Fisheries and Oceans Canada
Pêches et Océans Canada

Fish and Fish Habitat Protection Program
Arctic Region
301 – 5204 50th Ave. (Franklin)
Yellowknife, Northwest Territories
X1A 1E2

Programme de protection du poisson et de son habitat
Région de l'Arctique
301 – 5204 50th Ave. (Franklin)
Yellowknife, Territoires du Nord-Ouest
X1A 1E2

Your file *Votre référence*
February 6, 2026 3AM-IQA1626

Subject: Water Licence, Type A, City of Iqaluit; Renewal and Amendment Application

To whom it may concern,

On January 8, 2026, the Nunavut Water Board invited parties to comment on the Water Licence, Type A, City of Iqaluit; Renewal and Amendment Application: 3AM-IQA1626. The Fish and Fish Habitat Program of Fisheries and Oceans Canada (DFO) appreciates the opportunity to review the application and offers the comments below.

Comment DFO-01: Request For Review

The City of Iqaluit proposal has the potential to impact fish and fish habitat through the use of explosives, water withdrawal, the installation or replacement of culverts and pipes, and the dewatering of ponds. A Request for Review has been submitted to DFO and is actively being assessed.

Comment DFO-02: Use of Explosives

Blasting operations may be conducted during the construction phase of the proposal. The use of explosives in or near aquatic environments can cause harm to fish by rupturing the swim bladder and/or damaging other internal organs, and damaging incubating eggs. It could also result in physical and/or chemical alterations to fish habitat.

In Attachment 19 (LTWP Preliminary Design Report – Appendix J: Preliminary Blast Assessment), the City of Iqaluit commits to limiting water overpressures to 100 kPa at the location of a live fish. DFO recommends that if explosives are used in or near water, an instantaneous pressure change threshold of 50 kPa be applied to appropriately mitigate effects of blasting on fish, as recommended in Cott and Hanna (2005). In addition, the *Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters* (Wright and Hopky, 1998) specify that peak particle velocities must not exceed 13 mm/s at spawning beds during egg incubation periods.

Reference: Cott P and Hanna B. 2005. Monitoring Explosive-based Winter Seismic Exploration in Waterbodies, NWT 2000-2002. Pages 473-490. In: Proceedings of the Offshore Oil and Gas Environmental Effects Monitoring Workshop: Approaches and Technologies. Battelle Press. Columbus. 601 p + index

Canada

Comment DFO-03: Culvert Replacements

The project description indicates that road upgrades between Geraldine Lake and the Road to Nowhere may require the replacement of several culverts. However, no details have been provided. DFO recommends that the proponent provide the following information on all culverts included with the road upgrade works:

- location
- potential for fish presence
- current condition
- type/size (existing and proposed culverts)
- channel bankfull width
- gradient
- photos
- connecting waterbodies
- stream type
- description of the proposed upgrade or replacement methods, timing, and potential in-water work requirements.

Comment DFO-04: Water Withdrawal

Section 3.1 of the City of Iqaluit Type A Water Licence Amendment and Renewal Application states that the City of Iqaluit will monitor the Apex River discharge using WSC stations 10UH015 and 10UH002 to ensure water is not withdrawn when flow is below 30% of Mean Average Discharge (MAD). The Application further states that water withdrawal from the Apex River will be limited to 10% instantaneous discharge when flow is between 0.143 m^3/s and 0.156 m^3/s (between 30% and 33% MAD), or up to 20% instantaneous discharge when flow exceeds 0.156 m^3/s (>33% MAD).

DFO would like to inquire whether discharge logs and water withdrawal rates (including instantaneous withdrawal rates, associated percentages, and comparisons to MAD) will be reported in the annual report to confirm the withdrawal conditions have been met and to ensure protection of fish and fish habitat.

Comment DFO-05: Monitoring of Fish Habitat During Water Withdrawal

The Application proposes that withdrawal from the Apex River will be limited to 10% instantaneous discharge when flow is between 0.143 m^3/s and 0.156 m^3/s (between 30% and 33% MAD), or up to 20% instantaneous discharge when flow exceeds 0.156 m^3/s (>33% MAD).

Although DFO recommends the proponent follow the *Framework for Assessing the Ecological Flow Requirements to Support Fisheries In Canada* when withdrawing from watercourses (i.e., cumulative flow alterations <10% in amplitude of the instantaneous flow in the river relative to a natural flow regime), it is acknowledged that Stantec's 2023 study *Analysis of Fisheries and Hydrologic Information of Apex River* (referenced in Attachment 33), indicated that it is unlikely that the proposed pumping protocol would

…/4

result in negative impacts to fish and fish habitat in the Apex River. DFO, however, will further review the supporting evidence during our review process to assess the potential impacts from water withdrawal on channel hydraulics.

DFO notes that the proposed withdrawal protocol is based on hydraulic and habitat modelling supported by baseline field surveys, but no in-situ monitoring was conducted during pumping events (above 20% instantaneous flow) to validate model predictions. DFO recommends that the proponent implement field monitoring during future withdrawal periods to confirm that modelled changes in depth, velocity, and wetted area accurately reflect real conditions in the Apex River. This information is necessary to validate the modelling approach, confirm that withdrawal thresholds are protective of resident Arctic char, and ensure that increased withdrawal rates do not result in impacts to fish and fish habitat.

DFO further recommends that contingency measures be established in advance (e.g., reducing withdrawal rates) if monitoring indicates that non-predicted adverse effects to fish or fish habitat are occurring when pumping above 10% instantaneous flow.

