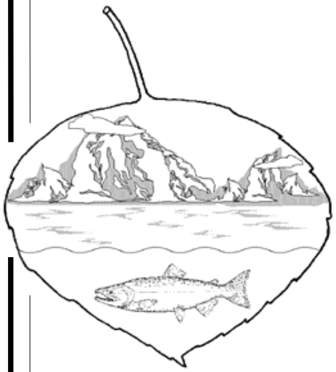

Addendum to the "British Columbia Water Quality Guidelines For the Protection of Aquatic Biota from Dissolved Gas Supersaturation (DGS)" and Protocols for Development of Site-specific Guidelines for DGS

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1.0 Introduction:

In British Columbia, dissolved gas supersaturation (DGS) has been recognized as a potential hazard to fish populations in many water bodies throughout the province (Clark 1977, R.L. & L. Environmental Services Ltd. 1984, Maxwell 1985, Hildebrand 1991, Fidler and Miller 1997a and b). In 1997, the Province of British Columbia, in cooperation with Fisheries and Oceans Canada and Environment Canada, developed water quality guidelines for DGS in British Columbia (Fidler and Miller 1997a). The Canadian Council of Ministers of Environment (CCME) subsequently adopted the guidelines as Canada-wide water quality guidelines for DGS.

The guidelines were developed to protect fish from two specific threshold responses to DGS. The first involved overinflation of the swimbladder in juvenile or small physostome fishes. This condition could lead to overbuoyancy and the requirement for small fish to seek greater water depth or swim continuously in a head down position to compensate for the overbuoyancy. At the time, there were concerns that this could lead to direct mortality from exhaustion and swimbladder rupture or indirect mortality from predation. Based on laboratory data, the total gas pressure (TGP) threshold for initiating swimbladder overinflation was about 103% (Cornacchia and Colt 1984, Shrimpton et al. 1990a and b).

The second response involved fish mortality perhaps associated with bubble formation in the cardiovascular system or other signs of GBT such as emphysema of external body surfaces, blockage of respiratory water flow, etc. This response occurred in all fish age classes with the exception of eggs and larval stages. Again, laboratory data from the literature suggested that the TGP threshold for this condition was about 110%. Although the data indicated mortality at this TGP, the exact cause of mortality was unknown.

2.0 B.C. and Canadian Water Quality Guidelines for DGS

In order to address these responses in natural aquatic and marine environments and at the same time account for specific man-made water environments, the British Columbia and Canadian guideline for DGS (Fidler and Miller 1997) consisted of the four following individual guidelines.

A. For Water Depths Greater than One Metre: <u>Where local water depth at a given location in a water body exceeds one metre, the maximum ΔP should not exceed 76 mmHg regardless of water pO_2 levels.</u> For sea level conditions, this corresponds to a TGP% of ≈ 110%.

B. For Water Depths Less than One Metre: Where local water <u>depth at a given location in a water body is less than one metre, the guideline should be based on Equation 1 which describes the threshold for swim bladder overinflation as a function of water depth and pO_2 levels. However, the maximum ΔP should not exceed 76 mmHg regardless of pO_2 level</u>.

$$\Delta P_{SB} = 73.89 \cdot h + 0.15 \cdot pO_2 \qquad \text{Eq. 1}$$

where: ΔP_{SB} = water ΔP required to initiate overinflation of the swim bladder in rainbow trout.

h = water depth at which the fish is located - metres.
pO_2 = partial pressure of dissolved oxygen (mmHg) in the environmental water.

The most conservative application of the guideline will be to use Equation 1 with h = 0. For example, at a water depth of zero metres and a pO_2 of 157 mmHg, the ΔP must not exceed 24 mmHg. This corresponds to a TGP% of ≈ 103% at sea level. This would apply to shallow water bodies and for stream margins, where the entire area less than one metre depth is used by juvenile fish.

C. For Natural Background Levels Higher than the Recommended Guideline: If natural background levels of DGS exceed the recommended guidelines, there should be no increase in the ΔP or %TGP over the background levels. This recognizes that background levels which are higher than the recommended guidelines may be harmful to fish, and hence, any increase over background levels should not be tolerated for the protection of aquatic life.

