A Pilot Study on Effects of High White Goose Populations on Aquatic Quality

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Karrak Lake, Queen Maud Gulf Migratory Bird Sanctuary, Nunavut Territory

Environment Canada Environnement Canada

Canadian Wildlife Service Service canadien de la faune

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Environment Canada
Meteorological Service of Canada & Environmental Conservation Branch (Canadian Wildlife Service)
Environment Canada / Environnement Canada

Indian & Northern Affairs Canada
Renewable Resources & Environment Directorate
Affaires indiennes et du Nord Canada / Indian and Northern Affairs Canada

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EXECUTIVE SUMMARY

Karrak Lake lies along the north-flowing Karrak River and upstream of the confluence with Simpson River, within the Queen Maud Gulf Migratory Bird Sanctuary (QMGMBS), the largest bird sanctuary in Canada. QMGMBS is located in Nunavut Territory, south of the community of Cambridge Bay and the Queen Maud Gulf (part of the Arctic Ocean). QMGMBS was set up to protect the nesting grounds of over 95% of the world's population of Ross'Geese, 15% of Canada's population of Lesser Snow Geese, as well as other Arctic nesting waterfowl.

Significant increases in the summer nesting populations of Ross' Geese and Lesser Snow Geese from 17,000 to 600,000 have been observed in the Karrak Lake area between 1966 and 1996, and the goose colony area has expanded in coverage of terrestrial extent from one to 110 square kilometres. The reasons for this increase in population are not well understood, but the increased populations are having an observed impact on the local habitat (e.g. loss of vegetative cover, increase in biological waste). The progressive increase in the size of defoliated areas is visible in successive LANDSAT satellite images. Similar increases have been observed and studied elsewhere within arctic and sub-arctic regions (e.g. Hudson Bay coastline, Banks Island). A management plan has been designed to help to cull the burgeoning snow geese population by 50% by the Year 2005, and involves Canada's first-ever migratory bird spring hunt.

During the summer 1996 and 1998 a water and sediment quality sampling and measurement program was undertaken at Karrak Lake and at a control lake referred to as Reference Lake. The purpose of this program was to determine whether overabundance of geese was impacting the physical, chemical, and biological characteristics of the water and sediment quality at Karrak Lake. Water quality variables analysed for include the following groups of variables: physicals, nutrients, major ions, and trace metals.

In order to compare water quality values, Reference Lake and the Armark River must be representative of the typical water quality of lakes and north-flowing rivers draining into the Arctic Ocean in the Back Lowlands. Reference Lake must be comparable to Karrak Lake with respect to hydrological, geological, and limnological variables (i.e. area, depth, sediment colour and composition, shape/orientation, number of inlets/outlets, etc.).

Water quality data from Reference Lake/Armark River was found to be similar to water quality at two sites near the mouths of two other north-flowing rivers, the Ellice and the Tree. Furthermore, Karrak Lake was judged to be similar to Reference Lake, in terms of geology, climate, hydrology, and vegetation types (despite limited amounts of data and information available). Discrete water level measurements at both Karrak and Reference lakes provides additional evidence supporting the conclusion that there are physiographic and hydrologic similarities between the two lakes.

Large numbers of samples were collected from the four (4) Karrak Lake/Karrak River sites and the three (3) Reference Lake/Armark River to permit a comparative analysis between the two sites using parametric and non-parametric statistics. As would be expected, data from Karrak Lake and Reference Lake were not normally distributed.

Box-and-whisker plots confirmed that sample population distributions were typically asymmetric/skewed and of highly variable kurtosis, thus limiting the utility of parametric statistical analysis. Use of non-parametric Wilcoxon Rank Hypothesis Testing of sample medians, however, revealed that several Karrak Lake water quality variable medians are significantly different (i.e. usually higher) than those obtained from Reference Lake.

Nutrient ratio analysis of the Karrak Lake and Reference Lake data revealed (not surprisingly) that there was no nitrogen, phosphorus, or general nutrient deficiency at either location, especially the Karrak Lake sites. Water quality in the Karrak Lake-Reference Lake study area is good overall, but turbidity routinely exceeds Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines in all samples and sites. Water temperature and dissolved oxygen occasionally exceed CCME Guidelines. Although data is limited, sediment quality varied little throughout Karrak Lake, and is good overall with only the total mercury exceeding CCME Interim Sediment Quality Guidelines.

We suspect that high populations of Lesser Snow Geese and Ross' Geese have influenced the water quality at Karrak Lake. Although the increased number of geese at Karrak Lake likely impacts on the water quality it is not clear whether it is a direct and/or indirect impact. It is obvious that the geese have an impact on the upland, typically defoliating the landscape, which can potentially influence local runoff regimes and thus the transport of nutrients to the aquatic ecosystem. Moreover, the large and concentrated population of geese can directly impact on the nutrient loading. To better understand the impact of large geese populations on aquatic quality a more detailed investigation, using replicated-paired sampling at other high-density colonies would be necessary.

RÉSUMÉ

Lac Karrak est située le long de la Rivière Karrak qui circule de sud à nord, et au-dessus de l'embranchement des Rivières Karrak et Simpson, dans les limites de la Réserve des Oiseaux du Golfe de la Reine Maud (ROGRM), la réserve des oiseaux la plus grande du Canada. ROGRM est située dans le Territoire du Nunavut, au sud de la communauté de Baie Cambridge et le Golfe de la Reine Maud (une portion du Océan Arctique). ROGRM était établi pour protéger les terres des nids des plus de 95% de la population mondiale des Oies Ross, 15% de la population Canadienne des Oies Moindre-Neiges, et les autres genres des oies.

Les populations dans l'été des Oies Ross et des Oies Moindre-Neiges était observées de monter considérablement de 17,000 de 600,000 aux environs de Lac Karrak entre 1966 et 1996, et la région terrestriale de la colonie des oies avait poussé d'un à 110 kilomètres carrés. Les raisons pour l'augmentation de la population ne sont pas bien comprender, mais cette augmentation de la population-ci fait un impact observé sur l'habitat locale (par exemple, la perte de la couverture de la végétation, l'augmentation des fumier et urine biologiques des oies). On peut voir l'augmentatation progressive des dimensions des régions sans végétation par les images successives du satellite LANDSAT. L'autres augmentations étaient observées et recherchées parmi les régions arctique et sous-arctique (par exemple, le côte du Baie Hudson, Île Banks). Un plan de la gestion était dessiné pour aider à arrêter l'augmentation de la population des Oies Moindre-Neiges par 50% entre le présent et L'Année 2005, et ce plan-ci à des relations avec la première chasse chaque printemps des oiseaux migrateurs dans l'histoire du Canada.

La raison d'être du programme d'hydrologique dans l'été 1996 était à mésurer les hauteurs des eaux continuellement à Lac Karrak près de le Campe du Recherches sur le Terrain à Lac Karrak de le 6 juin (aussi vite que le "break-up" avait terminé) à le 13 août 13, et à comparer ces resultats-ci avec les mésures individuelles pris dans le même periode près à Lac Référence. Une récession des hauteurs des eaux s'est passé en juin à Lac Karrak, suivre par des hauteurs des eaux presque constantes en juillet et août. Les mésures individuelles pris un lac du contrôle, nommé Lac Référence, située presque 25 kilométres à l'ouest de Lac Karrak et le long de la Rivière Armark, suggérent qu'il y a des similaritiés physiographique et hydrologique entre les deux lacs.

La raison d'être du programme de la qualité des eaux et des sédiments dans les étés du 1996 et 1998 aux environs de Lac Karrak et de Lac Référence est à discerner s'il y a des changements de la qualité des eaux et des sédiments physiques, chemiques, et biologiques à cause des impacts des oies trop abondantes. Les paramètres de la qualité des eaux mésurés sont les paramètres physiques, les nutrients, les paramètres bactériologiques, les ions majeures, et les métals traces.

Si l'étudie devient valable, la qualité des eaux du Lac Référence et de la Rivière Armark doit être représentative de la qualité de tous les eaux des lacs et rivières qui circulent de sud à nord et circulent à l'Océan Arctique par l'intermédiare les Terres Basses de la Rivière Back dans l'Arctique Canadien. Le Lac Référence doit être aussi similaire hydrologiquement, geologiquement, et limnologiquement à Lac Karrak que possible (e.g. la grandeur des lacs, la profondeur des lacs, les couleurs et les compositions des sédiments, les formes/l'orientations des lacs et leurs bassins, les numeros des avancées et sorties). On a ramassé assez des échantillons des quatres (4) emplacements du Lac Karrak/de la Rivière Karrak et les trois (3) emplacements du Lac Référence/de la Rivière Armark à permettre une comparison entre les mésures de la qualité des eaux des emplacements du Lac Karrak/de la Rivière Karrak et les mésures de la

qualité des eaux des emplacements du Lac Référence/de la Riviére Armark, vis-à-vis la tendance centrale et la variabilité/variation, utilisant les statistiques parametriques et non-parametriques.

Les données préliminaires de l'année 1996 n'était pas concluantes, parce que le nombre des échantillons était limité, quelques analyses de la qualité des eaux étaient manquantes, il n'y a pas assez des échantillons qui montraient la qualité assurance/la qualité contrôle, et il n'y a pas des échantillons de la qualité des sédiments. Ces données-ci suggéraient que la qualité des eaux du Lac Référence/de la Riviére Armark était similaire à la qualité des eaux des deux emplacements près des embouchures des autres rivières qui circule de sud à nord, les Rivières Ellice et Tree, autre part dans les Terres Basses de la Rivière Back.

La qualité des eaux du Lac Référence était trouvée d'être assez répresentative des Bas-Pays de la Rivière Back de l'Arctique Canadien. Lac Karrak était évalué d'être similaire au Lac Référence, vis-à-vis la géologie, le climat, l'hydrologie, et les genres de végétation (malgré les données et information maigres).

On prendrait note de la qualité des eaux du Lac Karrak et la qualité des eaux du Lac Référence suivraient le schéma mondial, où les niveaux de la qualité des eaux ne suivraient pas la Distribution Normale. Après l'achèvement des interrogations de la tendance centrale et la variabilité/variation par les essaies Student-t et F Ratio, les résultats n'étaient pas d'accord des observations de la recherches sur le terrain. La plupart de temps, les formes des plots "box-and-whisker" confirmaient que les distributions des populations des échantillons n'avaient pas de la symétrie où la kurtosis d'une Distribution Normale.

Utilisation des statistiques non-parametrique pour faire des recherches sur la tendance centrale par le "Wilcoxon Rank Hypothesis Testing" qui compare les 50ième percentiles (médianes) montrait que les 50ième percentiles étaient différents entre le Lac Karrak et le Lac Référence, et les 50iéme percentiles étaient généralement plus larges au Lac Karrak pour au moins de 16 paramètres de la qualité des eaux, par exemple les paramètres physiques, les nutrients et les ions majeures. On soupconne que l'augmentation des populations des Oies Moindre-Neiges et les Oies Ross faisaient les changements de la qualité des eaux au Lac Karrak, parce que ils portent les nutrients aux terres des nids dans l'Arctique. Aussi, les oies mangent toute la végétation et ils enlevent les racines pendant qu'ils broutent, laissant la terre sans feuillage, vraisemblablement augmentant la quantité des eaux qui cours sur la terre et les niveaux des certains paramètres de la qualité des eaux relatifs aux eaux qui cours sur la terre.

Les études des niveaux des nutrients au Lac Karrak et au Lac Référence montraient (pas étonnamment) qu'il n'y a pas un manque d'azote, de phosphore, où des nutrients généralement aux emplacements du Lac Référence et, particulièrement, aux emplacements du Lac Karrak. La recherche montre que la qualité des eaux dans la région du Lac Karrak et Lac Référence est très potable en général, mais les niveaux de turbidité étaient en excès des directives de Le Conseil Canadien des Ministres de l'Environnement (CCME) à tous les emplacements et à tous les échantillons. Aussi, les niveaux de la température et l'oxygène dissoudre étaient en excès des directives de CCME. La qualité des sédiments est bonne en général et il n'y a pas beaucoup de la variation partout dans le Lac Karrak; seulement les niveaux de mercure étaient en excès des directives de CCME.