Comment DFO-06: Existing Structures

DFO requests clarification on whether the existing Apex River temporary pump station and associated piping will be fully removed once the new water-withdrawal infrastructure is constructed. Information on the timing, methods, and extent of decommissioning is required to assess potential impacts to fish and fish habitat and to determine whether any additional mitigation measures may be necessary.

Comment DFO-07: Pond 5 Fish Absence

In Section 3.2.3.3 of the Fish & Fish Habitat Report (Attachment 30), Pond 5 is described as an isolated waterbody likely formed through snowmelt and rainwater accumulation in permafrost depressions. The Report states that Pond 5 is not connected to any known fish-bearing waterbodies, such as the Apex River or Lake Qikiqtalik, and that no hydrologic connections exist that would permit fish passage.

However, Figure 2-01 of the LTWP Preliminary Design Report – Appendix B – Topographic Survey (Attachment 11) illustrates a surface connection between Pond 5 and Lake Geraldine. As Lake Geraldine has the potential to support fish species such as Arctic char and ninespine stickleback, DFO recommends that the City of Iqaluit provide rationale explaining why fish, particularly ninespine stickleback, are not expected to migrate to Pond 5 despite the indicated connection.

Comment DFO-08: General

In order to comply with the *Fisheries Act,* it is recommended that the proponent follow DFO's protective measures for fish and fish habitat and standard codes of practice which can be found on DFO's website (https://www.dfo-mpo.gc.ca/pnw-ppe/measures-mesures-

…/4

eng.html and https://www.dfo-mpo.gc.ca/pnw-ppe/practice-practique-eng.html). By doing so, you ensure that any works, undertaking or activities where impacts to fish and fish habitat can be avoided.

It is also the proponent's Duty to Notify DFO if they have caused, or are about to cause, the death of fish by means other than fishing and/or the harmful alteration, disruption, or the destruction of fish habitat. Such notification should be directed to DFO.ARCEMTriage-TriageGEARC.MPO@dfo-mpo.gc.ca.

DFO looks forward to continuing the assessment of the proposal through DFO's regulatory process.

Yours sincerely,

Natalie Grishaber
Biologist
Fish and Fish Habitat Protection Program
Fisheries and Oceans Canada

Offshore Oil and Gas Environmental Effects Monitoring

Approaches and Technologies

Edited by Shelley L. Armsworthy, Peter J. Cranford, and Kenneth Lee

Library of Congress Cataloging-in-Publication Data

Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Technologies / edited by Shelley L. Armsworthy, Peter J. Cranford, Kenneth Lee.

p. cm.

Includes bibliographical references and index.

ISBN 1-57477-146-9 (alk. paper)

1. Offshore oil industry—Environmental aspects—Congresses 2. Offshore gas industry—Environmental aspects—Congresses. 3. Environmental monitoring—Congresses. I. Armsworthy, Shelley L., 1969- II. Cranford, Peter J., 1958- II. Lee, Kenneth, 1953- IV. Title

TD195.P4O38 2004
368.738′263–dc22

2004052187

Printed in the United States of America

Copyright © 2005 Battelle Memorial Institute. All rights reserved.

This document, or parts thereof, may not be reproduced in any form without the written permission of Battelle Memorial Institute.

Battelle Press
505 King Avenue
Columbus, Ohio 43201-2693, USA
614-424-6393 or 1-800-451-3543
Fax: 614-424-3819
E-mail: press@battelle.org
Website: www. battelle.org/bookstore

Monitoring Explosive-Based Winter Seismic Exploration in Waterbodies, NWT 2000–2002

Cott, P. (cottp@dfo-mpo.gc.ca) and B. Hanna (Department of Fisheries and Oceans, Yellowknife, NWT, Canada)

ABSTRACT: During the winter of 2000/2001, there was a resurgence of oil and gas exploration in the Mackenzie Delta area of the Northwest Territories. Explosives were the primary energy source for seismic exploration crossing waterbodies not frozen to the bottom. Industry initially followed burial depths outlined in the Department of Fisheries and Oceans, *Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters* (the Guidelines), when setting charges under waterbodies. The instantaneous pressure change (IPC) in the water column resulting from charge detonation was monitored and revealed that many charges produced IPC higher than DFO's 100 kPa threshold guideline for the protection of fish. DFO required additional monitoring and subsequently determined that 50% of the remaining charges monitored and recorded (n = 429) exceeded 100 kPa. As a result, DFO outlined a series of requirements for 2001/2002 winter seismic exploration programs. These included program-specific testing of charge size/burial depth combinations prior to initiating production

seismic programs over waterbodies. The test results indicated that 10 of 11 explosive-based seismic programs required increased burial depths for production shot holes; up to five-times the distance outlined in the Guidelines in order to not exceed the 100 kPa threshold. Despite using greatly increased burial depths for a given charge size in most cases, approximately 1 of 12 charges monitored and recorded (n = 507) still exceeded 100 kPa. Although the reasons for high IPC are not fully understood, it is clear that the IPC from the use of explosives in waters potentially bearing fish is not entirely predictable. Due to the potential negative impacts on fish, DFO no longer authorizes explosive-based seismic exploration programs under waterbodies not frozen to the bottom in the NWT.

