Report of the Non-Standard Surveys Technical Working Group

Part of the 2015-2016 Seismic Code of Conduct Review process

New Zealand Government

Department of Conservation
Te Papa Atawhai

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Cover photo: Deploying PAM equipment. *Photo: © Blue Planet Marine*

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Preface: Background to the Technical Working Group

The review of the Code

In 2012, the Department of Conservation (DOC) developed a voluntary Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations ('the Code'), in consultation with international and domestic stakeholders representing industry, operators, observers and marine scientists. The Code (and its supporting reference document) aims to provide effective, practical measures to minimise the acoustic disturbance of marine mammals during seismic surveys. It was updated in 2013 after being incorporated by reference into the Exclusive Economic Zone and Continental Shelf (Environment Effects – Permitted Activities) Regulations 2013 ('the EEZ Regulations'; see SR2013/283).

At the time the 2012 Code was implemented, DOC committed to the Code being reviewed after three years. Accordingly, the review of the 2013 Code began in July 2015, with a request for feedback from numerous stakeholders (the Seismic Code Review Group; SCRG). In August 2015, this feedback was combined with that obtained during the three years since implementation.

Role of the Technical Working Groups

In August 2015, DOC established nine technical working groups (TWGs) to address the technical issues raised in the feedback and to provide expert advice on the most suitable methods for addressing them. It was intended that DOC would then draw on this advice when redrafting the Code. The TWGs were:

1. Marine Mammal Observer/Passive Acoustic Monitoring Requirements
2. Marine Mammal Observer/Passive Acoustic Monitoring Observer Data
3. Marine Mammal Impact Assessments/Marine Mammal Mitigation Plans
4. Consultation Requirements for Operators
5. Sound Propagation and Cumulative Exposure Models
6. Acoustic Ground-truthing
7. Non-Standard Surveys
8. Non-Commercial Surveys
9. Biologically Relevant Sound Levels

The work of these TWGs was supplemented by two workshops that were co-hosted by DOC in association with scientific conferences in 2015, to discuss the appropriate mechanisms to facilitate the integration of methodological and technological advances into the revised Code.

The nine TWGs worked until January 2016 to provide feedback on the issues assigned to them. This is the report of the 7th TWG: Non-Standard Surveys.

Scope of work for the Non-Standard Surveys TWG

Not all seismic surveys are undertaken using a traditional towed-streamer setup: Vertical seismic profiling (VSP), borehole seismic surveys, check shot surveys, and undershoot surveys all sit outside this traditional practice. The extent to which the Code can be applied to these activities needs to be assessed, and specific language introduced when the various elements are not applicable. This TWG considered these operations and several others where non-standard survey activities are used, noting when Code elements might be unworkable. Where possible, the TWG recommended specific alternative measures that might appropriately mitigate against the effect of sound exposures, in cases where the Code cannot be fully implemented.

This report provides:

- Details on the need and options for specific rules for borehole seismic surveys/vertical seismic profiling (VSP), check shot surveys and undershot surveys, as well as any other non-standard survey techniques by:
    - Identifying elements of the current Code that can and cannot be applied to non-standard survey techniques
    - Providing appropriate options for minimising disturbance from these activities when the current elements are not transferable
- Options for ways to expand the Code to include non-airgun survey technologies, given the trend towards using underwater vibroseis.
- Potential application of the Code to non-seismic sources that may be deployed during seismic surveys, given increasing concern over multibeam sonar (eg Southall et al., 2013)
- Options for the best protocols for planning and mitigating multi-source operations

The output of this TWG will be used to advise DOC on Code elements relating to borehole and other non-standard surveys.

Part 1: Introduction

1. This report offers advice for applying the Code to non-standard seismic survey designs and techniques

As technology advances for the acquisition of marine data, the Code needs to keep pace with changing surveys designs and source technologies.

This report looks at the principles for non-standard surveys and makes recommendations on several different topics. There is likely to be some overlap with other TWGs, especially the Marine Mammal Observer/Passive Acoustic Monitoring Observer Data TWG.

The current 2013 Code's section 4.3 (relating to the borehole seismic surveys) needs revising, due to increased knowledge and understanding of the various borehole seismic surveys. Additional sections are also required to cover the variability of survey designs likely to be acquired in New Zealand waters such as simultaneous source, coil shooting, wide azimuth, undershoot, and transitional surveys. Emerging source types – such as marine vibroseis, or other non-seismic surveys such as swath bathymetry – are also addressed.

Ideally the revised Code will not reference older versions of the Code, but be self-contained for operators' ease of use.