Enfin, les recommendations pour la recherche dans l'avenir sont provisées par l'auteur après les entretiens avec les autres experts scientifiques.

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1.0 INTRODUCTION

The Queen Maud Gulf Migratory Bird Sanctuary (QMGMBS) in the Northwest Territories, established in 1961, is the largest Migratory Bird Sanctuary in Canada. It includes 300 kilometres of the south coast of Queen Maud Gulf and extends 135 kilometres inland, covering nearly 62,800 square kilometres (6.2 million hectares) (Figure 1). Designated in 1981 as a Ramsar site, QMGMBS includes the nesting grounds of over 95% of the world population of Ross's Geese, 15% of Canada's known population of Lesser Snow Geese (Alexander *et al.* 1991) and thousands of Brant Geese, Canada Geese, and Greater White-Fronted Geese (Alisauskas 1992).

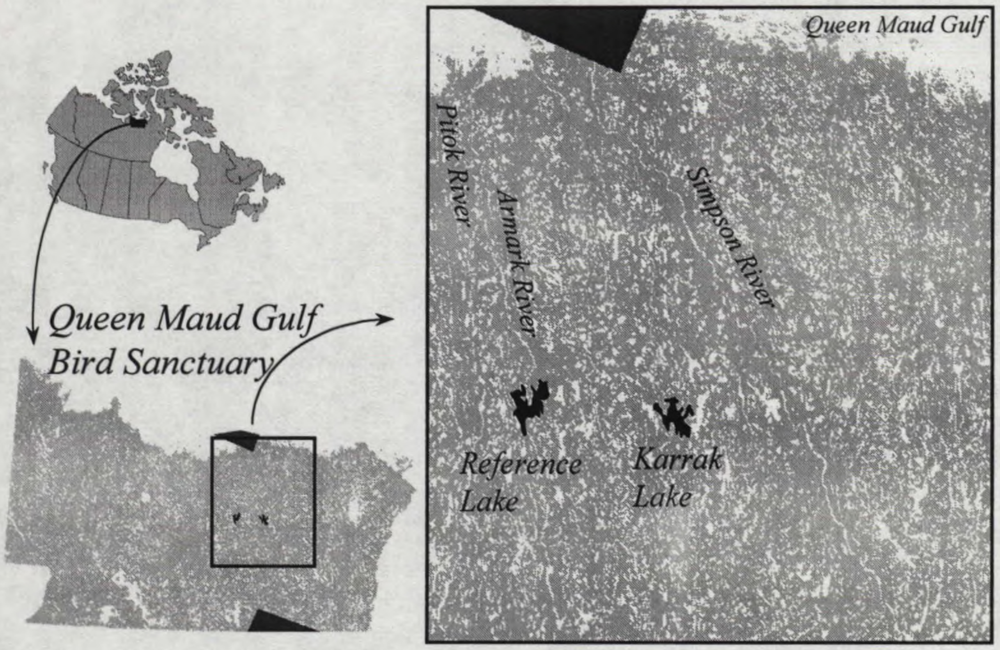


Figure 1: Location of Queen Maud Gulf Migratory Bird Sanctuary, Karrak and Reference Lakes.

Since the discovery of the nesting grounds of Ross's Geese near the mouth of Perry River in 1938 (Gavin 1940), QMGMBS has been the focus of considerable research on Ross' and Lesser Snow Geese (e.g. Ryder 1964, Ryder 1972, Ryder 1971, McLandress 1983, Alisauskas , 2001, McCracken et al 1997, LeSchack et al. 1998). Temporal analysis of nesting populations at known colonies of Ross's and Lesser Snow Geese in the QMGMBS by Kerbes (1994) identified increases from 44,330 in 1966 to 467,000 in 1988. These estimates can be considered conservative, as additional colonies have been discovered as recently as 1990 and 1991 (Alisauskas and Boyd, 1994). These previously unrecorded colonies suggest that: i) remoteness and size of QMGMBS makes it very difficult to do a complete census, ii) existing colonies are expanding and/or iii) new colonies have formed at previously unoccupied locations.

The reasons for increases in arctic goose populations are not completely understood but are likely related to improved feeding conditions during the non-breeding season due to nutritional subsidy from large-scale agriculture (Batt et al. 1997). Through intensive foraging, Snow and Ross's Geese can devegetate large areas of formerly intact plant communities. Thus, growing populations of Lesser Snow Geese are having serious effects on terrestrial arctic vegetation that may have long-term density-dependent consequences on not only Snow and Ross's geese, but on the diversity of other wildlife. Increases in goose populations have also occurred in other locations within the Arctic and sub-Arctic (e.g., Hudson Bay Coastline, Batt et al. 1997).

Karrak Lake in the QMGMBS (Figure 1) has been the centre of recent ongoing studies on the population dynamics of the Ross' and Lesser Snow Goose (Alisauskas 2001). This site was selected to study the nutritional ecology and population biology of Ross's Geese in 1991 because of the history of previous work at this location, and because it was the largest known colony of Ross's Geese. Moreover, it was the approximate centre of known colonies of Ross's and Lesser Snow Geese in QMGMBS, and so this location was considered to be representative of most breeding Ross's Geese continentally.

Overall, there are about equal numbers of Ross's and Lesser Snow Geese nesting at Karrak Lake, although there is considerable spatial variation in species composition of nesting birds within the colony. Figure 2 illustrates the population growth at Karrak Lake, which has increased exponentially from 17,000 nesting geese in 1966 to almost 600,000 in 1996 (Alisauskas 1998). During this time, the average rate of population increase per annum was 11% for Ross's Geese and almost 14% for Snow Geese. This value for Snow Geese is the highest rate of population growth for any colony contributing to the Mid-continent Population. Spatial extent of the colony increased from 1 to 108 square kilometers of terrestrial habitat, although the colony perimeter encloses about 152 square kilometers of the land and water surface.

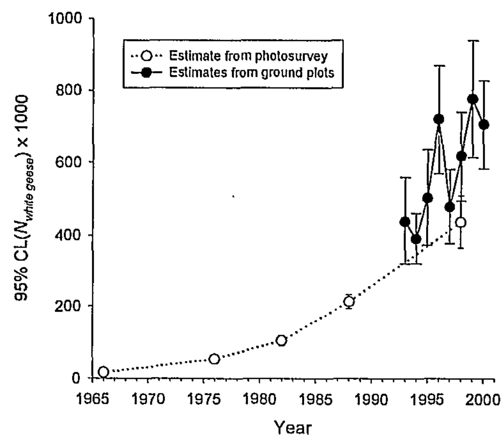


Figure 2: Temporal change in population size of total white geese at Karrak Lake. Shown are estimated from ground plots, and estimates from photo surveys (Alisauskas 2001, Kerbes 1994, and pers. comm.)

These high populations are removing vegetative cover within the colony boundary. By 1989, 52% of plant communities within the area occupied by nesting geese at Karrak Lake was converted to exposed peat, and a further 7% had eroded to bare mineral soils based on examination of Landsat imagery from 1988 (Figure 3). (Updated Landsat imagery from 1996 has been acquired and is in the process of analysis). The loss of vegetative cover, exposure of peat and mineral material coupled with an increase in biological waste from over a half million geese can potentially impact on the hydrologic characteristics of this area. Some impacts could include: changes in the thermal regime of the active layer; increased erosion from exposed substrate; and, changes in the water chemistry of surrounding lakes and ponds due to nutrient inputs from increased erosion and animal waste. Considering that the Arctic ecosystem is typically slow to recover, and that this region is already very arid, devegetating the landscape could potentially lead to desertification.

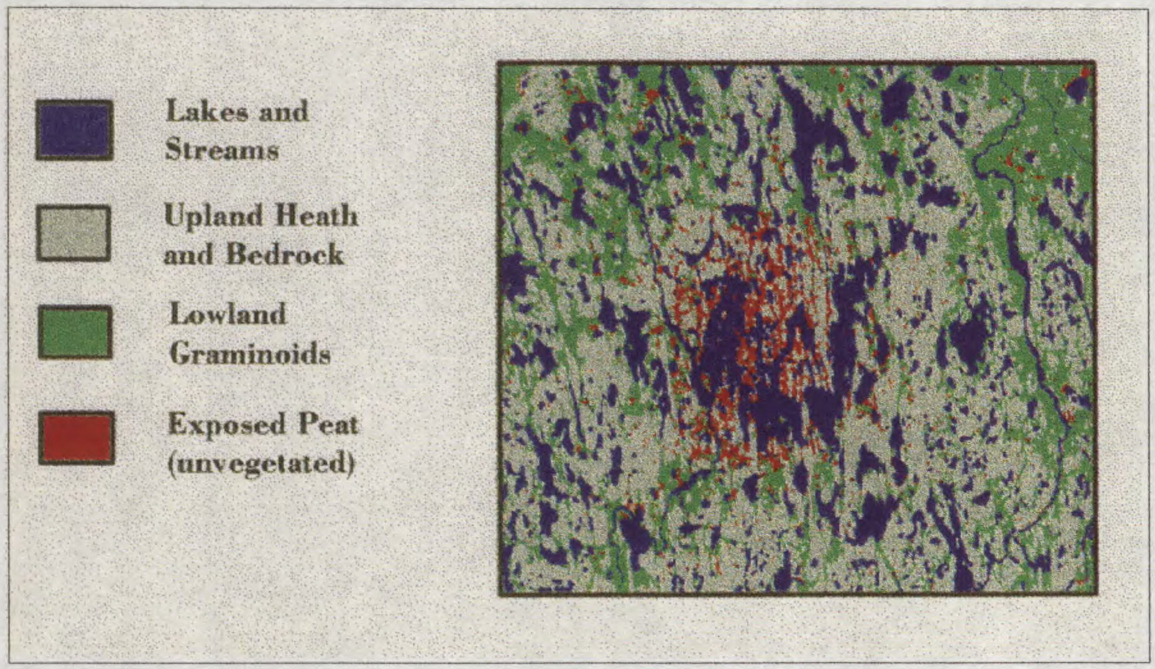


Figure 3: Satellite image (1988) illustrating habitat degradation around Karrak Lake, Nunavut.

As indicated, increases in goose populations have also occurred in other Canadian arctic and sub-arctic locations (e.g. McConnell River near Arviat, Nunavut along the western shore of Hudson Bay, Banks Island). It is estimated, for example, that 35% of the Hudson Bay-James Bay Lowland (i.e. Canada's largest wetland region) has been destroyed, 30% of the Lowland damaged, and 35% of the Lowland has been heavily grazed (Abraham and Jefferies, 1997). Considering that impacts to Arctic ecosystems can be long term and recovery very slow, it is important to quantify the effects of these increasing populations of white geese. As such it was considered appropriate to initiate a pilot study to evaluate the possible consequences to the water quality of Karrak Lake, particularly as it relates to increased nutrient loading.

2.0 BIOPHYSICAL DESCRIPTION

2.1 Geology and The Land

The Back Lowland physiographic unit, a generally flat plain of post-glacial marine emergent Precambrian bedrock, overlain by glacial till and marine clays and silts, dominates the landscape. Relief is provided by rock outcrops, drumlins, and old beach ridges, most common in the southern and western Back Lowland (Alexander *et al*, 1991). A till blanket underlies the area to the southwest, while till veneer underlies two areas, one north of Reference Lake and one north of Karrak Lake. Undivided glacial deposits underlie the rest of the area. Two north-northwest/south-southeast trending eskers occur along the eastern and western shorelines of Karrak Lake. Drumlins with similar orientations occur throughout the Karrak Lake area, with the best-developed drumlin fields occurring further north (NRCan *et al*, 1997).