INTRODUCTION

It has been well documented that the use of explosives in aquatic environments has the potential to negatively impact fish by rupturing the swim bladder and/or damaging other internal organs (Falk and Lawrence, 1973; Teleki and Chamberlain, 1978; Wright, 1982; Alaska Department of Fish and Game, 1991; CAPP, unpublished); hence, the Department of Fisheries and Oceans developed the *Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters* (hereafter the Guidelines). The Guidelines recommend burial depths for given charge sizes for certain generalized substrate types. These charge size/burial depth combinations were intended to keep peak pressures of the Instantaneous Pressure Change (IPC) in the water column below a critical threshold of 100 kPa, a level believed to cause fish injury or death. The killing of fish by any means other than fishing is prohibited under Section 32 of the *Fisheries Act* unless authorized by the Department of Fisheries and Oceans (Government of Canada, 1985).

Alaska has many similarities to the Northwest Territories (NWT) in both environment and types of hydrocarbon exploration and development. Current mitigation for seismic exploration in Alaska prohibits the use of explosives in fish-bearing waters, and charges cannot be set under or near fish-bearing waters if the explosive produces IPC values greater than 2.5 pounds per square inch (17.2 kPa) unless the waterbody and its substrates are solidly frozen (Alaska Department of Natural Resources, 2003). The last explosive-based seismic program near waterbodies approved in Alaska was in the late 1980s, however it was never conducted as the company withdrew the application (A. Ott, Alaska Department of Fish and Game, pers. comm.).

In 2000, seismic exploration and exploratory drilling programs re-commenced in the NWT at a scale not seen since the 1970s and early 1980s. Seismic exploration projects were conducted throughout the Mackenzie Delta and surrounding area within the Inuvialuit Settlement Region (ISR), using both dynamite and vibrator energy sources. Over 11,000 km of 2-D and 3-D seismic lines were surveyed (Cott et al., 2003; Fig. 1).

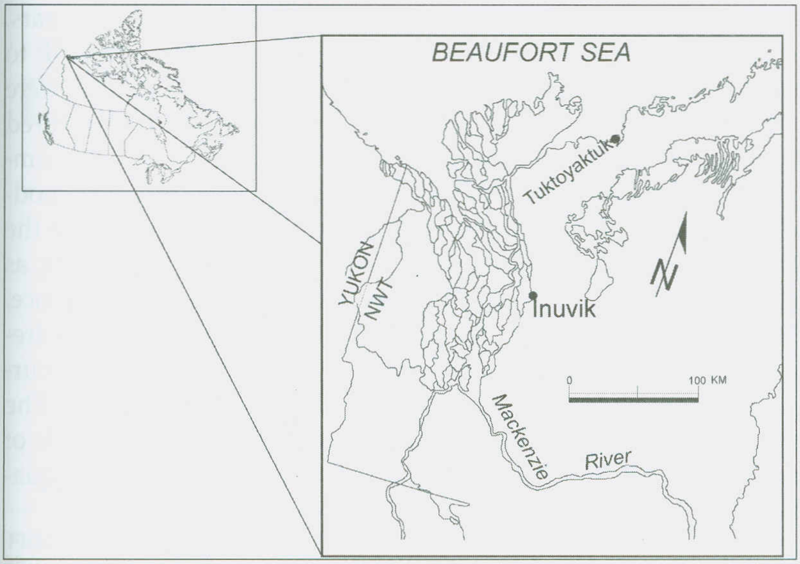

FIGURE 1. The Mackenzie Delta and surrounding area within the Inuvialuit Settlement Region, NWT where Instantaneous Pressure Change monitoring of explosive-based winter seismic programs 2000/2001 and 2001/2002 was conducted.

Most of the seismic exploration conducted under waterbodies not frozen to the bottom (including lakes, delta channels, and the near-shore Beaufort Sea) used dynamite as the energy source. Burial depths outlined within the Guidelines were followed when shooting under waterbodies not frozen to the bottom. In the winter of 2000/2001, industry experienced problems maintaining the desired depth of buried charges, particularly when using a Vibra-ram® (seismic drilling equipment using a vibrating rod designed to deploy explosive charges in soft substrates). Concerned with exceeding the instantaneous pressure change (IPC) threshold, industry voluntarily implemented an IPC monitoring program and notified DFO that in many cases, IPC was exceeding 100 kPa. This experience prompted DFO to increase requirements, such as extensive IPC monitoring, for seismic programs proposed for the following winter season.

MATERIALS AND METHODS

Monitoring of IPC was conducted in 2000/2001 and 2001/2002 during winter seismic exploration in the NWT. In both years, seismographs equipped with hydrophones were used to measure IPC. The most frequently used seismographs were the BlastMate™ and MiniMate™ series units manufactured by Instantel®. These units are portable and capable of a sampling rate greater than 16,000 s^{-1} (up to 65,536 s^{-1} on some models; Instantel, 2001). The sampling rate for units was set to the highest possible frequency in order to ensure a reading as close to the true peak pressure as possible (AquaScience, 2001a; R. Cyr, Explotech, pers. comm.). The waveform frequency of dynamite is very high, with peak pressure occurring within $1/1000^{th}$ of a second of detonation. The hydrophones used in the monitoring program are capable of recording IPC in the water-column up to 346 kPa (AquaScience, 2001a).

Monitoring for IPC was conducted using three hydrophones placed under the ice in the water column; each suspended approximately 15 cm above the bottom. Hydrophones set during the 2000/2001 monitoring were placed above the shot hole (0 m), 5 m, and 15 m laterally away from the shot hole, measuring from the initial auger hole on the ice surface where the charge was loaded (AquaScience, 2001b). The reason for the placement of three hydrophones at different distances from the charge was to determine the rate of energy attenuation and potential area of exposure of IPC to fish.