2. Non-traditional survey designs

Several seismic survey types have been identified as 'non-traditional'. These are, however, all merely variations of 'traditional' surveys. Accordingly, the majority of the standard Code provisions should apply, with certain adaptations. Non-traditional surveys can be broadly grouped into the following categories:

- Vertical seismic profiling/borehole surveys/check shot surveys – these are surveys undertaken from one or more fixed points, such as inside a borehole.
- Marine or shallow hazards surveys – these are carried out using small airgun arrays to image sub-bottom features in the top few hundred meters of the seabed
- Transitional surveys – where the survey transitions from a marine to freshwater or terrestrial environments.
- Multiple or separate source designs – the principle variation in these surveys is that there are multiple source vessels, or the sources are disconnected from the receiver locations, such as when the source vessel is different to the cable towing vessel. These include simultaneous source (more than one source vessel being used at the same time, such as IsoMetrix), coil shooting (where the path of the cable vessel is a transitional circular motion, one or more source vessels may be used), wide azimuth and undershoot surveys.

Part 2: Non-standard surveys under the Code

3. Vertical seismic profiling/borehole surveys/check shot surveys

3.1 Survey description

The code groups vertical seismic profiling (including check shot surveys and walk-way/offset VSP's) where the source is in the water into two categories: fixed source location survey and multiple fixed source locations (ie offset/walk away). Activities where the source is in the borehole should not be required to meet the Code, provided the source is 30 m below the surface, unless they involve explosives. In these cases, the largest source is likely to be the dynamic positioning system for the ship running the down-hole source.

Accordingly, this leaves two remaining source types:

- Fixed source location – the source remains in a single location within the water column and is fired based on the number of receiver locations in the well bore.
- Multiple fixed source location – the above is repeated with the source at multiple offset locations, such as a walk away/offset VSP that may move up to a couple of kilometres in any direction (horizontal wells)

3.2 Common elements

The survey types in this category share some common features:

- Acoustic similarities – airguns are still the standard source
- Operational cycle – burst type, with breaks
- Consistent number of airgun shots at each receiver depth (typically 5–7), with the number depending upon the required number of receiver locations within the well
- VSPs and check shot surveys are almost synonymous (except check shot has only a few shots)
- The longer the geophones string, the greater potential reduction in the number of receiver stops
- They can be run off rig OR vessel
- Operational variability – stationary (if on rig), contained area (if on vessel)
- Variable size of the airgun array – a few hundred to a couple of thousand cubic inches

3.3 Application of the Code

3.3.1 Monitoring mitigation zones

Observer and pre-start requirements may not be suitable, practical or beneficial for fixed survey types. For example, VSP survey source vessels are likely to have more restrictive accommodation space and HSE restrictions on numbers/weight, making it difficult to have MMOs and PAM observers on board. However, remote PAM[1] (or PAM operating from a close but separate vessel/rig) might be possible, and appropriate – especially for fixed location surveys. With the quieter, stationary sources, three PAM units could be easily deployed around the source and supported by rig-based microwave transmissions. However, if the source vessel is dynamically positioned this will also need to be considered, as background noise levels will be higher. Some VSP surveys can also continue for long periods, making them more like 2D/3D surveys in terms of potential effects. One option is for brief surveys or surveys with very small sources to have the option to operate without visual observers on board. Longer duration or large source VSP surveys should probably employ visual observers and/or PAM.

Similarly, it might be possible to strategically place observers on high 'ground' with clear ocean views, such as on a rig, especially as such surveys will typically be well-lit at night (except for walk-aways, which might require a mitigation zone more like a conventional survey).[2] In these cases, clear communication channels for authority to shut down or delay start should be emphasised in the MMIA/MMMP. However, the TWG was unable to advise on how mitigation zones might operate for multiple fixed-point surveys.

3.3.2 Soft starts

Most fixed-location surveys involve substantially fewer airguns and are typically of short duration. Conventional soft starts will therefore greatly increase the effect on marine mammals in these situations, as well as being difficult to implement. Other warning devices (eg acoustic alarms/seal scarers) might be considered, especially in situations when locations are changed, to prevent full soft starts being repeated. The TWG thus recommends the length of the soft start should also be reduced as it is a fixed-source location, which would mean the source cannot be chasing any animals. Soft starts also add a lot of unnecessary energy when final full-array configurations have small injury zones. Larger arrays would still require a soft start; however, in those cases a small source, such as a single airgun firing for a short time, may be a better deterrent. One possible limit for airguns used as an acoustic deterrent is 500 in^3.

3.3.3 Acoustic footprints

With regard to acoustic properties, fixed-location surveys will have a geographically limited impact area due to the stationary source. However, the SEL footprint at the source location will likely be larger than that for a mobile seismic survey with the same-sized

[1] Remote PAM is a PAM system where the operator is separate from the PAM equipment, potentially onshore, and connected through means of satellite or other communication forms.
[2] Note that observer requirements may vary if from a rig with good lighting.

source, as the latter has energy distributed over the length of the survey line. This is due to the period the source is operational at the single location, and the SEL footprint over that period. While near-field non-synchrony of airgun arrays leads to lower received pressure levels than would be suggested from far-field measurements, the SEL footprint would be unaffected by this. Due to the consistency of the operations, if the same-sized source with a very similar number of shots is typically used, modelling will likely only be needed once in each location for each season (ie winter and summer).