D. For Hatchery Environments: It is recommended that the DGS guideline for hatcheries be defined by Equation 1 with h = 0. This corresponds to a sea level TGP% of 103%. This guideline recognizes that fish in hatcheries may experience more stress due to higher densities and declining pO_2 levels along the rearing facility. Also, fish feed near the surface and are held in shallow water containers. This guideline also allows for higher DGS in systems using oxygen supplementation. For example, using Equation 1, if pO_2 is 250 mmHg (164% of saturation), then the maximum allowable DGS is 38 mmHg (TGP is 105%).

For non-hatchery environments, the more stringent criterion is Guideline B that applies to organisms in water less than 1 m deep. The guideline specifies a maximum sea level TGP that varies linearly from 103% to 110% for water depths ranging from 0 m to 1.0 m, respectively. As noted, this guideline was developed specifically to protect juvenile fish in shallow water from the effects of swimbladder overinflation. Clearly, this is the controlling guideline, as most water bodies will have juvenile fish present in shallow water environments at various times of the year.

As a part of the guideline document, there was extensive discussion of the uncertainties associated with applying the guidelines to different types of natural water bodies and the mitigating effects of water depth and fish behaviour on GBT. Perhaps the most important consideration that could not be included in the guideline was the effect of hydrostatic pressure on suppressing the growth of cardiovascular bubbles, body emphysema, and swimbladder overinflation. For every metre of water depth, the "effective[1]" TGP is reduced by approximately 10% (Colt 1984, Fidler and Miller 1997, Antcliffe et al. 2003a). Thus, fish depth behaviour plays an important role in their response to DGS. It was recognized that in rivers and lakes, fish utilize a range of habitats involving wide variations in water depth over time. With the corresponding variations in depth compensation[1], the exposure of fish to DGS would be dynamic, both spatially and temporally. In particular, there could be periods of GBT bubble growth followed by periods of bubble collapse. It was conceivable that, depending on available water depth and fish depth behaviour, the harmful effects of GBT could be suppressed, even under relatively high levels of DGS. A further consideration was that fish using depths much greater

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[1] For an explanation of the biological and physical principles of TGP and GBT along with terminology, see Appendix 1, Antcliffe, B.L., L.E. Fidler, and I.K. Birtwell. 2002.

than the compensation depth might acquire some added resistance to GBT (Knittel et al. 1980, White et al. 1991, Aspen Applied Sciences Inc. 1998). Given these possible mitigating effects, it is clear that DGS is unique as far as an environmental pollutant and requires additional considerations in developing and especially in applying water quality guidelines.

At the time the guidelines were developed, other concerns were raised as to the suitability of some of the data upon which the guidelines were based. Following the protocol for guideline development (B.C. Ministry of Environment and Parks 1986, CCREM 1987), the lowest observed effect level (LOEL) reported in the literature played a pivotal role in selection of the guideline criteria. However, there were unique circumstances associated with some of these LOEL data that raised questions. For example, some of the supporting data were developed in laboratories where fish were restrained in their movements and confined to shallow water environments. This was especially true for the data of Guideline B where laboratory data involving anaesthetized and restrained fish provided the LOEL criterion (Shrimpton et al. 1990a and b). Clearly, these laboratory conditions are not representative of free-swimming fish in most aquatic and marine environments. In yet another case, 10 day old larval striped bass (a marine species) experienced bubbles in the intestinal tract and overinflated swimbladders when held in 10 cm of water at a TGP of 103% (Cornacchia and Colt 1984). Although this response was important, especially in terms of fish culture situations, it was for a marine species that was not native to Canadian waters. Finally, hatchery data were referenced in which fish were held in shallow water (0.4 m) and low TGP (105%) for over 122 days before any difference in GBT mortality could be detected between treatment fish and control fish (Wright and McLean 1985). A situation in which fish in natural environments were restricted to this water depth continuously for nearly 4 months was considered highly unlikely.

In addition, the data that formed the basis for Guideline A were unclear as to the cause of mortality in the 110% to 115% TGP range. The situation was further complicated by the fact that not all research reported in the literature demonstrated fish mortality or other signs of GBT at these TGP levels. Specifically, there were contradictory results from different researchers for experiments involving essentially the same exposure conditions, fish species, and size. However, resolving the contradictions were beyond the scope of the original guideline development and, in many cases, would require independent verification through repetition of the original experiments.