The regional bedrock geology of QMGMBS consists predominantly of granites and gneisses, but local curvilinear belts of metamorphosed sedimentary and volcanic rocks may underlie portions of the Karrak Lake area. The oldest rocks in the Back Bay Lowland are Archean (i.e. at least 2500 millions years before present) metamorphosed sedimentary and volcanic rocks, which are locally intruded by layered gabbro-peridotite complexes. Rocks in the geological record are missing until the Aphebian (i.e. 1800-2500 million-years-old) Chantrey Group and Hurwitz Group metamorphosed sedimentary rocks. Agents of erosion have removed all younger stratified rocks over geologic time. These rocks are intruded and cross-cut by faulted and metamorphosed granites, granodiorites, and granitic gneisses of Hudsonian (i.e. 1640 to 1880 million years ago) age. The youngest rocks are faulted diabase dykes, which cross-cut all other (older) rock types. Though no detailed geological maps are available for use in this study, regional bedrock geology maps suggest that the most abundant bedrock types in the vicinity of Karrak Lake are Archean gneisses, with rarer Aphebian (usually quartz-poor) intrusive rocks (i.e. anorthosite, amphibolite, gabbro, diorite). It is unknown whether these rocks outcrop or underlie the Karrak Lake area.

2.2 The Climate

The climate of Queen Maud Gulf Bird Sanctuary is classified as cold continental, with long, cold winters and wide annual temperature and precipitation variations (Environment Canada, 1991). The closest meteorological station to Karrak Lake is located at Cambridge Bay, which has records extending back to June 1948. Daily mean temperatures for Cambridge Bay Airport range from -33.5°C. (February) to +8.0°C. (July). Normal precipitation for Cambridge Bay is 141.0 millimetres, 79.6 mm as snowfall (generally in May and October) and 73.2 mm as rainfall (primarily in July and August). Average wind directions are typically from the north, northwest, and northeast, and average wind speeds vary from 20 to 23 kilometres per hour. Weather data were also collected at hydrometric stations on the *Tree River near the Mouth* and *Back River above Hermann River* in 1992 and 1990, respectively, but records are not continuous.

2.3 The Water (Flows and Levels)

QMGMBS is traversed by several north-flowing rivers, including (west to east) the Ellice, Perry, Armark and the Simpson Rivers. The Karrak River is a tributary of the latter. The largest lake in QMGMBS is MacAlpine Lake (Alexander et al, 1991). Because of the remote nature of this region, few of these Arctic Rivers have been monitored for flows or water levels. The only River within the QMGMBS to be monitored is the Ellice River (HYDAT # 10QD001) although the Back River basin drains a portion of the sanctuary along its southern boundary. Figures 4 and 5 illustrate the maximum daily flows that can be expected from these basins.

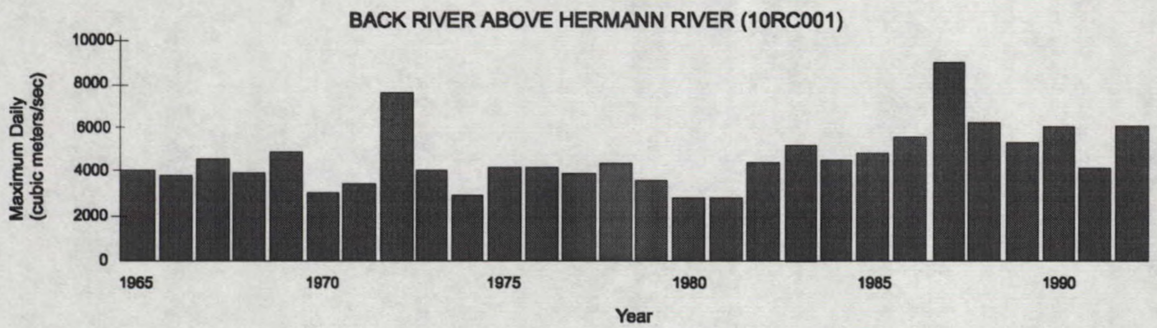


Figure 4. Maximum Daily Flows by Year, Back River above Hermann River (After HYDAT, MSC WSD & EcoAtlas Version 700, EC-MSC-AHSD, April 1999).

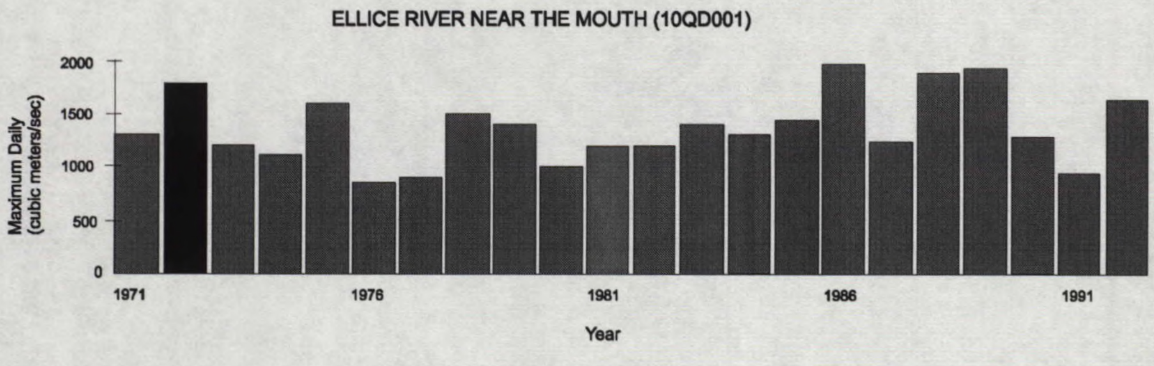


Figure 5. Maximum Daily Flows by Year, Ellice River near the Mouth (After HYDAT, MSC-WSD & EcoAtlas Version 700, EC-MSC-AHSD, April 1999).

3.0 PROGRAM DESIGN AND METHODOLOGY

Due to the remote nature of the QMGMBS no historic water quality data are available for Karrak Lake. In the absence of any historic data (i.e., prior to the exponential increase in white geese populations) it was considered appropriate to identify another lake with similar biophysical characteristics but with a much smaller population of geese surrounding the lake. Based on an analysis of topographic maps and site reconnaissance, a similar sized lake (here after referred to as Reference Lake) was identified on the Armark River, about 25 km west of Karrak Lake (Figure 1). Both Karrak Lake and Reference Lake have inflow and outflow streams, and drain a similar physiographic region (i.e., Back River Lowlands). Water level monitoring was initiated at both locations to compare water levels and recession characteristics. White Geese populations were estimated for both lakes in the early spring. Water samples were collected at both sites in 1996 and again in 1998. Samples were analyzed primarily for nutrients, but other parameters where also considered (i.e. physicals and major ions). In 1998 a trace metal analysis (total and extractable) was conducted and used in combination with the major ion analysis from both years to determine if there were any significant geochemical differences between the two lakes.

Nutrient samples were analyzed at Environment Canada's (EC) Saskatoon Laboratory (1996) and the Indian and Northern Affairs Taiga Environmental Laboratory in Yellowknife (1998) with major ions (1996, 1998) and trace (total and extractable) metals (1998) analyzed at EC's National Laboratory for Environmental Testing (NLET) in Burlington Ontario. A list of the water quality variables, laboratories used and laboratory method/parameter codes are provided in Appendix 1.

3.1 Water Level Monitoring

Water level monitoring was initiated at Karrak Lake on June 6, 1996. A permanent brass cap benchmark was installed in bedrock immediately north of the Karrak Lake Field Station. A staff gauge was also installed in the lake and tied into benchmark using an engineer's level. Water levels were read daily from the staff gauge, with periodic checks made by surveys to the benchmark. Water level monitoring was initiated at Reference Lake on June 14, 1996. As at Karrak Lake, a brass cap benchmark was installed in bedrock near the outlet of the lake. Unfortunately, the remote nature of Reference Lake relative to the Field Station at Karrak Lake did not allow for frequent readings of water levels. Only two water levels were obtained for Reference Lake, one on June 14, 1996 and one on August 13, 1996.

3.2 Summer 1996 Water Quality Program

Four sites on Karrak Lake, including one near the inlet and one near the outlet, were chosen initially in 1996 (Figure 6). Similarly, three sites were chosen on Reference Lake, including one near the inlet and one near the outlet. Site locations were recorded with a Garmin hand-held Global Positioning System (GPS) unit, so that these sites could be re-sampled during subsequent visits (Table 1). Sampling was carried out at all seven sites several times from ice-out (breakup) in June 1996 to ice-in (freeze-up) in August 1996. Field measurements of water temperature, conductivity, and pH were made using hand-held water quality meters. Secchi depth (water clarity) measurements were also made. Samples were collected for analyses of physical and nutrient water quality variables and major ions. Twelve samples were collected from each of the four Karrak Lake sites between June 3, 1996 and August 13, 1996. Six samples were collected from each of the three Reference Lake sites between June 14, 1996 and August 13, 1996. All samples were analyzed for field and lab pH, field and lab conductivity, water temperature, total dissolved solids (TDS), chlorophyll "a", phosphorus (total, dissolved, particulate, ortho-), nitrogen (total, dissolved-with ammonia and nitrate-nitrite forms, particulate), dissolved cations (calcium, magnesium, sodium, potassium), dissolved anions (chloride, fluoride, sulphate), total alkalinity, and reactive silica. Water quality results were compared with 1997 Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines.

Karrak Lake & Reference Lake Site Location Map

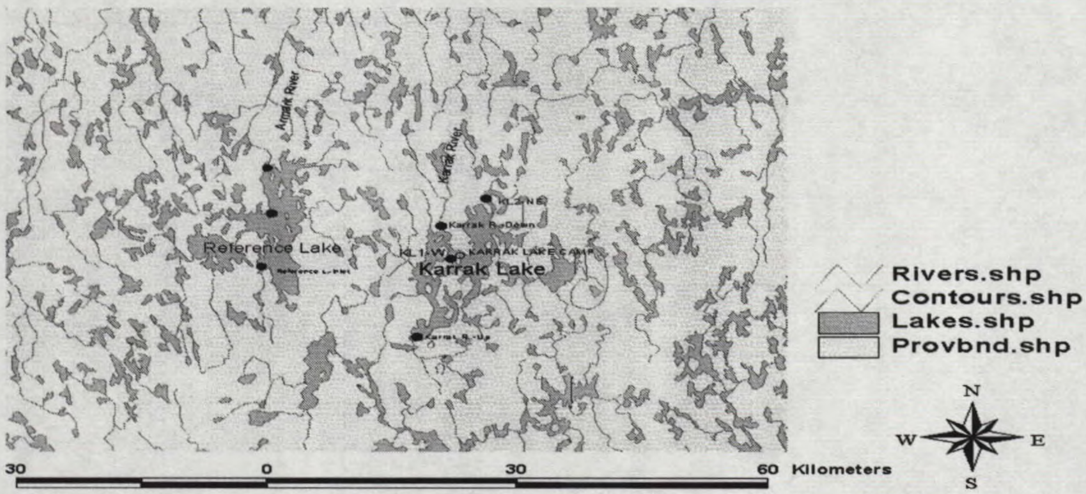


Figure 6: Sampling locations at Karrak Lake and Reference Lake (after NRCan et al, 1997).

Routine water quality samples were collected, but due to logistics (i.e., space and weight restrictions) there were no quality assurance/quality control (QA/QC) replicate samples collected. Field blanks were collected, however minimal sampling was conducted, again due to logistical constraints. Considering that the water quality data collection was being subsidized by other research programs at Karrak Lake, this was the first opportunity to obtain data in this area, and that some regional data, albeit limited, are available for this area, the limitations these logistical constraints imposed were considered acceptable.

Prior to a second year of sampling an initial analysis was conducted using standard parametric statistical tests of significance, testing whether sample means and variances between Karrak and Reference Lake sites were equal by using the Student-t and F-Ratio two-tailed tests (respectively) at a 95% level of confidence. As this was a first year of sampling, interpretations were limited by the small sample sizes (n=48, for Karrak Lake; n=18, for Reference Lake), but certainly provided insight to future sampling designs.