For monitoring in the winter of 2001/2002, a minimum sampling frequency of 16,000 s^{-1} per hydrophone was specified. In addition, there was a change made in the hydrophone placement requirements. The three hydrophones were now placed directly over the shot hole (burial depth plus 0 m), burial depth plus 5 m, and burial depth plus 10 m. Trigonometry was used to calculate the appropriate lateral distance on the ice surface. This method enabled standardized hydrophone placement laterally from the shot hole regardless of the burial depth achieved (Fig. 2).

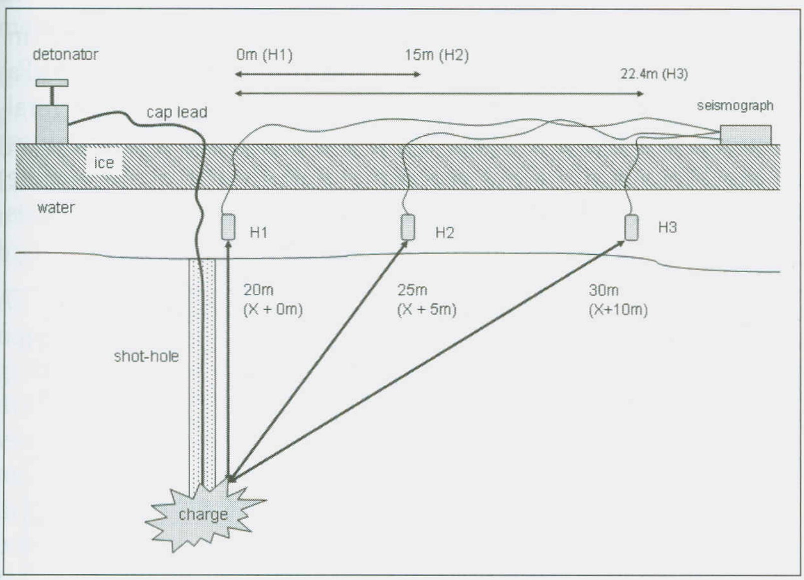

FIGURE 2. Hydrophone placement for instantaneous pressure change (IPC) monitoring using a 20 m burial depth example. Hydrophone 1 (HP1) is placed directly above the shot-hole to monitor burial depth of 20 m, HP2 is placed 15 m laterally from shot-hole to monitor burial depth + 5 m and HP3 is placed at 22.4 m laterally from shot-hole to monitor burial depth + 10 m.

It should be noted that pre- and post drilling, and pre- and post detonation water quality monitoring for turbidity, suspended solids and dissolved oxygen, and long-term water quality monitoring of waterbodies exposed to seismic activity was also conducted (Cott et al., 2003).

RESULTS AND DISCUSSION

Since it was not feasible to leave potentially shallow buried charges un-detonated due to safety concerns, DFO issued authorizations under section 32 of the *Fisheries Act* to allow for the completion of seismic programs experiencing high IPC values in the winter of 2000/2001. The authorizations stipulated monitoring 20% of the un-detonated charges remaining under waterbodies. Determination of charge burial depth was based on the amount of cap lead on the ice surface (i.e. burial depth of charge = total cap lead used – (ice depth + water depth + remaining cap lead on the ice surface)).

Of the 436 charges monitored and recorded for IPC in 2000/2001, 50.0% exceeded 100 kPa and 74.6% exceeded 50 kPa directly above the shot-hole (Table 1; Fig. 3). After several unsuccessful attempts were made to rectify the shortcomings of the Vibra-ram®, DFO recommended that it no longer be used when conducting seismic activities under waterbodies

TABLE 1. Summary of instantaneous pressure change data (IPC) data from monitoring explosive-based seismic exploration, by hydrophone (H) in the Mackenzie Delta area, NWT, 2000–2002. *Reasons for "no record" include an iced hydrophone, IPC value below the trigger setting on the monitoring equipment (< 5 kPa), or an undetonated charge.

IPC (kPa)	H-1 recorded and monitored % (n)	H-1 monitored % (n)	H-2 monitored % (n)	H-3 monitored % (n)
Winter 2000/ 2001	(n = 429)		(n total = 436)	
> 100	50.0 (214)	49.1 (214)	25.2 (110)	13.1 (57)
100 - 50	24.7 (106)	24.3 (106)	10.1 (44)	2.3 (10)
< 50	25.4 (109)	25.0 (109)	36.0 (157)	33.5 (146)
*no record	N/A	1.6 (7)	28.7 (125)	51.1 (223)
Winter 2001/2002	(n = 507)		(n total = 626)	
> 100	8.7 (44)	7.0 (44)	2.6 (16)	1.1 (7)
100 - 50	7.1 (36)	5.8 (36)	3.3 (21)	1.6 (10)
< 50	84.2 (427)	68.2 (427)	70.3 (440)	68.7 (430)
* no record	N/A	19.0 (119)	23.8 (149)	28.6 (179)