The purpose of this report is to summarize research that has been conducted in the last few years in an attempt to resolve some of the above issues. As will be described, this research has demonstrated that the B.C. and Canadian Water Quality Guidelines for DGS require a number of revisions. The recommended revisions will be described in Section 5.0 of this report.

3.0 Fisheries and Oceans Canada Laboratory Studies

Concerns about the data from the literature upon which the DGS guidelines were based and concerns about how the guidelines were to be applied led Fisheries and Oceans Canada to initiate a series of three laboratory studies. Specifically, the studies were to determine whether dynamic exposures delayed the onset of GBT and reduced its severity (Phase I experiments), if free-swimming fish actually displayed signs of DGS induced swim bladder overinflation (Phase II experiments), and whether exposure to hydrostatic pressure influenced fish susceptibility to GBT (Phase III experiments). These studies were conducted at the Fisheries and Oceans Canada Rosewall Creek Hatchery in 2000 and 2001 and are described in Antcliffe et al. (2002, 2003a and b) and Aspen applied Sciences Ltd. 2003a – Appendix A of this report). The key findings of thee studies are summarized as follows.

Phase I Studies:

- Application of the primary TGP guideline of 110% (Part A), which protects all species and life histories from the acute effects of DGS, would be conservative in some situations. It would be conservative for short exposures, since the literature data indicate long exposure periods are required to elicit mortality at low TGP, even in shallow water. It would also be conservative at TGPs of 110% or higher if fish periodically use sufficient water depth to reduce or eliminate bubble growth.
- Both volitional and intermittent dynamic exposures clearly show increased time to mortality and reduced rate of mortality.
- The use of water depth by fish can significantly reduce their susceptibility to GBT even at TGP levels well above the maximum (110%) specified by Guideline A.
- Although it is not possible to apply these results directly, the general features of dynamic TGP- depth exposures are an important consideration in applying DGS guidelines to rivers and lakes.

Phase II Studies:

- Swimbladder overinflation for TGPs up to 118%, if present, is not severe enough to affect time to seek cover performance in juvenile rainbow trout.
- There was no evidence of altered fish behaviour, swimming orientation, seeking deeper water, venting of bubbles from the swim bladder, or swimbladder rupture.
- There were no external signs of GBT for TGPs of 110% or below.
- It was evident that the primary B.C. guideline A, which limits TGP to 110% regardless of water depth, would protect juvenile fish in shallow water environments from the effects of swimbladder overinflation. The exception to this might be under conditions of very low water pO_2 combined with extremely shallow water depth.

Phase III Studies:

- These studies provided somewhat contrasting results with the earlier studies of Aspen Applied Sciences Inc. (1998) and Knittel et al. (1980) that examined the effects of hydrostatic pressure pre-exposure on susceptibility of fish to GBT.
- However, between the three studies there were, in some cases, differences in fish species, fish sizes, number of replicates, and TGP levels.
- Importantly, the depths of hydrostatic exposure in all three experiments were quite shallow in comparison with the depths available to fish in many rivers (e.g. the Columbia River) or lakes. Similarly, times of exposure at depth were short in relation to what fish might experience in natural environments.

4.0 Re-examination of Scientific Literature

In 2003, Fisheries and Oceans Canada asked Aspen Applied Sciences Ltd. to re-examine the TGP/GBT data from the literature in light of the problems discussed earlier and in relation to the results of the Fisheries and Oceans Canada Rosewall Creek studies. The review was to include more recent data from the literature that assessed GBT impacts of DGS in actual river environments and how these impacts differ from those of laboratory data from which the guidelines were derived. Some of the key points from the literature review are as follows.