3.3.4 Survey level categories

With consideration for the above, this TWG recommended that these survey types not be treated under the relevant level 1 and level 2 types (as categorised under the 2013 Code). Instead, a new survey category should be created for short-duration[3] fixed-location surveys to make it clearer to users, even though many rules may be the same. Additionally, MMIAs and MMMPs should reflect the scale and duration of the activity. Programmatic MMIAs that can be referenced for these types of surveys would be useful, although it is acknowledged that this setup might not be viable for a work-over in a period of extraction, rather than exploration.

As an aside, the TWG notes that the definitions at the start of the Code need to be restructured to use these redefined categories (eg check shot/VSP surveys, which have effectively the same design but with a change in the number of source detonations).

4. Marine hazard surveys

4.1 Survey description

Also referred to as 'shallow hazard' surveys, these are carried out using small airgun arrays to image sub-bottom features in the top few hundred meters of the seabed that could pose hazards to future drilling and/or to the structural support of bottom-mounted infrastructure. They are commonly performed along survey lines with tight spacing of 10–50 m, over spatial areas a few kilometres across. The sources often consist of small arrays of one to four airguns, with total volume typically less than 100 in^3.

4.2 Application of the Code

The TWG did not recommend any deviation from normal Code procedures for these surveys.

[3] Noting that source level remains the most important factor.

5. Transitional surveys

5.1 Survey description

Transitional surveys are performed in shallow water/ocean surf, swampland, deltaic or river conditions, to tie land and marine seismic data across these zones or to undertake surveys in challenging terrain. These may use a mix of traditional ocean cables or ocean bottom cable (OBC) nodes, and traditional land geophones. The source used can also vary from marine air gun arrays to the newer marine vibroseis, which are already becoming increasingly common in transitional surveys.

5.2 Application of the Code

If the Code is extended to cover internal/inland waters – ie lakes, rivers, fjords etc (as it should be) then the issues for transitional surveys are limited to the switch between in-water and on-land sources.[4] Essentially, if sources are in the water, a transitional survey should be treated much like a regular survey. However, such surveys typically employ small arrays and there may not necessarily be room for PAM (or even MMOs) onboard. Much like the small fixed location sources, issues arise regarding the practicability of soft-start for small arrays. Accordingly, there may be some value in cross-referencing soft start guideline revisions for smaller source arrays or vibroseis (see below).

However, coastal areas are often more sensitive than offshore areas and many marine mammals may still be present, especially during breeding season. It may be appropriate to consider preventing surveys at these times, if they are being conducted close to known breeding grounds. Other possible options could be:

- Land-based MMOs, as the sources would be near shore – provided they had the right gear and elevation to cover the mitigation zone effectively
- Remote PAM deployments or PAM on a separate vessel

In these cases, clear communication channels for authority to shut down or delay start should be emphasised in the MMIA/MMMP.[5]

6. Airgun surveys with a multiple or separate-source design

6.1 Survey description

Various survey types can be included in this broad category of surveys. Many of these involve separate source vessels that may have limited accommodation space. It is important for the Code to acknowledge this, as it will have implications for vessels' ability to deploy MMOs and PAM. Observers on chase boats ahead of the source vessel may

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[4] The Code should be specific to only cover where the source is in the water, as some surveys or parts of surveys may have the source onshore.

[5] Note – goal-orientated management needs to be supported by in-house expertise to assess efforts to meet them.

therefore be more feasible, and remote PAM could be more logistically viable than current PAM operational practices.

6.2 Features and the application of the Code

6.2.1 General considerations for monitoring and mitigation

The design of the survey may be such that, where a fleet of source vessels are being used in formation, sufficient PAM/observer coverage may be gained from:

- Strategic placing on fewer than all vessels
- Placement on the rig/platform, in the case of undershoot surveys

In both cases pre-approval must be received from DOC.

In the case of multiple source vessels, PAM/observer and soft start requirements need to be individually considered for each source vessel. Authority to shut down or delay start should be across all vessels when mitigation zone distances overlap for the observed species. The decision whether to place observers on chase vessels to cover multiple source vessels should be based on ability of those observers to effectively monitor the mitigation zones. The Code might not have to prescribe a specific approach.

6.2.2 Wide azimuth surveys

These employ an array similar to a standard array – slightly larger and using somewhat lower frequencies. These can be treated almost identically to a regular survey, except regarding safety zones and shut-downs, given the multiple sources. For example, if an animal caused a shut-down of one source, but was not likely to enter the mitigation zone of another source, then the latter should not be required to stop (even though the operator may choose to do that). Getting set up to re-acquire an interrupted line leads to a lot of repositioning effort, generating more overall sound energy. Propagation models, marine mammal impact assessments (MMIAs) and marine mammal mitigation plans (MMMPs) should note there is faster data acquisition, with a much-reduced duty cycle in these surveys.