3.3 Summer 1998 Water and Sediment Quality Program

Water and sediment samples were collected in July 1998 at the four Karrak Lake and three Reference Lake sites, using GPS co-ordinates to locate sites previously sampled in June-August 1996. QA/QC samples (consisting of field blanks and field triplicates) were collected at all seven sites. The water column was profiled using a Horiba U-10 automatic water-quality measurement device. The depths, pH, conductivity, turbidity, dissolved oxygen, temperature and salinity were recorded at one metre depth intervals to the bottom of Karrak and Reference Lakes. Hand-held thermometers, pH meters, and conductivity meters were also used as a check on the Horiba field measurements. Water samples were collected from all four Karrak Lake sites and three Reference Lake sites. Water samples were then sent to the DIAND Taiga Environmental Laboratory in Yellowknife for physical, nutrient, and chlorophyll-a analyses. Water samples were sent to EC's NLET in Burlington for major ions and trace (total and extractable) metals analyses scans.

Profundal zone, centre-lake sediments were collected at two sites on Karrak Lake and one site on Reference Lake, using a Phleger corer. The shallow, rocky bottoms of these lakes precluded collection of lake sediment cores, but the uppermost lake sediment collected on the corer bit was transferred into sample jars for nutrients and trace metals analyses at the EC NLET Burlington Lab.

Table 1. 1996 & 1998 Karrak Lake & Reference Water & Sediment Quality Sampling Sites & Locations

KARRAK LAKE & REFERENCE LAKE AQUATIC QUALITY SITES					D. Halliwell July 24/98
SITE	SITE NARRATIVE	LATITUDE or Zone 14 NORTHING	LONGITUDE or Zone 14 EASTING	WATER QUALITY?	SEDIMENT QUALITY?
KL1-W	West Side of Karrak Lake	7458355 metres North	444853 metres East	Yes	Yes
KL2-NE	Northeast Corner of Karrak Lake	7458750 metres North	447600 metres East	Yes	Yes
KARRAK R-UP	Karrak R. at Inlet to Karrak Lake	7454770 metres North	444780 metres East	Yes	No
KARRAK R-DOWN	Karrak R. at Outlet to Karrak Lake	7458570 metres North	443696 metres East	Yes	No
REFERENCE LAKE	Reference Lake	67o14.800'N Lat.	100o51.864'W Long.	Yes	Yes
REFERENCE L-INLET	Armark R. at Inlet to Reference Lake	67o12.549'N Lat.	100o51.034'W Long.	Yes	No
REFERENCE L-OUTLET	Armark R. at Outlet to Reference Lake	67o16.846'N Lat.	100o52.998'W Long.	Yes	No

4.0 RESULTS AND DISCUSSION

4.1 Population Estimates

Population estimates of Snow and Ross' Geese have been obtained in the Karrak Lake vicinity since 1991, with earlier estimates available in 1966, 1976, 1982 and 1988. Estimates for 1996 were 291,000 nesting Ross's Geese and 297,000 nesting Lesser Snow Geese (Alisauskas 1998). Estimates do not include an unknown number of non-breeders that are frequently associated with the colony (Alisauskas and Boyd 1994). As part of the water quality-sampling program a population estimate of 20,000 - 30,000 geese was determined for the area surrounding Reference Lake using the same protocol as is used at Karrak Lake. Moreover, there was little evidence of vegetation denudation surrounding Reference Lake.

4.2 Water Levels

Water levels at Karrak Lake were initiated as soon after ice break-up as was practical. It is not unusual for lake ice at this latitude (just north of the Arctic Circle) to remain intact into early June (Prowse and Onclin, 1987, Magnuson et al., 2000). Karrak Lake demonstrated a relatively rapid recession in water levels through the month of June, and leveling out through the month of July and into August (Figure 7). The overall decline in water level between June 14, 1996 and August 13, 1996 was 0.81 metres. Although there are no continuos water level records for the Reference Lake there was a similar decline in water levels (0.802 m) to that of Karrak Lake for the same period. Although there may be differences in the rates of recession between Karrak and Reference Lakes, the corresponding changes in water levels suggest that there are certainly physiographic similarities between the two lakes. Water level data for the two sites is provided in a tabular format in Appendix 2.

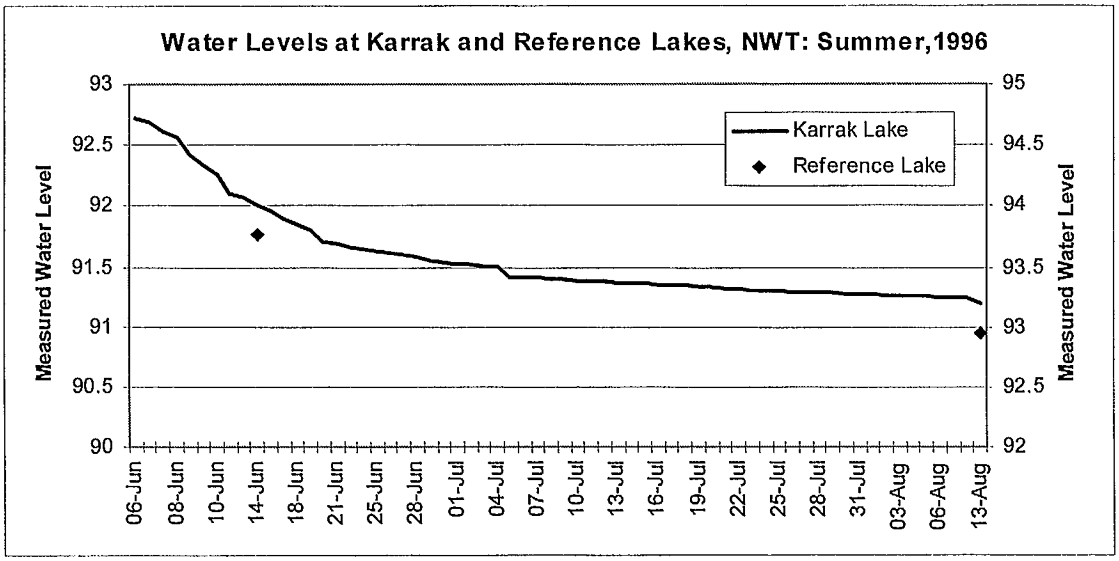


Figure 7. Water Levels at Karrak & Reference Lakes, Nunavut, Summer 1996

4.3 Geochemistry

In order to help discern if any significant differences existed in bedrock or surficial geology between Karrak and Reference Lakes, water quality samples collected in July 1998 were analysed for total and extractable trace metal scans. The geology of the area is poorly known as it has only been geologically mapped at a small scale(1;1,000,000) by the Geological Survey of Canada.

Sample median values for trace metals were compared using Wilcoxon non-parametric statistical testing (n=12 for Karrak Lake and n=3 for Reference Lake; Appendix 3). No significant differences of sample medians (+/- 95% confidence limits, two-tailed test) were detected, for dissolved arsenic and selenium; for extractable iron, manganese, and other elements; and for total aluminum, barium, beryllium, cadmium, cobalt, chromium, iron, manganese, molybdenum, nickel, lead, vanadium, and zinc. Sample medians were significantly different (i.e. higher for Karrak Lake) for only total lithium and strontium. Overall, the bedrock and surficial geology and trace metal geochemistry of Karrak Lake and Reference Lake appear to be very similar, suggesting that Reference Lake is a suitable control lake, from a geological/geochemical standpoint.

Median values for major ions were found to be significantly higher at Karrak Lake for total and dissolved calcium, magnesium, potassium and sodium, at the 95% confidence level. Such differences in major ion concentrations between Karrak Lake and Reference Lake could be due to different geology and geochemistry, but other factors can also contribute to these differences. This disparity could also be due to differences in surface runoff and landscape characteristics between the two sites (e.g., denudation of vegetation). Further effort will be required to evaluate whether there is a difference in the geochemistry of the surface runoff from the various land surfaces.

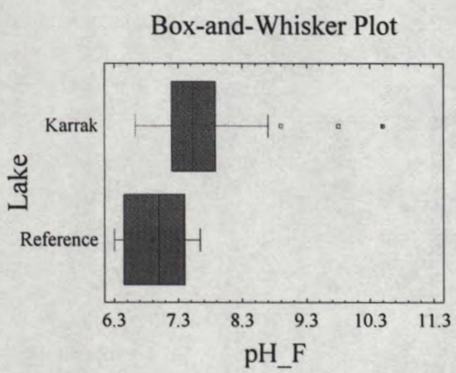
4.4 Water Qulaity

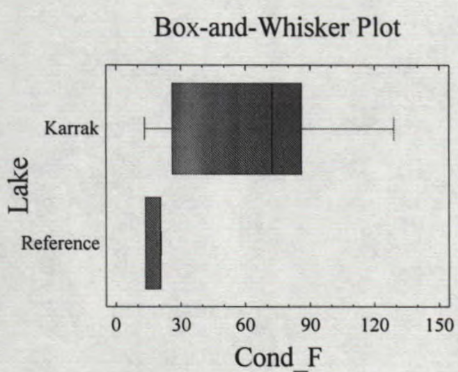
Lab results from both 1996 and 1998 are available through Environment Canada via the Prairie and Northern Region's regional water quality database – (ACBIS). Parametric statistics, which assume normal and/or lognormal distributions, were used to make comparisons between the two lakes (Appendix 3). Specifically the Student-t Test was used to test the null hypothesis that Karrak Lake and Reference Lake sample means are equal using a two-tail test at the 95% confidence level. The F-Ratio test was also used to test the null hypothesis that Karrak Lake and Reference Lake samples had equal sample variances. Considering the limitations of parametric statistics for water quality data, which is rarely normally and/or log-normally distributed, non-parametric statistics were also employed in the analysis. The use of non-parametric (ranked values, percentile) statistics are often better suited and more reliable for analysing water quality data (Sanders *et al.*, 1983). The Wilcoxon Unpaired Test was used to test the null hypothesis that the Karrak Lake and Reference Lake sample medians (i.e. 50^{th} percentile values) are equal (Appendix 3).

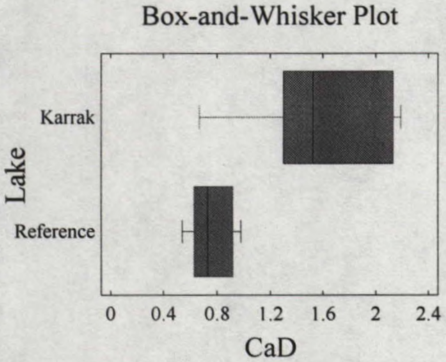
4.4.1 Spatial Variability

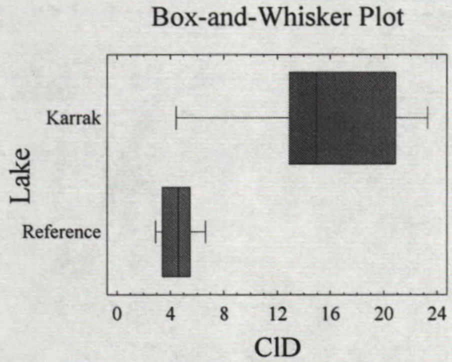
Student-t tests indicated that of the physical and nutrient parameters only the dissolved organic carbon was significantly different (i.e. higher at Karrak Lake at a 95% confidence level) between the two lakes (Table for F-test and Student t). Although there was little difference between the composite sample means between the two sites F-Ratio tests revealed that 34% of the variables had variances significantly higher (95% confidence level) at Karrak Lake as compared to Reference Lake. Sample standard deviations were significantly higher (wider) at Karrak Lake for water temperature; field pH and conductivity; lab conductivity; true colour; total dissolved solids; ortho- and particulate phosphorus; total and particulate nitrogen; nitrate-nitrite; alkalinity; dissolved calcium, magnesium, potassium, and sodium; total hardness; dissolved chloride and sulphate; reactive silica; particulate organic carbon; total aluminum, barium, iron, lithium, strontium; and total calcium and magnesium. (i.e. 28 of 81, or 34%, of the variables measured). The higher variability at Karrak Lake sites may be an artifact of the larger sample sizes for Karrak Lake samples, the larger number of Karrak lake sites (i.e. four versus three), or a combination of both.