The key points of the literature review specific to part B of the guideline are:

- The data of Shrimpton et al. (1990a and b) were derived from laboratory studies in which restrained anaesthetized fish were used to determine swimbladder overinflation characteristics of juvenile physostome fish held in DGS water. These laboratory conditions are unrealistic for free swimming fish in most aquatic and marine environments and, as such, should not be used in the derivation of DGS guidelines.
- Based on the DFO Canada Phase II experiments, it is clear that free swimming fish either do not encounter swimbladder overinflation or they have ways of avoiding or dealing with overinflation that restrained anaesthetized laboratory fish do not.
- The experiments of Wright and McLean (1985), in which juvenile chinook were held in shallow water at a TGP of ≈105% for 122 days before any noticeable effect of GBT could be detected, are unrealistic as far as natural aquatic and marine environments are concerned. Even after 122 days of exposure at a TGP of ≈ 105%, the difference in mortality between the treatment fish and control fish in the Wright and McLean (1985) experiments was only 2% and the cause of this mortality difference could not be established.
- The data of Wright and McLean (1985) are appropriate for DGS guidelines applicable to hatchery environments (Guideline D).
- The data of Cornacchia and Colt (1984) are for a marine species that is not normally native to Canadian waters and, as such, should not be used in the derivation of DGS guidelines for Canada.
- The larval stages of most fish species found in Canada show much higher resistance to GBT than the striped bass of Cornacchia and Colt (1984).

The key points of the literature review specific to part A of the guideline are:

- The data from the literature are contradictory in that some investigators observe mortalities at a TGP of 110% while others find no mortalities at TGPs up to 115%.
- Similarly, some investigators observe external signs of GBT at a TGP of 110% while others find few if any signs.
- When mortalities are observed, they are always in shallow water environments involving long exposure times with no indication as to the cause of mortality.
- Much of the data on signs of GBT near a TGP of 110% are from early studies where % saturation was reported as %N_2 saturation and/or the water vapour pressure was not accounted

for in the TGP calculation. Consequently, the TGPs, depending on temperature, may have been 1% to 2% higher than reported.

- It is not clear at this time how to derive a guideline for TGPs near 110% given the contradictory nature of the literature data and uncertainties in the reported TGP levels.
- The contradictions and uncertainties in the literature data must be resolved before a reliable Guideline A can be derived. This is especially true of the Meekin and Turner (1974) observations since, out of the many studies that have been done, these are the only observed mortalities at a TGP of 110%.
- The mortalities and external signs of GBT reported in the literature at a TGP of 110% all occurred in laboratory environments where fish were confined to shallow water (< 1 m) for lengthy exposure periods. Fish in rivers and lakes are not likely to spend long periods of many days or weeks confined to the water surface and limited in their swimming freedom.

The key points specific to more recent literature that describes the response of fish to DGS in natural water bodies are summarized as follows.

The key elements of two Columbia River studies (Hildebrand 1991 and Prince et al. 2000) are:

- The field studies of Hildebrand (1991) in which fish were sampled directly from the river (i.e., electro-shocking, angling, etc.) contrast sharply with observations reported in the literature from laboratory studies. Specifically, very low levels of GBT signs were found in a range of fish species that had been exposed to TGPs between 135% and 137% for a period of over 200 days.
- No dead fish were found; whereas, data from the literature for shallow water exposures at these TGP levels would indicate 100% mortality in 10 – 24 hours (Fidler and Miller 1997).
- This level of mortality was plainly evident in Hildebrand’s (1991) live cage studies.
- Fish depth behaviour, perhaps coupled with some selective resistance, must play a role in the low levels of GBT that existed in the Columbia River in 1990.
- The depth behaviour of adult rainbow trout, as observed by Prince et al. (2000), is consistent with depth compensation providing fish significant levels of protection from GBT.

The key elements of the Bighorn River study (White et al. 1991) are:

- The Bighorn River below the Yellowtail Afterbay Dam often has high levels of DGS (>120% TGP) during spring and summer months.
- For nearly 18 miles below the Afterbay Dam fish in the river are restricted to a maximum depth of about 1 m, depending on location and dam discharges. This fixes the maximum DGS compensation depth at 1 m or less.
- Fish in the river often display severe signs of GBT when river TGPs exceeds 118%. This is accompanied by significant mortality in juvenile rainbow trout populations.
- Although brown trout often display severe external signs of GBT during these periods, the mortality does not appear to be severe, as the brown trout fishery of the river is considered outstanding.