6.2.3 Undershot surveys

These surveys must use two vessels to fill in the area under the rig: the source on one side and the streamers on other. The roles may then swap. It is also possible to have multiple source vessels and one receiver vessel. Many factors must be considered, including overlapping impact zones, multiple mitigation radii, additional MMOs and PAM operators, MMO observer locations, etc. Like wide-azimuth, there may be issue related to multiple sources/shut-downs. Additional issues may be present for any PAM (or G-T) systems attached to streamers.

6.2.4 Coil shooting

These surveys shoot in a transitioning circular motion, where either one or two vessels are sailing in a series of overlapping, continuously linked circles. Depending on the survey design, one or more source vessels may be used – some recent coil surveys have used up to four source vessels. Shut down or partial shut-down of these surveys is an issue, as it is with other multi-source surveys.

6.2.5 Simultaneous sources

This covers a wide range of survey designs where one or more (in some cases up to four) source vessels are used. This type of survey will be designed so the vessels sail in formation. Mitigation zones will then be much larger or more numerous; depending on the survey tolerance, marine mammal incursions into one vessel zone may require all vessels to shut down and re-start.

7. Non-airgun sources

Recent technological advances have led to alternatives to traditional airgun arrays as seismic sources.

7.1 Vibroseis

One prominent type of source is the marine vibroseis (sometimes referred to as 'MarVib'). A continuous source that produces sound at lower frequencies than airguns, this technology is being developed by several major acquisition companies in parallel, with subtle differences between the respective technologies. Some reports suggest that vibroseis may phase out airgun in three to five years, especially if policy from some governments encourages this.

7.1.1 Description of the technology

While frequency transmission may be less with this than with airguns, the marine vibroseis will transmit for a higher proportion of the time. As vibroseis is a moving (but non-pulsed) source, consideration of impacts from vibroseis will likely be more focussed on disturbance than injury/permanent threshold shifts (PTS)/temporary threshold shifts (TTS). Given the potential for widespread use of this technology, a more in-depth description follows.

In order to describe and contextualise marine vibroseis, it is best to compare it with an airgun array.[6] An inherent benefit of any vibroseis system is that its source pressure level (SPL) would be lower than an airgun array.[7] The SPL of the source is normally quoted on

[6] This was the approach taken by LGL and Marine Acoustics Inc. in their report for the Joint Industry Program (LGL and MAI, 2011).

[7] The concept of source level is somewhat abstract and complex when dealing with a distributed source such as an array of airguns or an array of vibroseis units; however, it can be used as a far field approximation.

an instantaneous peak or peak-to-peak basis for impulsive sources like an airgun array, but is quoted on a time-averaged root-mean-square (rms) basis for non-pulsed sources such as marine vibroseis. The required SPLrms of the vibroseis array also depends on the selected signal duration and other factors – which will be specific to the design of specific vibroseis array.

For the purpose of the assessment conducted by LGL and MAI (2011) they assumed a typical airgun array, a 4,140 cu in airgun array with 30 guns in 21 positions at 7-m depth, with a SPLpk–pk source level of about 261 dB re 1 µPa @ 1 m and a SPLpeak pressure level of ~256 dB re 1 µPa @ 1 m. In contrast, a vibroseis array with comparable source energy level (or sound exposure level: SEL) of ~235 dB re 1 μPa^2.s @ 1 m would have a nominal source level 226–232 dB re 1 µPa SPLrms, depending on signal duration (within the 2–8 sec range; LGL and MAI. 2011.). The corresponding nominal SPLpk–pk source levels for the vibroseis would be 235–241 dB re 1 µPa @ 1 m (assuming roughly SPLrms + 9 dB), or 229–235 dB SPLpeak (rms + 3 dB), as compared with the 261 dB SPLpk-pk and 256 dB SPLpeak for the airgun array.

7.1.2 Biologically relevant source characteristics

Compared with an airgun array, a vibroseis source would (at any specific distance) produce a lower peak pressure level and a lower SPLrms, measured over the durations of the respective signals. To the extent that biological effects are a function of received SPL, effects of the vibroseis system should be substantially reduced with a vibroseis source, compared with airguns. The effects of vibroseis would be further reduced because of the slower rise time, at least in terms of direct impacts on hearing. However, in marine mammals (and probably other species), auditory impairment effects that occur at high exposure levels (and thus close distances) are probably more directly a function of the cumulative SEL (ie total amount of acoustic energy received) than of received the SPL (Southall et al. 2007).

To meet the geophysical objectives, vibroseis transmissions at a given location would be longer than a single airgun shot.[8] To a first approximation, the vibroseis may emit a similar amount of energy to an airgun system per 'shotpoint'. Some reduction in the required energy per location may be possible if signal processing is more efficient for vibroseis signals than for airguns, and if signal components above ~100 Hz can be better suppressed with vibroseis systems.

