fish spawning (Imperial Oil Resources 2005, Bates 2005).

A segment could be defined as the watercourse between one pool and a riffle, or a pool to run sequence. At each segment, a habitat assessment can be conducted including the following observations:

- Riparian and in-stream vegetation;
- Substrate description;
- Percent of undercut banks;
- Bank stability;
- Percentage of shade; and,
- Water velocity.

Appendix A provides a typical template for habitat assessment that could be followed or a modification of it. This is not a difficult Table to be completed by students (with DFO/consultant supervision), and would provide the basis for fish habitat and spawning activities. More sites could be added if necessary.

Fish habitat and spawning studies should be conducted bi-annually over a multi-year period to determine whether Bosworth Creek is being used by spawning fish, frequency of use, and if required, further studies could be done to optimize fish habitat and increase fish productivity. DFO has also developed a Watercourse Resource Database and a Risk Assessment Tool (Rempel 2006) which could also be of benefit to assess the sedimentation impacts from the removal of the weir.

APPENDIX A

EXAMPLE OF SUBSTRATE AND FISH HABITAT TEMPLATE

UNIT NO.	STREAM TYPE	CHANNEL TYPE	CHAINAGE END	LENGTH (m)	AVE WIDTH (m)		SUBSTRATE (%)			
					WET	BANK CHANNEL	BEDROCK	BOULDER	ROCK	RUBBLE
1.										
2.										
3.										
4.										
5.										
6.										
7.										
8.										

APPENDIX A (CONT.)

EXAMPLE OF SUBSTRATE AND FISH HABITAT TEMPLATE

UNIT NO.	SUBSTRATE (%) (Cont.)			AVE DEPTH - WET WIDTH (cm)	0-50% UNDER-CUT BANK		0-50% OVER-HANGING BANK		LARGE WOODY DEBRIS IN STREAM (m)	EMBEDDEDNESS (CRITERIA) 1 : 20% 2 : 20% - 35% 3 : 35% - 50%	INSTREAM VEGETATION	COMMENTS	GPS REFERENCE NUMBER
	GRAVEL	SAND	FINES		L	R	L	R					
1.													46 10 52.5 N 59 57 57.3 W
2.													46 10 48.2 N 59 57 58.7 W
3.													46 10 29.3 N 59 58 7.5 W
4.													46 10 25.4 N 59 58 12.6 W
5.													46 10 22.1N 59 58 20.8 W
6.													46 10 15.4 N 59 58 45.1 W
7.													46 10 23.6 N 59 58 17.8 W
8.													46 10 31.6 N 60 1 47.6 W

NOTES