- Given the high productivity of the river in the face of often high TGP levels, there is the suggestion that the fish of the river, especially the brown trout may have adapted to the DGS environment of the river.

The key elements of the Des Moines River study (Lutz 1995) are:

- The Red Rock Dam on the Des Moines River in Iowa can produce TGP levels in the river below the dam of over 130% for a wide range of discharge conditions.
- The river depth below the dam can vary significantly depending on the yearly runoff and dam discharges, ranging from depths above the compensation depth to depths well below the compensation depth.
- There is strong correlation between TGP compensation depth, actual river depth, and severity of fish GBT signs and mortality.
- For river depths of 0.5 to 2.0 m, mortality occurs when river TGPs rose above 118%.

A full discussion of the results of this re-examination of the literature can be found in Aspen Applied Sciences Ltd. (2003a – Appendix A of this report)

5.0 Guideline Revision

Based on this review it became apparent that a revision to part B of the B.C. guideline for DGS was needed and that additional experimental studies were required to resolve uncertainties associated with part A of the guideline. Subsequent to the review, Fisheries and Oceans Canada conducted a workshop in Vancouver, B.C. (July 10, 2003) in which the results of the Rosewall Creek studies and the Aspen Applied Sciences Ltd literature review were presented to a panel of representatives from Fisheries and Oceans Canada, Environment Canada, the B.C. Ministry of Water, Land, and Air protection, and B.C. Hydro. The workshop agenda, discussions, and recommendations are described in Aspen Applied Sciences Ltd. (2003b). The main recommendations to come from the workshop were:

1. Part B of the B.C. and Canadian Guideline for DGS is not appropriate for fish in natural water bodies and should be removed from the guideline.
2. Part D of the guideline should protect fish in hatchery environments.
3. Part A of the guideline should protect fish in natural water bodies from the effects of swim bladder overinflation.
4. Although there is considerable uncertainty as to the validity of some of the data that form a basis for part A of the guideline, it is unlikely that the data can be experimentally re-examined in the near future.
5. Until such experimental re-examinations are possible, part A of the guideline (110%) should be the primary guideline for the protection of fish from DGS in natural water bodies.
6. Provisions should be added to the B.C. and Canadian Guideline for DGS to allow for site-specific guidelines. It was recommended that this provision become the new Guideline B.

In the case of recommendation 6, the province of B.C. has, in the past, permitted site-specific guidelines, although this was not stated explicitly in the original guideline document.

Based on these recommendations, the B.C. and Canadian Water Quality Guidelines for DGS are revised as follows.

A. Primary Guideline For All Water Bodies Other Than Fish Culture Environments: The maximum ΔP should not exceed 76 mmHg regardless of water pO_2 levels. For sea level conditions, this corresponds to a TGP% of ≈ 110%.

B. Site Specific Water Quality Guideline: A site specific DGS guideline is permitted where sufficient information exists that would assure protection of all aquatic and marine organisms from the effects of GBT. The guideline applies to all TGP regimes that might occur in the water body. This provision must also apply when species are present for which their susceptibility to GBT is unknown. This provision may require GBT bioassay studies and a site-specific guideline less than 110%.

C. For Natural Background Levels Higher than the Recommended Guideline: If natural background levels of DGS exceed the recommended guidelines, there should be no increase in the ΔP or %TGP over the background levels. This recognizes that background levels that are higher than the recommended guidelines may be harmful to fish, and hence, any increase over background levels should not be tolerated for the protection of aquatic life.

D. For Hatchery Environments: It is recommended that the DGS guideline for hatcheries be defined by Equation 1 with h = 0. This corresponds to a sea level TGP% of 103%. The guideline recognizes that fish in hatcheries may experience more stress due to higher densities and declining pO_2 levels along the rearing facility. Also, fish feed near the surface and are held in shallow water containers. This guideline also allows for higher DGS in systems using oxygen supplementation. For example, using Equation 1, if pO_2 is 250 mmHg (164% of saturation), then the maximum allowable DGS is 38 mmHg (TGP is 105%).