Even so, the longer duration of each transmission with vibroseis than with airguns could limit the environmental benefits of a vibroseis source to the few associated with SPL alone – if (as expected) SEL is the more important indicator of some biological effects.

However, vibroseis systems could be immediately beneficial for SPL-related effects, due to their lower SPL and associated lower received level at any given distance, and there should be less need for specific mitigation measures than for airguns. There are some uncertainties, especially around the received SPLs: it is possible that vibroseis systems will have a masking impact. However, there is little information available about the relative importance of received energy v. pressure in inducing behavioural disturbance

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[8] Seconds v. milliseconds.

effects or masking effects. Particularly for masking, it is reasonable to expect received SPL to be the main variable. This is important as additional mitigation measures (beyond the lower SPLs and slower rise times inherent with vibroseis) could be needed if some biological effects are more directly related to received energy.

7.1.3 Biological effects of vibroseis

Although vibroseis systems (as compared to airguns) would have notably lower source pressure levels, and lower received pressure levels at any specific distance, the source and received energy levels for vibroseis and airgun systems are probably similar given the longer anticipated duration of vibroseis signals. Occurrence and extent of TTS and PTS are, to a first approximation, a function of received energy level. Thus, regarding TTS or PTS, the lower pressure level of a vibroseis system would not be as much of an advantage as might be expected.

In any type of marine mammal, the sound exposure levels necessary to cause onset of TTS or PTS are lower for impulse sounds (like airgun pulses) than for non-pulse sounds such as vibroseis (Southall et al. 2007). For example, the proposed PTS onset criteria for exposure to pulsed v. non-pulse sound are, respectively, 198 dB v. 215 dB re 1 $\mu Pa^2.s$ for cetaceans, and 186 dB v. 203 dB for pinnipeds. Thus, TTS and PTS would extend to greater distances from the track-line during an airgun survey than during a vibroseis survey, despite the similar received SEL/energy levels from the two types of sources.

However, the degree to which marine mammals would avoid an operating vibroseis source is uncertain. Some avoidance is expected, but it could be less pronounced than for airguns, which could – at least partially – offset the benefits of a non-pulse source that require higher SELs to induce TTS or PTS.

Information to determine the effects of masking are limited, and thus these effects are currently hard to quantify.

7.1.4 Source variability

This overview borrows heavily from LGL and MAI (2011), and is therefore a summary; read the referenced document for more details. It is difficult to make general recommendations for marine vibroseis systems (including some not in the LGL and MAI, 2011, report) due to the wide variety in these systems' characteristics. For example, source levels, operating frequencies, depths, duty cycles and pause times can differ substantially between systems. Perhaps the Code could provide operators with an approach to calculate their specific mitigation zones based on TTS/PTS – the Code could then focus on the monitoring requirements for those zones.

7.1.5 Application of the Code

The modelling of vibroseis sources will be addressed in the Sound Propagation and Cumulative Exposure Models TWG report (Sound Mod), ground-truthing in the Acoustic Ground-truthing TWG report, and the mitigation zones by the Biologically Relevant Sound Levels TWG report (Bio Rel TWG). Vibroseis sources will likely need their own category, as they will be classed as a 'continuous source', which potentially will have its own source level categories. The Sound Mod TWG will recommend the classification of sources by impulsive/continuous, and then by source level. It is also possible that further breakdown will be recommended by the Bio Rel TWG.

PAM in continuous noise should be left to the Marine Mammal Observer/Passive Acoustic Monitoring Requirements (MMO/PAM Reqs) TWG, as it will be decided by the ability of technology to detect marine mammals in relation to the sound source, and also upon the frequency range and signal strength of both the source and the marine mammals. For soft starts, there is currently not enough knowledge to adequately discuss their use. However they might be similar in function to an increase in airgun source levels over time. As the received levels are not expected to be injurious, this might be able to happen faster than for a standard seismic source. The tow position and depth of the source relative to the vessel is likely to depend on individual sources and surveys. The ranges of offset from the source for the MMOs will need to be considered in project planning. If the sources are shown not to be injurious to marine mammals, and the possible effects will be more of a cumulative and chronic nature, then MMOs may not be required and the methods to determine impact might change.

If it is not possible to 'future-proof' the Code, it is recommended this part of the Code is revised after a two- year period due to the rapid development of this study and the lack of field data to study the impacts of this new source type.