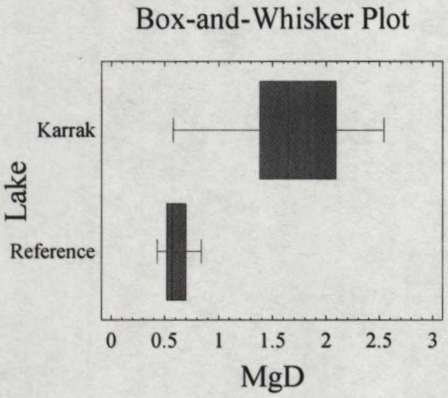
Recognising the limitations of using parametric statistical tests on water quality data (see discussion above) the non-parametric Wilcoxon Ranked Test, (two-tails and the 95% confidence level), was also employed to compare composite sample medians for all water quality variables between the two lakes (Appendix 3). Sample medians are significantly higher at Karrak Lake for an number of variables including: (field and lab) pH, (field and lab) conductivity, total and dissolved major cations (i.e. calcium. magnesium, potassium, sodium), total hardness, dissolved major anions (chloride, sulphate), dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), particulate organic carbon (PON), and total dissolved solids (TDS). The Wilcoxon Ranked Test also revealed that turbidity and total suspended solids (TSS), the latter sometimes being known as non-filterable residue (NFR), are statistically higher at the Reference Lake. Water quality data are shown in box-and-whisker plots representing those variables which are higher at Karrak Lake (Figure 8) those which are higher at the Reference Lake (Figure 9) and those which do not appear to show any difference between the two lakes (Figure 10) based on median values.

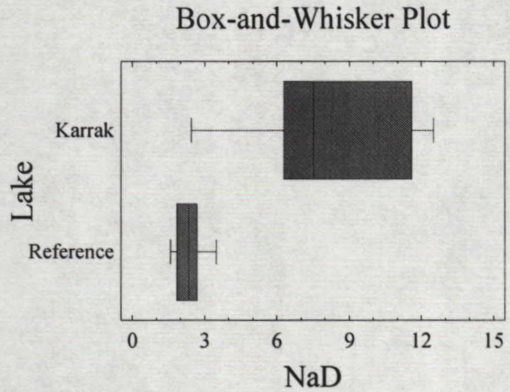


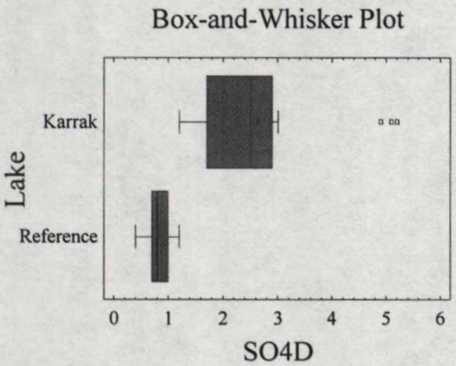


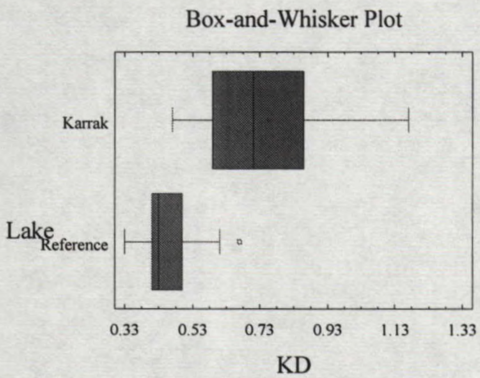

Box-and-Whisker Plot
Karrak
Lake
Reference
0 0.4 0.8 1.2 1.6 2 2.4
CaD


Box-and-Whisker Plot
Karrak
Lake
Reference
0 4 8 12 16 20 24
ClD


Box-and-Whisker Plot
Karrak
Lake
Reference
0 0.5 1 1.5 2 2.5 3
MgD


Box-and-Whisker Plot
Karrak
Lake
Reference
0 3 6 9 12 15
NaD


Box-and-Whisker Plot
Karrak
Lake
Reference
0 1 2 3 4 5 6
SO4D


Box-and-Whisker Plot
Karrak
Lake
Reference
0.33 0.53 0.73 0.93 1.13 1.33
KD

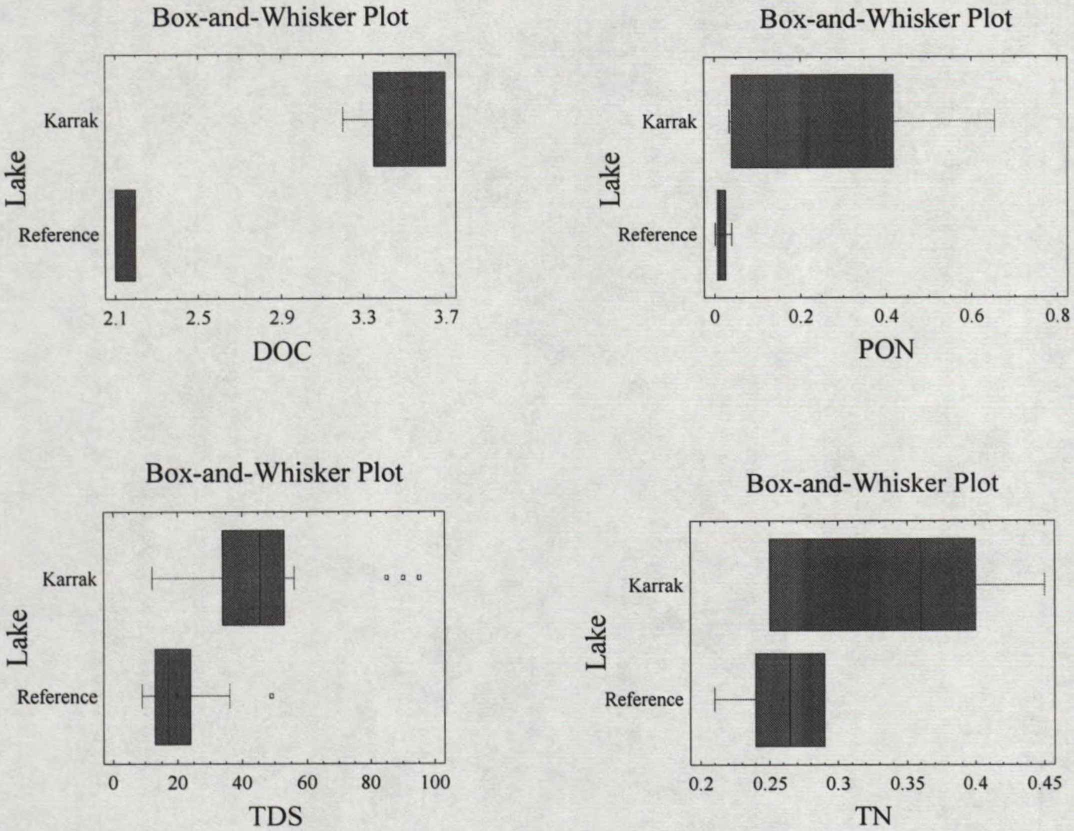


Figure 8. Multiple Box-and-Whisker Plots. Water Quality Variables where median values appear significantly higher at Karrak Lake than Reference Lake. Field conductivity is measured in microsiemens per centimetre (μs/cm), pH is measured in pH units, and all other water quality variables are measured in milligrams per litre (mg/L). NOTE: PH_F = Field pH, Cond_F = Field Conductivity, CaD = Dissolved Calcium, ClD = Dissolved Chloride, MgD = Dissolved Magnesium, NaD = Dissolved Sodium, SO4D = Dissolved Sulphate, KD = Dissolved Potassium, DOC = Dissolved Organic Carbon, PON = Particulate Organic Nitrogen, TDS = Total Dissolved Solids, TN = Total Nitrogen.

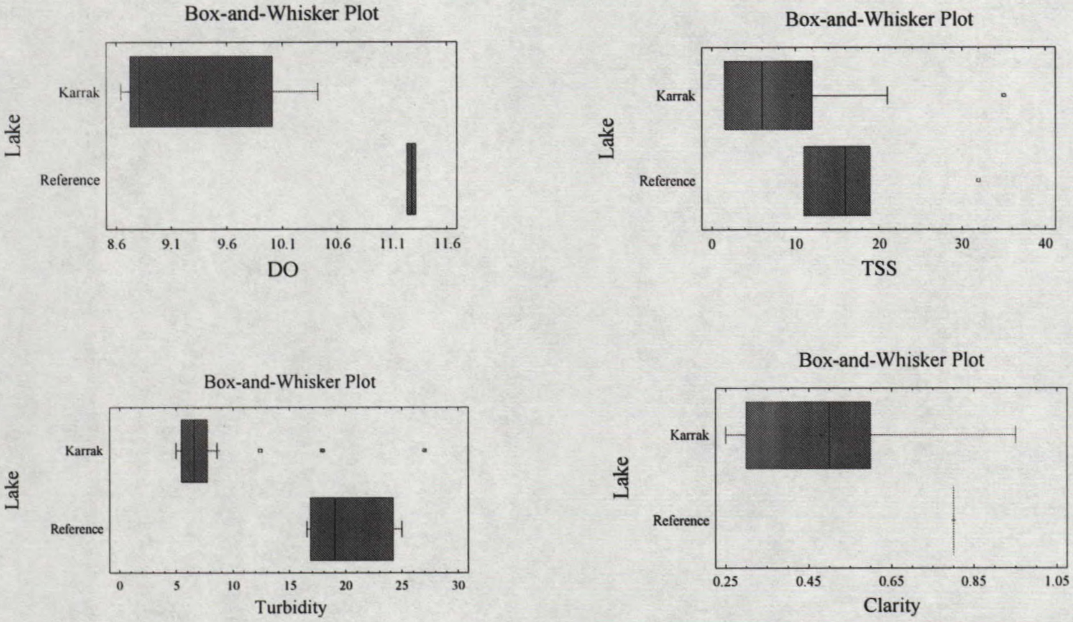


Figure 9. Multiple Box-and-Whisker Plots. Water Quality Variables where median values appear significantly higher at Reference Lake than Karrak Lake. Turbidity is measured in Nephelometric Turbidity Units (NTUs), Clarity is measured in metres. All other water quality variables are measured in milligrams per litre (mg/L). NOTE: DO = Dissolved Oxygen, TSS = Total Suspended Solids.