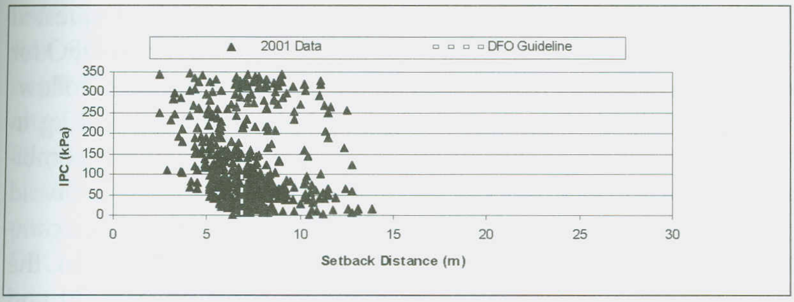

FIGURE 3. Instantaneous pressure change (IPC) values (kPa) versus burial depth (m) for 2.0 kg charges recorded directly above the shot-hole with hydrophone 1 for waterbodies not frozen to the bottom in the Mackenzie Delta area, NWT (January–April 2001).

not frozen to the bottom in the NWT. However, a great deal of variation in IPC values between program areas suggested that the reasons for excessive pressures were not limited to equipment problems or inadequate burial depths (Cott et al., 2003).

It should also be noted that a summer, open-water seismic test program using explosives on Parson's Lake, NWT, resulted in IPCs over 100 kPa and confirmed fish kills (Golder Associates Limited, 2000). This included charges buried to depths recommended in the Guidelines, indicating that the problem with high IPC values is not limited to winter conditions.

As a result of the previous year's experience, DFO outlined new requirements for conducting and monitoring seismic programs in the NWT. These requirements included the use of drilling technology proven to be effective in northern environments under winter conditions, proven mitigation to minimize the exposure of fish to critical IPC thresholds, contingency plans in place for unexpected events such as shallow buried charges, an assessment of alternative seismic exploration methods, IPC monitoring, long-term aquatic monitoring, and baseline studies on certain waterbodies likely to be encountered in the program areas (Cott et al., 2003). Also, it appeared that the Guidelines were being used too prescriptively, and that adjustments were required to account for site-specific conditions.

By the fall of 2001, industry had not presented the requested contingency plans and proven mitigation methods to DFO for review. As a result of these deficiencies, DFO issued a follow-up letter stipulating that charges should not exceed 2 kg in size, and that a conservative charge size/burial depth combination of 2 kg/15 m was being implemented in order to avoid exceeding the 100 kPa threshold. This charge size/setback combination is approximately double what is outlined in the Guidelines when using the rock substrate value (Wright and Hopky, 1998). As rock offers the most conservative value in the Guidelines, it was thought that that this precautionary approach would assist in providing an additional margin of safety to avoid or reduce impacts to fish.

Some proponents felt the 15 m minimum burial depth was too conservative, and that acceptable IPC values could be achieved with shallower depths. As such, a request was made to conduct field tests to demonstrate that shallower burial depths could achieve low IPC. DFO agreed to allow testing, and under *Fisheries Act* authorizations outlined IPC monitoring requirements for both tests and subsequent production seismic operations. The *DFO Western Arctic Area 2001/2002 Protocol for Monitoring the Use of Dynamite in Waterbodies not Frozen to the Bottom* was developed to assist proponents in developing monitoring programs, and to ensure consistency between seismic projects. The protocol was distributed to industry in February 2002. To take into account likely variations in subsurface geology, program-specific tests were used to determine appropriate combinations for individual program areas. Charge size/burial depth combinations for full production seismic exploration would be determined, pending the outcome of each program's test. The charge size/burial depth combinations using the rock substrate values outlined within the Guidelines would act as the minimum to begin testing.

Upon conclusion of the test programs, the burial depth for production seismic exploration on 10 out of the 11 programs had to be increased beyond double the Guideline levels, in some cases up to five times deeper (e.g. 24 m burial depth for 2 kg charge) in order to maintain IPC at levels that were consistently below 100 kPa. Also, through monitoring of production seismic operations, it was determined that the burial depths had to be increased for some programs as they encroached on different waterbodies in their program areas. During one program, the IPC on several charges surpassed 100 kPa in one lake after achieving safe IPC over much of their program area. In this case, the program was suspended by DFO until additional testing was conducted and a revised and acceptable charge size/burial depth combination was determined.

Despite the burial depths equal to, or in most cases, well beyond those outlined in the Guidelines, 8.7% of detonations monitored and recorded still produced IPCs in excess of 100 kPa, and 15.8% exceeded 50 kPa (n = 507) (Table 1; Fig. 4). The majority of charges used in production seismic were 2 kg, although other charge sizes were used experimentally and in limited production shooting.

Data derived from seismograph units that measured at frequencies of 16,000 s^{-1} and 65,000 s^{-1} were analysed together. This was acceptable as measurements taken at a frequency of 16,000 s^{-1} may be an under-representation of peak pressure. A higher sampling rate can more accurately delineate the peak pressure (R. Cyr, Explotech, pers. comm.; AquaScience, 2001a). Studies have indicated that seismograph units sampling at the

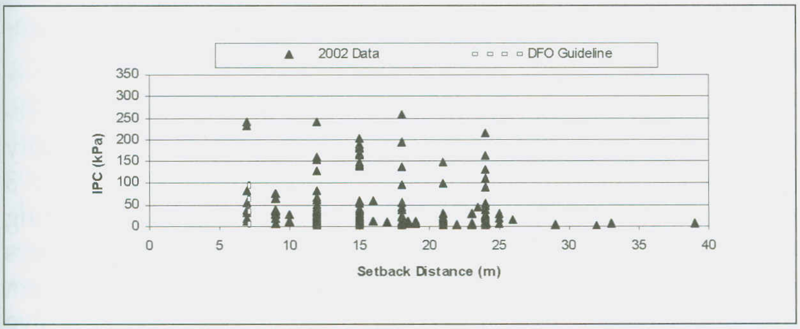

FIGURE 4. Instantaneous pressure change (IPC) values (kPa) versus burial depth (m) for 2.0 kg charges recorded directly above the shot-hole with hydrophone 1 for waterbodies not frozen to the bottom in the Mackenzie Delta area, NWT (January–April 2002).