7.2 Other non-airgun sources

Seismic surveys provide information about the sediment structure of the seabed. Conventional seismic sources include air and water guns, sparkers, boomers, and chirp sonar, which each produce frequencies from several hertz to 10 kHz. Since the penetration depth of airgun sound decreases with increasing frequency, seismic sources do not typically operate at frequencies above 10 kHz, although some emit acoustic energy in that band as a side-effect. However, small airguns generate relatively more noise energy at higher frequencies and with larger bandwidth than larger airguns, which provides better resolution of small structures in the upper sediments. Also, electroacoustic sources often have directivity that focuses sound vertically, thereby reducing levels in horizontal directions. Typically, seismic sources cannot act as receivers.[9]

7.2.1 Electromagnetic/electroacoustic surveys

These surveys employ a sound source with an electromagnetic remote-sensing technology. The TWG believes that 'electroacoustic' surveys should be handled the same way as other seismic arrays, with appropriate consideration of source level, frequency and attenuation of the signal.

7.2.2 CHIRP sub-bottom profilers

Compressed High Intensity Radar Pulse (CHIRP) systems produce a swept-frequency signal, ie the transmitted signal is emitted over time and over a specific frequency range. The pulse length, frequency bandwidth, and phase/amplitude characteristics of the pulse

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[9] A hydrophone or hydrophone array is used to record the reflected acoustic pulses.

of the chirp sub-bottom profiler are selectable. CHIRP systems usually employ various types of transducers as the source. The transducer that emits the acoustic energy also receives the reflected signal.

CHIRP signals do not penetrate as deeply into the seabed as impulse sources (eg airguns, sparkers, boomers) and are usually used for mapping shallow soft sediments. Newer systems have penetration depths comparable to the boomer. CHIRP systems provide much better resolution than boomers. The operating frequency varies from 500 Hz to 24 kHz. The maximum source levels are about 200–205 dB re 1 µPa @ 1 m. The frequency spectrum depends on the settings, and can be either flat or with a highly-pronounced centre frequency.

Since the CHIRP systems employ transducers as a sound source, their beam patterns can be calculated using transducer theory. The beamwidth is usually between 15° and 55°. CHIRP system transducers are usually circular and point down.

7.2.3 Sparkers

Sparkers are seismic sources that create an electric arc between electrodes with a high voltage energy pulse. The arc momentarily vaporises water in a localised volume and the vapour expands, generating a pressure wave. The generated frequencies are generally between 50 and 4,000 Hz. The source level depends on the input energy and is between 215 and 225 dB re 1 µPa @ 1 m. The receiver for the sparker system is usually a hydrophone or hydrophone array.

7.2.4 Boomers

Boomers consist of a circular piston moved by electro-magnetic force. The high voltage energy that excites the boomer plate is stored in a capacitor bank. The typical frequency spectrum of boomer systems spreads between 0.2 and 10 kHz, with an effective bandwidth of 1 to 10 kHz. The source level depends on the amount of discharged energy and can vary from 100 to 220 dB re 1 µPa @ 1 m.

Boomer sources show some directionality, which increases with frequency. Although they can be considered omnidirectional for frequencies below 2 kHz, they are actually quite directional in the vertical. That is because they are typically towed just a few centimetres below the surface, and the directivity arises from Lloyd's mirror effect (not just the transducer itself).

7.3 Other non-seismic sources

Bathymetric surveys image the topography of the seafloor. Acoustic sources include single or multibeam echosounders, side-scan sonar, and swath bathymetry systems. The working frequencies for these sources are from 10 kHz to 1 MHz. Typically, transducers utilised in bathymetry systems can also act as receivers.

All the exchange of data with remotely-operated underwater vehicles or recording systems is currently conducted by acoustic underwater communication systems. This group includes various acoustic modems. The operational frequency range is between 20 and 32 kHz. The same transducer that generates an acoustic wave also receives the acoustic information.

7.3.1 Side-scan sonar

Side-scan sonar systems are commonly used for bathymetric surveys or for mapping objects on the seafloor. Side-scan sonar utilises a pair of rectangular transducers oriented away from the sides of the vessel. Side-scan sonar transducers usually have a narrow beam pattern in the along-track direction (typically 0.5°–1.5°) and a wide beam pattern in the vertical direction (50°–70°). The central axis of the transducers is oriented perpendicular to the towing direction of the system, and tilted below the horizontal (typically 10°–25°) to reduce cross-talk between transducers. The source levels of side-scan transducers are between 210 and 220 dB re 1 µPa @ 1 m. Common operating frequencies are 70 kHz, 110 kHz, 220 kHz and 440 kHz, but some can reach up to 1,600 kHz.

7.3.2 Multibeam echosounders

Multibeam echosounders utilise multiple beams per ping, ranging from one to several hundred beams per echosounder head. Dual-head systems that can produce more than 500 individual beams are common (eg, Kongsberg EM3002 D). The systems operate at high frequencies of 100 to 900 kHz, allowing narrow beamwidths ranging from one-tenth to several degrees. The beam fan of each head provides vertical coverage for a 100°–130° sector, in the plane perpendicular to the towing direction. If two heads are used, the coverage sectors of the heads overlap giving a combined coverage as wide as 200°. The beam pattern of a multibeam system is highly anisotropic, with the greatest acoustic energy emitted in the across-track direction.