The provisions for a site-specific guideline were included to address difficulties that exist in the application of a guideline to water bodies having very diverse physical and biological characteristics and to address uncertainties in the susceptibility of different fish species to DGS. The diversity of water bodies was evident from the three field studies summarized above. Accordingly, a guideline TGP for one water body may not be appropriate for the other water body. A comparison of the Canadian portion of the Columbia River and the Bighorn River are cases in point. Thus, if sufficient data exists or can be developed which would demonstrate that a guideline different from Guideline A is appropriate, a site-specific guideline should be derived and applied.

In the case of species susceptibility, DGS is different from conventional chemical pollutants in that only a limited number of species have been examined for their susceptibility to DGS. For example, most of the studies of fish susceptibility to DGS have focused on the cold water species of the Pacific Northwest and especially on the anadromous salmonid species. On the other hand, there are many other fish species in B.C. and the rest of Canada for which their susceptibility to DGS is unknown. Consequently, it is possible that there are species that are even more susceptible than those that form the basis for guideline A. Clearly, these species would not be protected by the guideline and a site-specific guideline requiring a maximum TGP somewhat less than the 110% would be required. The following describes some of the protocols that might be applied in developing site-specific guidelines.

6.0 Protocols for Developing Site Specific Guidelines for DGS

The information requirements for site-specific DGS guidelines fall into two general categories. These encompass the physical environment of the water body and the biological properties of that environment. The requirements for each are as follows.

6.1 Physical Environment

Before any assessment can be made of the effects of DGS, the physical properties of the environment must be known. These include:

- TGP as a function of time (i.e., exposure levels and durations), especially during periods when critical fish activities are occurring (e.g., spawning, juvenile rearing, etc.). In the case of dams, this information would come from operations information (i.e., discharge facilities in use, their temporal and spatial discharge regimes, etc.) and mathematical models that predict the facility DGS production characteristics as a function of those operations. Dam operations information may come from historical data, but must account for future operations that may differ from those of the past. TGP monitoring programs may be required to establish the functional relationships between TGP and specific operations. Once these relationships are established, it will be necessary to apply these to a range of years of operations that capture the full risk of GBT to fish. In most cases, daily average information is sufficient for these analyses. The exception would be those facilities where there are large changes in discharge operations and wide swings in TGP occurring over short periods (i.e., measured in hours and not days).
- Water temperature as a function of time and especially during periods when critical fish activities are occurring. Of particular concern are those facilities where water temperatures already exceed existing temperature guidelines and where water temperatures can vary significantly over short periods. In the latter case, those facilities that may alternately discharge warm surface water at one time and cooler water from depth at another time would be of major concern. It should be noted that although water temperature does not appear to affect the TGP thresholds where signs of GBT or mortality occurs, it does affect the rate of development of signs and the rate of mortality once the thresholds are exceeded (Weitkamp and Katz 1980, Fidler and Miller 1997). In general, the rates at which signs of GBT and GBT mortality occur appear to increase with increasing temperature. However, the relationship is not linear. Nebeker, Hauck, and Baker (1979) found the time to 50% mortality decreased in an logarithmic manner as temperature increased.
- River elevation in relation to river bathymetry downstream of high TGP discharge facilities as a function of time and facility discharges. As with TGP and temperature, it will be especially important to know river depths in relation to critical fisheries habitat. This information is essential during periods when critical fish activities are occurring. Steady state and dynamic hydraulic computer models may be required to establish this information (e.g., U.S. Army Corps of Engineers HEC RAS models). Clearly, dynamic models would be needed where large changes in river elevation occur over short periods (i.e., < 24 hour). As shown by Lutz (1995) the available water depth in relation to the compensation depth will be crucial information. The compensation depth is that depth below which bubbles do not grow and bubbles that already exist will collapse. Compensation depth (H_{comp}) is defined by the following equation.

$$H_{comp} = \frac{(TGP\% - 100) \bullet P_{bar}}{7389}$$

where P_{bar} is the barometric pressure in mmHg and H_{comp} is in metres.