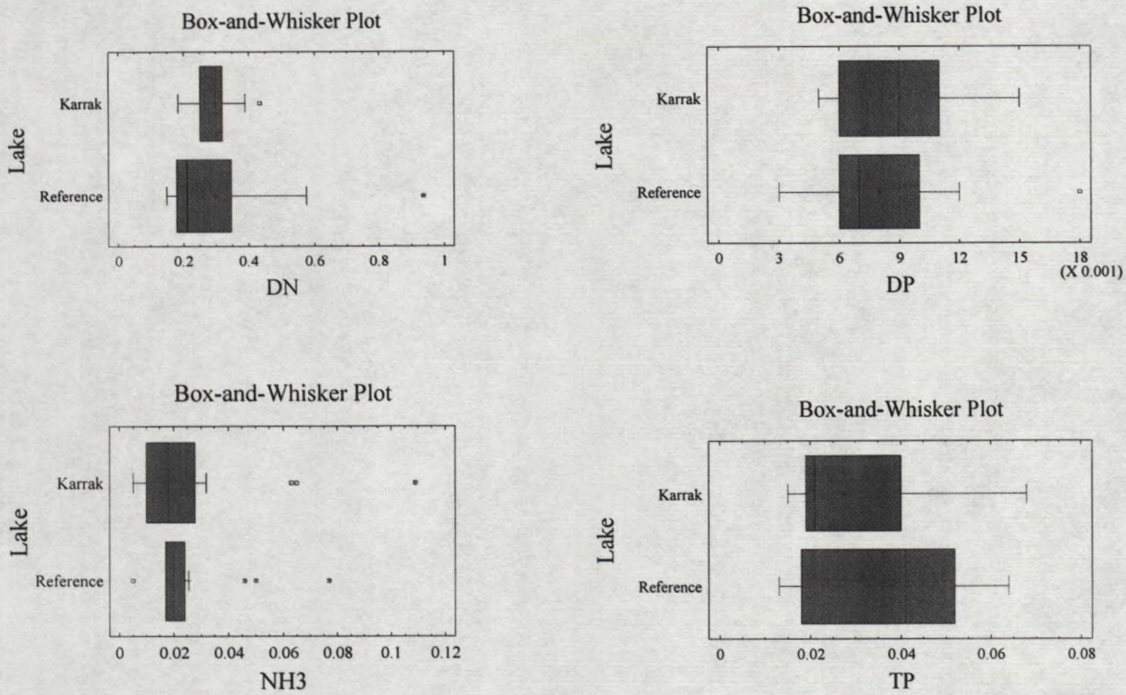


Figure 10. Multiple Box-and-Whisker Plots. Some Water Quality Variables where the median values appear not to be significantly different between Karrak Lake and Reference Lake. NOTE: All water quality variables are measured in milligrams per litre (mg/L). NOTE: DN = Dissolved Nitrogen, DP = Dissolved Phosphorus, NH3 = Total Ammonia, TP = Total Phosphorus.

Given that 58 pairwise comparisons were done at the $\alpha = 0.05$ level, one would expect three (3) to be significantly different by chance alone. To correct for this, the Bonferoni Correction was used to calculate a two-tail probability threshold value for significance at $\alpha = 0.05$, (i.e., P = 0.05/58 = 0.0008621). Based on the corrected probability threshold, there are still nine (9) water quality variables (dissolved calcium, dissolved chloride, field conductivity, lab conductivity, dissolved potassium, dissolved magnesium, dissolved sodium, dissolved sulphate, and total dissolved solids) which demonstrate a significant difference.

Considering that the physiographic characteristics (i.e., surficial geology and hydrology) of Karrak Lake and Reference Lake are essentially the same, the differences in water quality may be attributed to the differences in goose populations around each lake. By defoliating the landscape, they may impact on surface run-off and subsequently influence physical water quality variables such as pH, conductivity and total dissolved solids (TDS). There are also other possible factors that could result in the differences seen between these lakes, but will require further detailed study. A necessary step, however, in any future investigations will be to compare and evaluate several control or "reference" lakes relative to Karrak Lake. Moreover it will be necessary to expand this investigation into other high population areas (i.e., white geese) to determine if similar trends can be detected.

4.4.2 Temporal Variability

The short sampling record involving June-August 1996 and July 1998 does not permit much inter annual interpretation with regard to long-term temporal variability of water quality. Proxy water quality data from other monitoring sites are available, but unfortunately they are not in the direct vicinity of the QMGMBS and Karrak Lake area and records are also relatively short. Notwithstanding the limitations of a short record, the June-August 1996 water quality data provides some insight into seasonal temporal variability, or seasonality. Since, however, the Karrak and Reference lake sites are in an area of relatively mild topographic relief and consist predominantly of lake samples, seasonality will be more subtle than if sample sites were located in streams and/or in high relief terrain.

As would be expected, water temperatures display a typical seasonality, rising through the open water season and then dropping off as air temperatures cool. August 1996 lab pH values tend to be slightly higher than those from June 1996, perhaps due to variations in runoff and precipitation. Samples from June 1996 also demonstrate higher conductivities (lab) and higher total nutrient (nitrogen, phosphorus) values as compared to those collected in August 1996, again likely due to differences in spring runoff. Similarly, dissolved major ion and nutrient values tended to be higher in June 1996 than August 1996 samples. Major ions and nutrients levels, however, generally increased from June 1996 to August 1996 in both Karrak and Reference Lake, especially in the former case. This is in contrast to results from other water quality studies in the NWT which demonstrate a decrease in nutrient levels during the open-water season, typically due to biological uptake (e.g., Halliwell and Catto, 1998). An interesting question would be whether "imported" nutrients by a large population of geese could offset the normal biological uptake within an aquatic ecosystem.

4.4.3 Nutrient Deficiency Ratios

Mean molar carbon- nitrogen (C:N), nitrogen-phosphorus (N:P), carbon-phosphorus (C:P), and carbon-chlorophyll "*a*" (C:chl *a*) ratios can be used to characterize nutrient deficiencies in lakes and oceans with lake values generally lower and more highly variable than ocean values (Hecky et al., 1993). Applying this technique to the Karrak and Reference Lake data and assuming that particulate organic carbon (POC) approximates total particulate carbon (i.e. concentration of dissolved inorganic carbon is negligible), demonstrated that there is no nitrogen, phosphorus, or general nutrient deficiency in either lake. The particulate C/N, N/P, C/P and C/chlorophyll *a* ratios (i.e., 8.3, 22, 129, and 4.2, respectively) are well below threshold reference ratios. Of particular interest is that the Karrak Lake ratios for particulate C/N, N/P and C/P are lower than the Reference Lake ratios, again suggesting that Karrak Lake has relatively more nutrients.

4.4.4 Regional comparison of Karrak and Reference Lake water quality

The number of water quality samples collected at Karrak and Reference Lakes in 1996 and 1998 begins to approach the number of water quality samples historically collected in this region (i.e., Ellice River near the Mouth, Tree River near the Mouth, and to a lesser extent the Back River above Hermann River/Deep Rose Lake). Relative to these regional water quality sites, Karrak and Reference Lake water temperatures are higher, due in part to the shallow depths of Karrak and Reference Lakes and that the historic samples were collected from rivers rather than lakes. Chlorophyll "a" and dissolved inorganic nitrogen forms are comparatively lower at both Karrak and Reference Lakes, whereas total, dissolved (organic forms), and particulate nitrogen are higher, particularly for Karrak Lake. Phosphorus levels at Karrak and Reference Lakes were reasonably consistent with other regional data. Karrak Lake sites also exhibited some elevated major ion concentrations (e.g. sodium, potassium, and chloride) relative to the Ellice and Tree River sites. Overall the water quality values at Reference Lake are generally more comparable to regional water quality values as reflected by data from the Ellice and Tree River values. This provides support to the selection of Reference Lake as a control, and additional evidence to suggest that the high populations of geese at Karrak Lake may be influencing the water quality.

4.4.5 CCME Canadian Water Quality Guidelines

Overall, measured water quality variables at Karrak Lake and Reference Lake seldom exceed the Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines designed to protect drinking water and freshwater aquatic life (CCME, 1999). Water temperatures in the shallow Karrak Lake, however, can exceed the CCME Canadian Water Quality Guideline of 15°C. The turbidity at Karrak Lake and Reference Lake appears to always exceed the CCME Canadian Water Quality Guideline (> 5 NTU). The high levels of turbidity is, perhaps, the most serious water quality problem at both Karrak Lake and Reference Lake, though it is much more serious at Karrak Lake (where the median value is 19.1 NTU and the range is 16.5 to 25 NTU). Finally, dissolved oxygen exceeds the upper CCME Canadian Water Quality Guideline of 5.0 to 9.5 milligrams per litre range at the northeast corner of Karrak Lake and the centre of Reference Lake (two out of three sites where it was measured using an Horiba U-10 automatic water quality instrument).

4.5 Sediment Quality

Lake sediment cores could not be collected in Karrak Lake and Reference Lake because of the rocky bottoms of the lakes. Samples were collected at the top of the sediment column in Karrak Lake at the KL1-W and KL2-NE sites, as well as the Reference Lake Centre site. Unfortunately, there was not sufficient sample size for analysis from Reference Lake. In the absence of Reference Lake sediment quality data, the similarity or dissimilarity of the lake sediment geo-chemistry between Karrak Lake and Reference lakes cannot be determined at this time.

The similarity in lake sediment chemistry between the two Karrak Lake sites sampled (i.e. KL-1W, KL2-NE) suggests minor spatial variability within the Karrak Lake area. The Karrak Lake sediments contained 0.005-0.030% inorganic carbon, 1.13-1.60% organic carbon, and 0.09-1.14% organic nitrogen (all values being higher in the KL-1W site). The 3.4-9.2 milligrams per kilogram dry weight (mg/kg) arsenic and 0.10 mg/kg selenium values were low, with arsenic values less than the CCME Interim Sediment Quality Guideline for freshwater sediments (CCME, 1999). Total aluminum values (5.18-5.36%) and total iron values (1.95-3.57%) were high. The 0.50 mg/kg cadmium values, 34.00-36.00 mg/kg chromium, 13.00-14.00 mg/kg copper, 19.00-20.00 mg/kg lead, and 41.00-53.00 mg/kg zinc values were well below the CCME Interim Sediment Quality Guidelines for freshwater sediments. Only the 0.316-0.330 mg/kg total mercury value exceeded (i.e. nearly doubled) the CCME Interim Sediment Quality Guideline for freshwater sediments of 0.17 mg/kg (the KL2-NE site was the higher of the two sites). Fortunately, the total mercury levels for the two sites are below the 0.486 mg/kg CCME sediment quality probable effects limit (PEL) for freshwater aquatic life. Total mercury is either transported long-range atmospherically (i.e. LRTAP) or is geological in origin (i.e. sulphides in outcrop, leakage up geological faults).

5.0 SUMMARY & RECOMMENDATIONS

5.1 Summary of Results

Karrak Lake and Reference Lake areas appear to be geologically similar, based on a comparison of median values for trace metals between the two lakes and a review of the available geological literature. Despite the lack of bathymetric knowledge about the two lakes, Karrak and Reference Lakes appear to have similar hydrology, in terms of area, size, number of inlets and outlets, and drainage basin shape, size, and flow direction. Climatic differences between the Karrak Lake and Reference Lake areas are not expected because there is no significant topographic relief and the lakes are located only 30 kilometres apart. There is no known evidence of different wetland or vegetation types (e.g. bogs versus fens), and none are expected, given the similar location, geology, hydrology, and climate. These comparative data support the selection of Reference Lake as a paired control for determining water quality impacts at Karrak Lake due to increased populations of geese.

Notwithstanding the similarities between the two lakes there were also notable differences in several water quality parameters. Non-parametric statistical analyses of the water quality data indicate that field pH and conductivity; dissolved calcium, chloride, magnesium, sodium, sulphate, and potassium major ions; dissolved organic carbon and particulate organic nitrogen; total dissolved solids; and total nitrogen values are all significantly higher for Karrak Lake as compared to Reference Lake. In contrast, dissolved oxygen, total suspended solids (i.e., non-filterable residue), turbidity, and clarity are significantly higher for Reference Lake. Although there are some differences in the nutrients between the two lakes, nutrient ratios, which can be used as indicators of nutrient deficiency, indicate that there is no nitrogen, phosphorus, or general nutrient deficiency in either the Karrak Lake or the Reference Lake. Results of this comparative analysis provide support for the hypothesis that high populations of geese have affected the water quality at Karrak Lake. This hypothesis is further supported by a review of historic water quality data, which indicates that Reference Lake data is more regionally analogous than that of Karrak Lake.

Water quality variable values measured at Karrak Lake and Reference Lake sites exceed CCME Canadian Water Quality Guidelines designed to protect drinking water for turbidity (virtually all samples from all sites, especially Karrak Lake sites), water temperature (July only), and occasionally dissolved oxygen. All other values are below CCME Canadian Water Quality Guidelines for freshwater aquatic life and drinking water, meaning that there is good water quality, overall. Total and fecal coliforms, however, were not measured.