Additionally, some very high-power multibeams operating at 10–20 kHz are used for deep-water bottom profiling. For example, the Kongsberg Simrad EM 120 is a multibeam echosounder that operates at a nominal centre frequency of 12 kHz for accurate sounding of the deep ocean. The transducer arrays for the sonar are hull mounted (**Figure 6**). The system can produce 191 individual beams with a maximum angular coverage in the cross-track direction of 150°. Each individual beam has a possible width of 1° or 2°. Technical notes obtained from the manufacturer's website specify an rms SPL of 242 and 236 dB re 1 µPa @ 1 m for 1° and 2° beams, respectively (Hammerstad 2005, Kongsberg 2005). A summary of the acoustic model parameters for the Kongsberg Simrad EM 120 are presented in **Table 1**. The beam patterns from the 191 simultaneously engaged beams of
2° × 2° beamwidth were calculated and summed to produce the total beam pattern (150° equi-angled swath; **Figure 1**, **Figure 2**).

Table 1: Kongsberg Simrad EM 120 multibeam sonar parameters (Zykov 2012). A 2° beamwidth was assumed for all model scenarios.

Characteristic	Value
Frequency	12 kHz
Pulse duration (ms)	2, 5, or 15
Pulse rate (Hz)	≤5
Transducers beamwidth	1° | 2°
rms SPL (dB re 1 µPa @ 1 m)	242 | 236
SEL per pulse (dB re 1 µPa^2.s @ 1 m)	224* | 218*
Number of beams	191
Across-track beam fan width	150°

* Source level calculated using a pulse duration of 15 ms.

7.3.2.1 Potential impacts of multibeam sonars

These deep-ocean multibeam sonars have been implicated as a possible cause of at least one stranding event (Madagascar, Southall et al., 2013). These types have potential injury zones that must be considered. Animal caught directly within the beam of a large multibeam sonar (eg, 12 khz EMN120 system) would be exposed to sound levels greater than most airgun-based seismic surveys. It was noted that these have a standard source and beam pattern, burst shape etc. compared with standard seismic sources. One result of the beam patterns is that multibeam sonar will have very small injury footprints, but can have very large disturbance footprints in one direction (sideways from the vessel) while providing little or no 'warning' to marine mammals in the other direction – especially ahead of the vessel.

Figure 1: Calculated beam pattern for the transducer of the Kongsberg Simrad EM 120 multibeam sonar at 12 kHz. The beam power function is shown relative to the on-axis level using the Robinson projection.

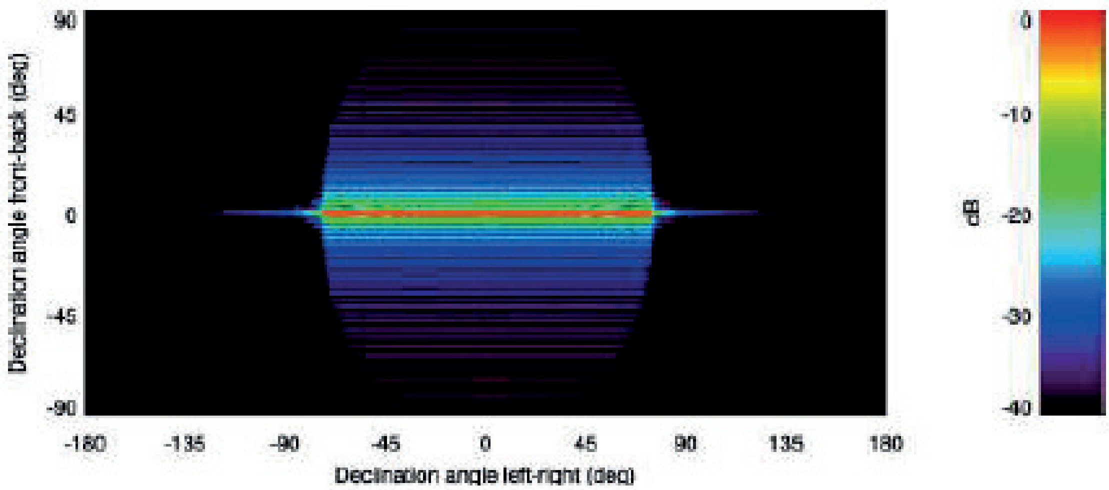
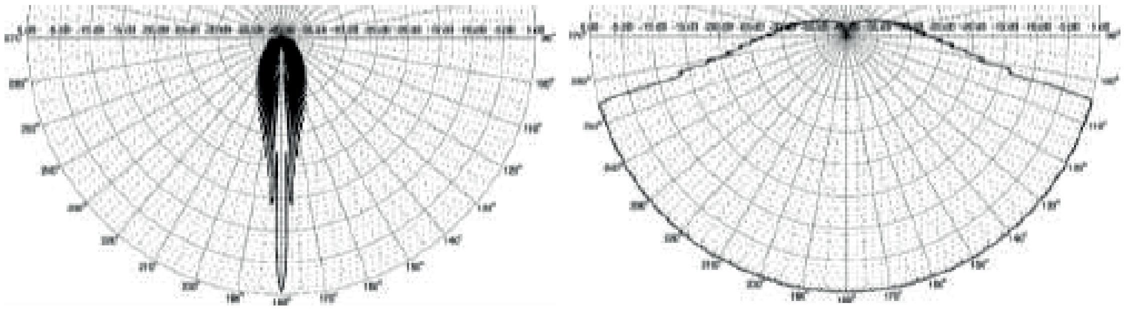