higher frequencies record IPC values up to 25% higher than those sampling at lower frequencies, e.g. 65,000 s^{-1} versus 16,000 s^{-1} (Instantel, 2003; Explotech, unpublished data; T. Linton, Texas A and M University, unpublished data). If this is indicative of the differences between the two sampling rates it implies that the data sampled at 16,000 s^{-1} may be a gross underestimation of IPC peak pressure.

IPC was highly variable from waterbody to waterbody and within waterbodies even when the substrate appeared similar (similarity based on drillers' logs). This variability has been noted in other studies (T. Linton, Texas A and M University, unpublished data), and is possibly due to variations of the substrata, which further complicates the process of making accurate IPC predictions when applying the general substrate category values listed in the Guidelines (Cott et al., 2003).

No dead fish were observed in lakes by government regulators or industry during post-program site inspections. Due to the time between the seismic activity and ice melt (> 2 months), observed fish mortality was not anticipated as scavengers would have consumed any dead fish. Also, small-bodied fish are most susceptible to impacts from high IPC and would be very difficult to observe during aerial reconnaissance (Alaska Department of Fish and Game, 1991). Even during open water conditions, less than 50% of pressure-killed fish may actually be observed, due to injured fish swimming out of the immediate area prior to expiring or initially sinking to the bottom and surfacing at a later date (Teleki and Chamberlain, 1978).

Water quality monitoring from pre- and post drilling and pre- and post blasting showed that dissolved oxygen and turbidity exhibited a short-lived temporal and spatial increase (< 3 meters, < 10 minutes), or no change at all. The rapid settling of suspended sediments was observed with spot surveys using underwater video. Preliminary results from long-term monitoring suggest that seismic operations using explosive charges set several meters below the substrate of a waterbody do not adversely alter selected water quality parameters such as dissolved oxygen and turbidity. Similar findings were reported from water quality monitoring of the seismic operations during open-water conditions at Parsons Lake (Golder Associates Limited, 2000) and during underwater construction blasting in Lake Erie (Teleki and Chamberlain, 1978).

As a result of the data collected through the monitoring programs in 2000 to 2002, DFO released a position statement on February 14, 2003 that explosive-based seismic exploration in areas of waterbodies not frozen to the bottom in the NWT will not be authorized by DFO (Cott et al., 2003).

Lessons Learned

It became obvious that there were many potential reasons for the unpredictability of IPC values when conducting exploration under areas of waterbodies not frozen to the bottom. Differences were noted between program areas, within program areas, and between sequential shot holes under individual waterbodies. Possible reasons for high and/or unpredictable IPCs may include differences in substrate type, substrata, ice thickness, water depth, as well as equipment failure, human error, and subjectivity regarding substrate type on the part of drilling operators when working with different types of equipment. Most of these variables are difficult to predict or control in the field, and many are also a challenge to measure.

Conducting tests to determine acceptable charge size/burial depth combinations prior to initiating production seismic programs proved to be a prudent decision. The mean IPC level for production seismic exploration was approximately 43% lower than what was recorded during the testing phase as a result of using site-specific burial depth/charge size combinations determined for each production area. This was a successful example of adaptive management. If explosive-based seismic exploration programs under waterbodies are proposed elsewhere in Canada, it is imperative that project-specific testing to determine safe charge size/burial depth combinations be conducted to ensure that the potential for negative impacts to fish and fish habitat is minimized as much as possible.

A more conservative threshold of < 50 kPa should be utilized, rather than the 100 kPa in the Guidelines, which is essentially an LD_{50} where mortality of 50% of fish species exposed to that IPC would be expected (Wright and Hopky, 1998; D. Wright, DFO, pers. comm.). The < 50 kPa threshold should be used until such time that further research determines the correct threshold necessary to protect all life stages of fish. A lower threshold is also supported based on the results of IPC monitoring required by DFO biologists in the Pacific Region on a pile-driving operation after fish kills were observed. The IPC responsible for the fish kills were < 65 kPa (C. Salomi, DFO, pers. comm.; Cott et al., 2003). This would be closer to the guidelines used in Alaska; an area that has had much more experience with seismic exploration than the NWT.

Based on the results of short term and long term monitoring for dissolved oxygen (DO) and turbidity, the disturbance associated with deploying and detonating charges is thought to be negligible, and is not anticipated to have any adverse impact on fish and fish habitat in the Mackenzie Delta area.

Methods that were used to confirm burial depth of charges included keeping track of the number of drill stem sections and the total amount of cap-lead used. These methods are not precise and are subject to error such as slack cap-lead frozen under the ice giving an overestimation of burial depth. It is essential that a method to accurately measure and confirm burial depth be developed.