Sediment quality was only measured at two Karrak Lake sites, the rocky bottom of the lake making sampling difficult, and damaging the coring bit. All total metals are below CCME Guidelines, with the exception of total mercury, which is approximately twice the 0.17 milligram per kilogram dry weight total mercury CCME Guideline for freshwater sediments, but (fortunately) less than the Probable Effects Limit (PEL) for effects on aquatic life. The total mercury is likely of a natural (geological) origin and/or of anthropogenic origin (i.e., Long Range Transport of Atmospheric Pollutants, LRTAP-Cold Condensation Hypothesis).

5.2 Recommendations for Future Work

Requirements for baseline aquatic quality monitoring:

1) Ongoing water quality monitoring of Karrak Lake for water temperature, field conductivity, field pH, water clarity, dissolved oxygen, turbidity, water quality variables. All water quality variables can be easily measured in the field with thermometers, hand-held conductivity meters, hand-held pH meters, Secchi discs, and automatic water quality instruments (i.e. for turbidity and dissolved oxygen). Hand-held meters and Secchi discs cost less than $200 each; automatic water quality checkers (to measure turbidity and dissolved oxygen) are, however, more expensive. In general, however, this base line water quality monitoring is relatively low cost and can provide a very valuable data set over time. In the absence of annual monitoring a biennial monitoring program could also

be considered, recognising of course, that it will take longer to obtain enough data to detect any trends.

2) Bacteriological samples (i.e. total & faecal coliforms, Escheria coli bacteria) should be collected in Karrak Lake primarily for Occupational Health and Safety concerns for the operation of the remote field camp at this location. Bacteriological analyses should be performed in the field, because of the short holding time (i.e. time between sampling and sample deterioration) for bacteriologicals.

Requirements for specific studies/surveys:

1) Additional regional (i.e. within the QMGMBS) water quality sampling to confirm applicability of the Reference Lake area as a suitable control area for the Karrak Lake Study.

2) Similar water quality sampling should be done at other sites of high geese populations to determine if there are similar effects occurring (e.g., McConnell River Sanctuary).

3) The state of environmental health of the two lakes should be compared, using Rigosha Meter drift net zooplankton enumeration (of different species) and chemical analyses.

4) If there is nutrient transfer by geese from agricultural lands in the southern United States and Mexico to Nunavut, it is possible that there might be similar pesticides and herbicides transfer, as well. Some future water and sediment quality samples should be analysed for these as well, during at least one summer field season.

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APPENDIX 1

NAQUADAT/ENVIRODAT 1998 Field and Lab Parameter Codes. Water & Sediment Quality Samples

NAL=TEL=INAC Yellowknife Northern Analytical Laboratory = Taiga Environmental Laboratory,
NLET=EC Burlington National Lab for Environmental Testing.

Sample Media	Water Quality Variable	NAQUADAT/ENVIRODAT Parameter Code	Lab
Water	Temperature (Field)	02061F	HORIBA
Water	pH (Field)	10301F	HORIBA
Water	pH (Lab)	10301L	NAL
Water	Conductivity (Field)	02041F	HORIBA
Water	Conductivity (Lab)	02041L	NAL
Water	True Colour	02021L	NAL
Water	Turbidity	02081L	NAL
Water	Non-Filterable Residue (NFR)	010406	NAL
Water	Filterable Residue (FR)	010451	NAL
Water	Ammonia	007557	NAL
Water	Total Phosphorus	015406	NAL
Water	Dissolved Phosphorus	015104	NAL
Water	Dissolved Nitrogen	007617	NAL
Water	Particulate Organic Carbon	006902	NLET
Water	Particulate Organic Nitrogen	007902	NLET
Water	Dissolved Inorganic Carbon	100300	NLET
Water	Dissolved Organic Carbon	006104	NLET
Water	Nitrate-Nitrite	07110L	NLET
Water	Total Alkalinity	10111	NLET
Water	Chlorophyll A	Field	FIELD
Water	Dissolved Oxygen	Field	HORIBA
Water	Sulphate	16306	NLET
Water	Reactive Silica	14108	NLET
Water	Chloride	17206	NLET
Water	Dissolved Calcium	100431	NLET
Water	Dissolved Fluoride	009117	NLET
Water	Dissolved Magnesium	100432	NLET
Water	Dissolved Sodium	100433	NLET
Water	Dissolved Potassium	100434	NLET
Water	Dissolved Selenium	100254	NLET
Water	Dissolved Arsenic	100253	NLET
Water	Extractable Aluminium	100081	NLET
Water	Extractable Barium	100082	NLET
Water	Extractable Beryllium	100083	NLET
Water	Extractable Boron	100097	NLET
Water	Extractable Cadmium	100084	NLET
Water	Extractable Chromium	100086	NLET
Water	Extractable Cobalt	100085	NLET
Water	Extractable Copper	100087	NLET
Water	Extractable Iron	100088	NLET
Water	Extractable Lithium	100089	NLET
Water	Extractable Lead	100093	NLET

Sample Media	Water Quality Variable	NAQUADAT/ENVIRODAT Parameter Code	Lab
Water	Extractable Manganese	100090	NLET
Water	Extractable Molybdenum	100091	NLET
Water	Extractable Nickel	100092	NLET
Water	Extractable Strontium	100094	NLET
Water	Extractable Vanadium	100095	NLET
Water	Extractable Zinc	100096	NLET
Water	Extractable Calcium	100098	NLET
Water	Extractable Magnesium	100099	NLET
Water	Extractable Sodium	100100	NLET
Water	Extractable Potassium	100101	NLET
Water	Total Aluminium	100216	NLET
Water	Total Barium	100217	NLET
Water	Total Beryllium	100218	NLET
Water	Total Cadmium	100219	NLET
Water	Total Chromium	100221	NLET
Water	Total Cobalt	100220	NLET
Water	Total Copper	100222	NLET
Water	Total Iron	100223	NLET
Water	Total Lead	100228	NLET
Water	Total Lithium	100224	NLET
Water	Total Manganese	100225	NLET
Water	Total Molybdenum	100226	NLET
Water	Total Nickel	100227	NLET
Water	Total Silver	100234	NLET
Water	Total Strontium	100229	NLET
Water	Total Vanadium	100230	NLET
Water	Total Zinc	100231	NLET
Water	Total Calcium	100232	NLET
Water	Total Magnesium	100233	NLET
Water	Total Sodium	100234	NLET
Water	Total Potassium	100235	NLET
Sediment	Inorganic Carbon	002674	NLET
Sediment	Organic Carbon	006912	NLET
Sediment	Organic Nitrogen	007912	NLET
Sediment	Total Aluminium	103202	NLET
Sediment	Total Arsenic	033052	NLET
Sediment	Total Cadmium	048053	NLET
Sediment	Total Chromium	024053	NLET
Sediment	Total Cobalt	027053	NLET
Sediment	Total Copper	029053	NLET
Sediment	Total Iron	026053	NLET
Sediment	Total Lead	082053	NLET
Sediment	Total Manganese	025053	NLET
Sediment	Total Mercury	100404	NLET
Sediment	Total Nickel	028053	NLET
Sediment	Total Selenium	034052	NLET
Sediment	Total Zinc	030053	NLET

APPENDIX 2

Water Levels Measured at Karrak Lake, Nunavut: 1996

Date	Calculated Actual Water Level Karrak Lake	Reference Lake Surveyed Water Level Reference Lake	Surveyed Water Level	Staff Gauge	Time	Comments
06-Jun	92.7175		92.7175	0.7800	2132	first measurement
07-Jun	92.6855			0.7480	830	
07-Jun	92.6155			0.6780	2205	
08-Jun	92.5575			0.6200	935	
08-Jun	92.4305		92.4305	0.6480	1700	gauge reset
09-Jun	92.3375			0.5550	1457	
10-Jun	92.2550			0.4725	1020	gauge fell over
12-Jun	92.0975			0.6850	1110	
12-Jun	92.0675		92.0675	0.6550	2303	gauge reset
14-Jun	92.0025	93.7650		0.5900	942	
15-Jun	91.9525			0.5400	1300	
16-Jun	91.8925			0.4800	1140	
18-Jun	91.8425			0.4300	2000	
19-Jun	91.8075			0.3950	2200	
20-Jun	91.7075		91.7075	0.3750	2330	gauge reset
21-Jun	91.6875			0.3550	2245	
23-Jun	91.6625			0.3300	124	
24-Jun	91.6525			0.3200	145	
25-Jun	91.6325			0.3000	100	
26-Jun	91.6225			0.2900	1213	
27-Jun	91.6025			0.2700	150	
28-Jun	91.5825			0.2500	1520	
29-Jun	91.5575			0.2250	1300	
30-Jun	91.5425			0.2100	1335	
01-Jul	91.5300			0.1975	1350	
02-Jul	91.5275			0.1950	1350	
03-Jul	91.5125			0.1800	1945	
04-Jul	91.5075			0.1750	1235	
05-Jul	91.4200		91.4200	0.4800	2315	gauge reset
06-Jul	91.4150			0.4750	2215	
07-Jul	91.4075			0.4675	2230	
08-Jul	91.4025			0.4625	2200	
09-Jul	91.3975			0.4575	2035	
10-Jul	91.3900			0.4500	2340	
11-Jul	91.3800			0.4400	2330	
12-Jul	91.3775			0.4375	2115	
13-Jul	91.3625			0.4225	2155	
14-Jul	91.3625			0.4225	2205	
15-Jul	91.3625			0.4225	2337	
16-Jul	91.3575			0.4175	2305	
17-Jul	91.3550			0.4150	2345	
18-Jul	91.3500			0.4100	2335	
19-Jul	91.3400			0.4000	2115	
20-Jul	91.3300			0.3900	2215	
21-Jul	91.3250			0.3850	2305	
22-Jul	91.3150			0.3750	2350	
23-Jul	91.3075			0.3675	2251	
24-Jul	91.3050			0.3650	2310	
25-Jul	91.3000			0.3600	2105	
26-Jul	91.2950			0.3550	2237	
27-Jul	91.2900			0.3500	2320	
28-Jul	91.2850			0.3450	2350	
29-Jul	91.2850			0.3450	2235	
30-Jul	91.2800			0.3400	2050	
31-Jul	91.2750			0.3350	2035	
01-Aug	91.2700			0.3300	2210	
02-Aug	91.2650			0.3250	2015	
03-Aug	91.2625			0.3225	2310	
04-Aug	91.2600			0.3200	1950	
05-Aug	91.2550			0.3150	2200	
06-Aug	91.2500			0.3100	2045	
07-Aug	91.2500			0.3100	2135	
08-Aug	91.2450			0.3050	2230	
13-Aug	91.2000	92.9550	91.2000		1242	gauge removed