Figure 2: Calculated beam pattern vertical slice for the Kongsberg from broadside (left) and ahead (right) of the vessel.



7.3.3 Underwater communication systems

Underwater communication systems provide wireless command or data transfer between the control ship and the underwater recording system or remotely operated vehicle. They use a transducer to generate and receive acoustic signals. Transducers used for underwater communication vary in beamwidth – typically from 30° to 90°, although systems may have a wider beam (120°) or may be omnidirectional. The transducers are oriented vertically. The operating frequency of communication systems is usually between 7.5 and 44 kHz, although some systems operate at frequencies as high as 89 kHz. Source levels produced by these systems typically range between 180 and 205 dB re 1 µPa @ 1 m (SPLrms).

Communication systems may utilise multiple transducers on the control ship end. It was noted in the TWG that application of the Code to non-seismic sources would be problematic in many ways.

7.4 Adaptation of standard mitigation procedures to non-standard surveys

7.4.1 Generalising through objective-based Code provisions

For seismic source configurations, deviations from ‘normal’ mitigation protocols may be needed in various seismic survey set-ups. However, it should often be possible (despite the various source types) to generalise how standard mitigation procedures could be adapted to less-common seismic survey types (especially if disparate sources are closely situated). For example, moving v. stationary and intermittent v. continuous. There are also ‘multiple static sources’ that can be treated as repeated stationary sources, which would be much easier if the Code was less prescriptive and based more towards achieving certain objectives. For example:

- Use language such as “MMOs need to work no more than x hours in one session, with no more than y hours per day”.
- Use of “continuous monitoring” rather than “Two MMOs at all times”.
- Use of language such as “you need continuous effective PAM coverage to operate, but HOW you provide it is up to you”.

- It was suggested we should aim for dB ranges (or similar), rather than try to be prescriptive for every source type. This would help future-proof the Code against new sources; however, this would need to be advised by the Bio Rel TWG.
- With this in mind, recording impacts at sanctuary boundaries, etc may be useful.

However, there would need to be some consideration of what the tolerance for excess risk should be (eg, impacts sought to be avoided by any given threshold criteria).

7.4.2 Soft starts and mitigation zones

It was noted that no special considerations should be needed for soft starts, although soft starts would not be practical for small arrays if a doubling of energy approach is to be used. Otherwise:

1. Stepped, rather than gradual and continuous, increases in sound levels appear to be most scientifically supported at this time, although this should be confirmed by the Bio Rel TWG.
2. Consider additional mitigation guns (or non-airguns) on a string specifically for soft starts. However, this should be linked to a proper investigation of the source levels that are possible for the soft starts. The total amount of noise put into the water for return 'value' should be considered. Public modelling reports exist for soft start operations, and some measurement programs have also characterised them.
3. Pressure also influences airgun noise and can be lowered to a certain extent, which reduces noise. However, airguns can't work at too low pressures without risking water leakage and auto-fires.
4. Associated mitigation zones need to be linked to injury thresholds as they specifically induce disturbance.

Alternatively, any requirement for 'stepped increases of approx. 3 dB SEL' would be qualified with additional text such as 'within operational limitations (4–8 dB, for example)' and note that this may not be possible on the last step may not be possible to do this (eg, below 80% of full volume).

With regard to mitigation zones, the TWG noted that no special considerations should be needed.

7.4.3 Non-seismic sources

The use of the various non-seismic source types is much wider than the petroleum or mineral exploration industries. More study (and information gathering) of the use and frequency of these survey types is therefore needed before any guidance can be given. Although the TWG considered these alternate source types should be 'out-of-scope' for the Code, the TWG recommended that:

- DOC should collect data on the use of non-seismic sources, particularly the lower-frequency multibeam sonars. This might take the form of pre-survey 'notification and use' plans; however, there would be no notice to mariners as there is no towed gear. DOC might wish to draw from IUCN recommendations that focussed on data-gathering.

- DOC should also consider deploying MMOs on board multibeam sonar vessels to look for in-path marine mammals.

8. Additional issues

The TWG noted that DOC needs to revise its definition of a line turn, as data acquisition can occur on turns at this point.

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