It is likely beneficial to allow time to elapse between charge burial and detonation. This is commonly referred to as "sleep time". If the detonation of a charge is delayed, the shot-hole has the opportunity to collapse on itself and re-consolidate; depending on substrate, the amount of energy escaping up the shot-hole may be reduced (R. Prudholm, Conoco, pers. comm.). The length of sleep time would be dependent on the type of substrate and its consolidation properties. The collapse of a shot-hole immediately upon drill stem removal was observed by using underwater video. Reducing the amount of energy transmitted up the shot-hole into the water column has the potential to lower the IPC value, likely minimizing impacts to fish. However, prolonged sleep time does not negate the need for adequate charge burial depth. Some extremely high IPCs (> 200 kPa) resulted from charges that "slept" for over a month.

Some of the most difficult variables to control are human error and subjectivity. In some cases, this relates directly to the equipment type being used by the individual operator. For instance, the operator's "feel" for what substrate is being encountered can be influenced by how powerful or heavy the particular drill is, and how the equipment is handled by different individuals. In one instance, an operator determined that consolidated material had been reached after going through 3 m of water. When this was checked by the person monitoring IPC, the water depth was actually 13 m. Mistakes happen. This is why it is imperative to develop and have on site mitigation that can minimize the effects of high IPC. Also, it is important that monitoring results are clear regarding "no-record" events. To accurately interpret data, the reason for "no-record" events must be established, distinguishing those that occur because the IPC is below recordable levels from those that are due to equipment or charge failure.

With all other variables being equal, deeper burial depths are an effective mitigation measure against high IPC. Unfortunately, all of the other variables are never equal, making it impossible to predict IPC strictly from a charge size/burial depth combination. The only completely effective mitigation measure currently available is to avoid conducting explosive-based seismic operations under fish bearing waters.

CONCLUSIONS

Monitoring of seismic programs in the ISR was conducted in a stepwise, exploratory fashion and yielded a significant amount of new information for management purposes. We now recognize that explosive-induced IPCs are very difficult to predict with any accuracy in waterbodies, and that the charge size/burial depth combinations suggested in the DFO *Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters* may not provide the required level of protection to fish.

The following recommendations are based on lessons learned during seismic exploration monitoring in the winter seasons of 2000/2001 and 2001/2002.

General Recommendations and Areas for Further Study

1. Seismic exploration should not be conducted under waterbodies not frozen to the bottom in the NWT due to the unpredictability of IPC and absence of proven mitigation to suppress the negative effects of a detonated charge.
2. The existing Guidelines should be re-investigated using data obtained from modern monitoring equipment that is the current industry standard.
3. Guidelines should be used as intended, as "guidelines", and be adjusted to site-specific conditions accordingly, not applied as mitigation.
4. Additional research should be conducted to determine what the exact IPC threshold should be to offer protection for all affected life stages of fish species likely to be impacted.
5. Ice profiling on waterbodies should be used as a tool to determine the extent of bottom-fast ice. If the bottom-fast ice zones are determined, it may be possible to infill/undershoot the non-bottom fast portions without large gaps being left in the seismic data, while providing the necessary protection for over wintering fish and incubating eggs. Also, when the bottom fast ice zone of a lake is accurately delineated, it allows the use of vibrator-based energy sources.
6. The results of a recent fish deterrent study in the Mackenzie Delta area of the NWT demonstrated that the deterrents tested in winter conditions did not successfully move fish out of a designated area, and therefore should not be used as mitigation (Racca et al., 2004). Further investigation with other fish deterrent options is needed.

Recommendations for Project Requirements and Monitoring of Explosive-based Seismic Exploration Programs in Fish-bearing Waters

Steps need to be taken to minimize human error as much as possible.

1. Equipment must be proven to be appropriate for the operating environment. The use of new technology, as it becomes available, is encouraged, but it must be tested to ensure it can operate as intended in the environment selected (e.g. Canada's Western Arctic in winter conditions) before it is used for the full seismic program. This applies to all equipment from drill rigs to dissolved oxygen probes.
2. Proven mitigation to minimize the impact on fish from the effects of high IPC should be available on site in the event that an unforeseen event occurs, such as a shallow buried charge. Currently no such mitigation has been proven to be effective in the NWT.
3. For any explosive-based seismic program, a protocol must be developed that clearly indicates what is expected, how monitoring is to be conducted, what and how information is to be recorded, and when the results are to be submitted. The protocol should be designed well in advance of the proposed seismic exploration program, and be a joint effort between industry and regulators. Maintaining effective communication with the people conducting the field monitoring is essential.
4. Initial testing should be conducted to determine site-specific charge size/burial depth combinations.
5. Charge burial depth must be accurately measured and confirmed.
6. Substrate type must be carefully recorded. Drill logs completed at the end of the day do not provide an accurate assessment.

7. A maximum threshold of < 50kPa should be set for testing and production seismic operations.

8. Two hydrophones should be utilized for monitoring each shot hole as a contingency to minimize "no-record" events. However, if "no-record" events do occur, the reasons should be well documented (e.g. charge not detonating). See point 4 above. Additional hydrophones radiating from the shot hole could be used if monitoring IPC attenuation is desired.

9. Monitoring equipment should be capable of monitoring at the highest frequency available; currently 65,000 s^{-1} is standard. Also, the hydrophones must be compatible with the monitoring equipment being used.

10. A pre-determined number of production holes should be monitored to confirm the adequacy of site-specific charge size/burial depth combinations for the entire project area. Shot holes should be monitored sequentially rather than monitoring a certain number of charges after everything else has been detonated. They should also be distributed in a manner that ensures the shot holes monitored sufficiently represent the variation found within the program area.