Appendix 3

Summary of Water Quality Data and General statistics

T- Test and F- Test results

Wilcoxon Unpaired Test results

General Statistics and results of T- Test and F- Test

Parameters	Units	Karrak Lake			Reference lake			Significance	
		N of cases	Mean	Standard Dev	N of cases	Mean	Standard Dev	Student T-test	F-test
Temp	oC	43	9.605	5.897	17	8.771	3.164	N	Y
pH-F	pH	26	7.730	0.901	14	6.903	0.520	N	Y
Cond-F	uS/cm	17	62.547	32.667	11	18.764	3.324	N	Y
Turbidity	NTU	16	8.638	5.918	8	20.225	3.771	N	N
DO	mg/L	6	9.237	0.772	2	11.280	0.057	N	N
Salinity	%	6	0.000	0.000	2	0.000	0.000	NA	NA
Clarity	m	11	0.480	0.222	1	0.800	NA	NA	NA
CAVol	mL	21	330.000	163.982	12	357.500	174.362	N	N
Chloro-a	mg/L	18	0.002	0.002	12	0.002	0.001	N	N
pH-L	pH	19	6.705	0.227	15	6.506	0.162	N	N
Cond-L	uS/cm	19	76.189	24.985	15	25.553	5.069	N	Y
TrueCol	TCU	12	5.542	2.958	8	4.250	1.414	N	Y
TDS	mg/L	18	46.661	23.860	15	20.067	11.304	N	Y
TSS	mg/L	11	9.682	10.216	6	17.500	7.868	N	N
TP	mg/L	23	0.028	0.014	15	0.038	0.019	N	N
DP	mg/L	23	0.009	0.003	15	0.008	0.004	N	N
OP	mg/L	12	0.003	0.002	6	0.002	0.000	N	Y
PP*	mg/L	7	0.012	0.004	6	0.012	0.002	N	Y
PN	mg/L	12	0.084	0.027	6	0.069	0.008	N	Y
NH3	mg/L	23	0.026	0.024	15	0.026	0.019	N	N
NO3NO2	mg/L	24	0.008	0.005	15	0.006	0.003	N	Y
DN	mg/L	21	0.294	0.067	14	0.297	0.219	N	N
TN*	mg/L	7	0.339	0.079	6	0.260	0.032	N	Y
AlkT	mg/L	19	5.026	2.275	10	3.300	0.961	N	Y
Ca-dis	mg/L	19	1.587	0.476	10	0.769	0.158	N	Y
Mg-dis	mg/L	19	1.678	0.554	10	0.609	0.139	N	Y
F-dis	mg/L	19	0.024	0.020	10	0.022	0.016	N	N
K-dis	mg/L	19	0.753	0.198	10	0.461	0.105	N	Y
Na-dis	mg/L	19	8.271	2.990	10	2.396	0.635	N	Y
Cl-dis	mg/L	19	15.848	5.383	10	4.596	1.258	N	Y
SiO2	mg/L	18	0.240	0.147	10	0.266	0.072	N	Y
SO4-dis	mg/L	19	2.632	1.195	10	0.830	0.236	N	Y
Hard-T	mg/L	7	10.214	4.516	6	4.800	1.028	N	Y
POC	mg/L	11	0.586	0.157	4	0.538	0.077	N	N
PON	mg/L	8	0.231	0.264	4	0.016	0.017	N	Y
DOC	mg/L	12	3.525	0.201	3	2.167	0.058	Y	N
DIC	mg/L	11	1.527	0.283	3	1.200	0.100	N	N
As-diss	mg/L	12	0.000	0.000	3	0.000	0.000	N	NA
Se-diss	mg/L	12	0.000	0.000	3	0.000	0.000	N	NA
Al-tot	mg/L	12	0.262	0.169	3	0.399	0.008	N	Y
Ba-tot	mg/L	12	0.004	0.002	3	0.005	0.000	N	Y
Be-tot	mg/L	12	0.025	0.000	3	0.025	0.000	N	NA
Cd-tot	mg/L	12	0.000	0.000	3	0.000	0.000	N	NA
Co-tot	mg/L	12	0.000	0.000	3	0.000	0.000	N	N

		N of cases	Mean	Standard Dev	N of cases	Mean	Standard Dev	Student T-test	F-test
Cr-tot	mg/L	12	0.000	0.000	3	0.001	0.000	N	N
Cu-tot	mg/L	11	0.001	0.000	3	0.001	0.000	N	N
Fe-tot	mg/L	11	0.485	0.358	3	0.544	0.034	N	Y
Li-tot	mg/L	12	0.003	0.003	3	0.001	0.000	N	Y
Mn-tot	mg/L	12	0.018	0.007	3	0.012	0.006	N	N
Mo-tot	mg/L	12	0.000	0.000	3	0.000	0.000	N	NA
Ni-tot	mg/L	12	0.001	0.000	3	0.001	0.000	N	N
Pb-tot	mg/L	12	0.000	0.000	3	0.001	0.000	N	N
Sr-tot	mg/L	12	0.016	0.003	3	0.007	0.001	N	Y
V-tot	mg/L	12	0.001	0.000	3	0.001	0.000	N	N
Zn-tot	mg/L	11	0.002	0.002	3	0.002	0.001	N	N
Ca-tot	mg/L	12	1.856	0.335	3	0.863	0.047	N	Y
Mg-tot	mg/L	12	1.859	0.431	3	0.680	0.096	N	Y
Na-tot	mg/L	12	7.777	2.246	3	1.963	0.547	N	N
K-tot	mg/L	12	0.774	0.144	3	0.507	0.050	N	N
Ag-tot	mg/L	12	0.000	0.000	3	0.000	0.000	NA	NA
Al-extr	mg/L	11	0.149	0.069	3	0.180	0.078	N	N
Ba-extr	mg/L	12	0.002	0.001	3	0.002	0.002	N	N
Be-extr	mg/L	12	0.001	0.000	3	0.001	0.000	NA	NA
Cd-extr	mg/L	12	0.003	0.000	3	0.003	0.000	N	N
Co-extr	mg/L	12	0.003	0.000	3	0.003	0.000	N	N
Cr-extr	mg/L	12	0.003	0.000	3	0.003	0.000	N	N
Cu-extr	mg/L	12	0.003	0.000	3	0.003	0.000	N	N
Fe-extr	mg/L	12	0.338	0.216	3	0.311	0.067	N	N
Li-extr	mg/L	12	0.003	0.000	3	0.003	0.000	N	N
Mn-extr	mg/L	12	0.018	0.008	3	0.010	0.006	N	N
Mo-extr	mg/L	12	0.003	0.000	3	0.003	0.000	N	N
Ni-extr	mg/L	12	0.005	0.000	3	0.004	0.003	N	N
Pb-extr	mg/L	12	0.010	0.000	3	0.010	0.000	N	N
Sr-extr	mg/L	12	0.017	0.005	3	0.005	0.002	N	N
V-extr	mg/L	12	0.003	0.000	3	0.003	0.000	N	N
Zn-extr	mg/L	12	0.003	0.001	3	0.003	0.000	N	NA
B-extr	mg/L	10	0.027	0.021	3	0.017	0.020	N	N
Ca-extr	mg/L	12	1.850	0.378	3	0.500	0.000	N	NA
Mg-extr	mg/L	12	1.856	0.737	3	0.500	0.000	N	NA
Na-extr	mg/L	12	9.575	2.837	3	1.733	1.102	N	N
K-extr	mg/L	12	1.000	0.000	3	1.000	0.000	NA	NA

Wilcoxon Unpaired Test Comparing Sample Medians, Karrak Lake versus Rreference Lake.

NOTE: Significant? Y = Yes; N = No

	Karrak Lake		Reference Lake				
Variable	Avg. Rank 1	# values	Avg. Rank 2	# values	Z-test stat.	Prob>Z-2 tail	Significant?
AlkT	17.0000	19	11.2000	10	-1.7217	0.08512740	N
CaVol	16.3095	21	18.2083	12	0.5277	0.59773700	N
CaD	19.4474	19	6.3500	10	-3.8570	0.00011481	Y
ChloroA	14.5833	18	16.8750	12	0.7022	0.48253700	N
Clarity	6.0909	11	11.0000	1	1.1711	0.24156600	N
Chloride	19.6842	19	6.1000	10	-4.0637	0.00004834	Y
Cond F	19.3529	17	7.0000	11	-3.8706	0.00010862	Y
Cond L	24.4737	19	8.6667	15	-4.5797	0.00004660	Y
CuT	8.3182	11	4.5000	3	-1.3759	0.16886700	N
DO	3.5000	6	7.5000	2	1.8333	0.06672500	N
DIC	8.7273	11	3.0000	3	-2.0537	0.04000950	Y
DOC	9.5000	12	2.0000	3	-2.5794	0.00989629	Y
DN	20.4762	21	14.2857	14	-1.7345	0.08283620	N
DP	21.2391	23	16.8333	15	-1.1884	0.23468500	N
Hard T	9.2143	7	4.4167	6	-2.1458	0.03188820	N
FD	15.5263	19	14.0000	10	-0.1446	0.65575900	N
KD	19.2105	19	7.0000	10	-3.6491	0.00026327	Y
MgD	19.7105	19	6.0500	10	-4.0871	0.00004369	Y
NaD	19.7368	19	6.0000	10	-4.1065	0.00004019	Y
NH3	19.0652	23	20.1667	15	0.2839	0.77646300	N
N3N2	21.0000	24	18.4000	15	-0.7704	0.44103400	N
pH F	24.9615	26	12.2143	14	-3.2790	0.00104192	Y
pH L	22.5263	19	11.1333	15	-3.2986	0.00097198	Y
POC	8.2727	11	7.2500	4	-0.3276	0.74323500	N
PON	8.2500	8	3.0000	4	-2.3009	0.02139600	Y
PN	10.2083	12	8.0833	6	0.7516	0.45229000	N
SiO2	12.5000	18	18.1000	10	1.7174	0.08589870	N
SO4	19.9737	19	5.5000	10	-4.3223	0.00001543	Y
TDS	22.2778	18	10.6667	15	-3.4178	0.00063140	Y
TP	18.1522	23	21.5667	15	0.9129	0.36131800	N
True Colou	11.2917	12	9.3125	8	-0.7871	0.43120700	N
TSS	7.1818	11	12.3333	6	1.9659	0.04931500	Y
Temp F	30.8605	43	29.5882	17	-0.2466	0.80523600	N
Turbidity	9.2500	16	19.0000	8	3.1613	0.00157087	Y
OP	10.3750	12	7.7500	6	-1.1197	0.26284800	N
AsD	7.7500	12	9.0000	3	0.6115	0.54086600	N
SeD	8.3750	12	6.5000	3	-0.8315	0.40570100	N
BaT	7.2500	12	11.0000	3	1.2302	0.21863300	N
BeT	8.0000	12	8.0000	3	1.0000	0.31730900	N
CdT	7.7500	12	9.0000	3	0.6115	0.54086600	N
CoT	7.6667	12	9.3333	3	0.5373	0.59103900	N
CrT	7.2500	12	11.0000	3	1.2552	0.20940300	N
FeT	6.8182	11	10.0000	3	1.0911	0.27522900	N
LiT	9.5000	12	2.0000	3	-2.5614	0.01031340	Y
MnT	8.7500	12	5.0000	3	-1.2291	0.21904600	N
MoT	8.6250	12	5.5000	3	-1.2185	0.22301700	N
NiT	7.9583	12	8.1667	3	0.0000	1.00000000	N
PbT	7.0417	12	11.8333	3	1.6259	0.10396900	N
SrT	9.5000	12	2.0000	3	-2.5327	0.01131880	Y
VT	7.2917	12	10.8333	3	1.1949	0.23214600	N
ZnT	7.7273	11	6.6667	3	-0.3124	0.75470900	N
CaT	9.5000	12	2.0000	3	-2.5373	0.01117240	Y
MgT	9.5000	12	2.0000	3	-2.5373	0.01117240	Y
NaT	9.5000	12	2.0000	3	-2.5259	0.01154000	Y
KT	9.5000	12	2.0000	3	-2.5304	0.01139230	Y
AgT	8.0000	12	8.0000	3	1.0000	0.31730900	N
FeE	7.2500	12	11.0000	3	1.2291	0.21904600	N
MnE	8.7500	12	5.0000	3	-1.2335	0.21739000	N

NOTE: PH_F = Field pH, Cond_F = Field Conductivity, CaD = Dissolved Calcium, ClD = Dissolved Chloride, MgD = Dissolved Magnesium, NaD = Dissolved Sodium, SO4D = Dissolved Sulphate, KD = Dissolved Potassium, DOC = Dissolved Organic Carbon, PON = Particulate Organic Nitrogen, TDS = Total Dissolved Solids, TN = Total Nitrogen, Etc.

QL A pilot study on effects of
673 high white goose population
.K37 on aquatic quality at Karrak
H38 Lake, Queen Maud Gulf
2001 Migratory Bird Sanctuary
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