11. When designing a program to monitor activities of industry, it is important that the requirements be practical and considers the technical and environmental conditions in which industry is bound to operate. Involving industry in the development of such monitoring programs is a good way to ensure that the requirements set forth are actually feasible. It is important to have all monitoring requirements clearly defined to ensure consistency and compliance, and to avoid the intent of the requirement from being misinterpreted. From the authors' experiences, fostering good and cooperative working relationships with industry, other government agencies, and co-management partners are essential ingredients in having successful monitoring programs that assist in the effective management and protection of NWT's fisheries resources.

ACKNOWLEDGEMENTS

The authors would like to thank the following people and companies for their assistance and cooperation in monitoring seismic activities in the NWT and helping to conserve fisheries resources: Ron Allen, Julie Dahl, Jeff Stein, Ray Pierce, Gerry Leering, Kathleen Simms, Kelly Cott, Dave Tyson, Corino Salomi, Dennis Wright, and Sam Stephenson from DFO; John Korec and Laura Van Ham from the National Energy Board; Conrad Baetz and Rob Walker from Indian and Northern Affairs Canada; Ed McLean and Bob Bell and the Fisheries Joint Management Committee; all of our Alaskan colleagues and participants of the 2002 and 2003 Oil and Gas Regulators meetings; Anadarko Canada Corporation; Darwin Monita and Aquatics; Chevron Canada; Conoco Canada (formerly Gulf Canada, presently ConocoPhilips); Delta Trace Ltd.; Devon Canada Corporation (formerly Anderson Exploration); Encana Corporation (formerly AEC West Ltd.); Golder Associates; IMG —Golder Corporation; Inuvialuit Environmental and Geotechnical Inc.; Petro-Canada; Salmo Consulting Inc.; Shell Canada; Veri-Illuq Geophysical Ltd.; and WesternGeco. Thanks also goes to Colin Lake of Kestrel Biological Consulting for his help with the figures, Dale McGowan for map preparation, Rob Cyr of Explotech for providing useful information, Andy Majewski, Dennis Wright and two anonymous reviewers for manuscript review and providing excellent comments, and Shelley Armsworthy (editor) for all of her assistance. We extend our apologies to anyone who was missed above.

REFERENCES

Alaska Department of Fish and Game. 1991. *Blasting Standards for the Protection of Fish. Rational for Blasting Standards (11 AAC 95) Developed to Prevent Explosive Injury to Fish.* 35 p.

Alaska Department of Natural Resources. 2003. "Mitigation Measures, North Slope Foothills Areawide Oil and Gas Lease Sale." http://www.dog.dnr.state.ak.us/oil/ (accessed May 1, 2003)

AquaScience. 2001a. *TUK 3D Aquatic Monitoring and Mitigation Program.* Prepared for Anderson Resrources Ltd. Calgary, Alberta. 34 pp.

AquaScience. 2001b. *Hanson Harbour Aquatic Monitoring Program.* Prepared for WesternGeco. Calgary, Alberta. 34 pp.

Canadian Association of Petroleum Producers (CAPP). 2003. *Background Paper on Explosive Use beneath Waterbodies.* Draft report.

Cott, P. A., B.W. Hanna, and J.A. Dahl. 2003. *Discussion on Seismic Exploration in the Northwest Territories 2000–2003.* Canadian Manuscript Report of Fisheries and Aquatic Science. 2648:vi+36 p.

Department of Fisheries and Oceans. 2002. *Canada's Oceans Strategy.* Department of Fisheries and Oceans, Oceans Directorate. Ottawa. vi + 30 p.

Falk M.R. and M.J. Lawrence. 1973. *Seismic Exploration: Its Nature and Effect on Fish.* Environment Canada, Fisheries and Marine Service. Technical Report No. CEN T-73-9:v+51 p.

Golder Associates Limited. 2002. *Parsons Lake Seismic Research Program—Environmental Impact Monitoring.* Calgary, Alberta. 53 pp. + appendices.

Government of Canada. 1985. *Fisheries Act, R.S.C.* c.f-14. Amended list April 23, 1993.

Instantel. 2001. *MiniMate PlusTM Operators Manual.* Kanata, Ontario. x + 74 p.

Instantel. 2003. "Sampling Rate and Underwater Overpressure. Just for the Record." Volume 3:Q4. http://www.instantel.com/Newsletters/news_current.htm (last accessed March 20, 2004)

Racca R.G., D.E. Hannay, R.B. Murray, W.B. Griffiths, and M. Muller. 2004. *Testing Fish Deterrents for Use Under-Ice in the Mackenzie Delta Area.* Environmental Studies Research Funds Secretariat. Calgary. 28p.

Teleki, G.C. and A.J. Chamberlain. 1978. "Acute effects of underwater construction blasting on fishes in Long Point Bay, Lake Erie." Journal of Fisheries Research Board of Canada. 35:1191-1198.

Traxler, S.L., B.R. Murphy, and T.L. Linton. 1992. "Subsediment Seismic Explosions Do Not Injure Caged Fishes in a Freshwater Reservoir." Journal of Freshwater Ecology. 8(1):73-75.

Wright, D.G. 1982. *A Discussion Paper on the Effects of Explosives on Fish and Marine Mammals in the Waters of the Northwest Territories.* Canadian Technical Report of Fisheries and Aquatic Sciences. 1052: v + 16 p.

Wright, D.G. and G.E Hopky. 1998. *Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters.* Canadian Technical Report of Fisheries and Aquatic Sciences. 2107: iv + 34 p.