- Duration of exposure must account for not only the dynamics of the TGP and temperature regimes, but also the dynamics of the water depth at which the exposure occurs. Again, compensation depth will be the key factor. In general, the exposure dynamics become most important at high TGPs and temperatures combined with shallow water depths. For example, exposures of juvenile life stages of most fish species to TGPs of 140% in 0.25 m of water depth will lead to mortality within 3 – 5 hours, depending on species and water temperature. Thus, even short exposure periods under these conditions may be critical. One of the difficulties in tracking short exposure periods is that they may come and go unnoticed. Although short exposures of fish to very high TGPs are generally harmful, it should be recognized that, even under conditions of high TGP (e.g., 130% or higher), exposures of an hour or less may not be detrimental to fish, providing the pre- and post-exposure regimes involve TGPs of 100%.

  At the other end of the TGP spectrum, exposures to TGPs of 110% in 0.25 m of water depth may lead to no GBT mortality. However, external signs of GBT may appear, but take several days to become evident. At TGPs of 115% (the threshold for cardiovascular bubble growth) under shallow water conditions, mortality may occur within 2 to 5 days depending on species and temperature

From the above information, it may be possible to obtain an initial estimate of the potential for GBT problems in fish. For example, if the river or lake is deep (i.e., > 5 m) and TGPs are greater than those specified by Guideline A, it may be possible to establish a site specific TGP guideline above 110%. However, this will also depend on certain biological information requirements that are described below. In general, the deeper the water body, the less danger there is to fish from GBT. Conversely, the shallower the water body, the greater the danger to fish, and the physical and biological information requirements become more demanding. Comparisons with other river systems where the effects of DGS on fish populations are know may provide further indications of what an appropriate site-specific guideline should be. Where deep water is available and exposure periods are short in relation to the time to initiate GBT mortality (at the prevailing TGP and temperature), it may be possible to allow a guideline above 110%. The upper limit for a site-specific guideline based on the above information should be 115% unless other biological assessments are made (see below).

6.2 Biological Information

- As a minimum, it will be necessary to establish a comprehensive species inventory for the water body being subjected to DGS.
- Where available, depth behaviour and age class structure information should be examined for each species identified.
- Time to initiation of mortality information should be consulted for each species that spends significant amounts of time near the water surface.

- Age class will play an important role in establishing potential GBT impacts. In general, of the fish that have been examined, larvae and fry are the most resistant to GBT (Weitkamp and Katz 1980, Fidler and Miller 1997). Due to inter-capsular pressure, salmonid eggs have a TGP buffer of about 10% (Alderdice et al. 1984, Alderdice and Jensen 1985). Because of high TGP associated with the Columbia River hydro-system in the United States and Canada, most of the experimental studies of fish susceptibility to GBT have focused on the salmonid species. Of these species, rainbow trout appear to show the highest susceptibility to GBT. However, as noted, there are many more species that have not been examined for their susceptibility to GBT than have been examined.
- If, in developing a site specific guideline, a species is identified that has not been examined for it's susceptibility to GBT, it may be necessary to conduct laboratory bioassays to establish the susceptibility. However, this will depend on the species depth behaviour characteristics, including all life stages of the species. If the species is a physoclyst fish that spends most of it's time in deeper water, and deep water is available, it is likely that it is not severely affected by DGS. Alternatively, physostome fishes in shallow water environments will be of significant concern. If laboratory bioassay studies show the species is more susceptible to DGS than rainbow trout, it may be necessary, to establish a site-specific TGP guideline less than the 110% of Guideline A. However, this will also depend on a variety of other factors such as TGPs, exposure regimes, temperatures, and depth behaviour. Where maximum water depths are less than one metre, it may also be necessary to establish a guideline less than 110%.
- Should a guideline of 115% or above be suggested by the available physical and biological data, it may be necessary to conduct comprehensive field studies to assess safe TGP levels for the fish populations present. This might involve incremental controlled increases in TGP accompanied by field bioassays to detect signs of GBT in fish. Once signs are detected, an appropriate TGP guideline might be 5% less than the TGP at which the signs were first detected.
- Where TGPs above Guideline A have existed for many years in a water body (e.g., > 10 years), it may be possible that the resident fish species have adapted to the historic TGP regimes. In this case, it may be necessary to conduct field bioassays to establish evidence that the fish are free of signs of GBT and population numbers are compatible with the expected species structure and carrying capacity of the system. Should this be the case, a site-specific guideline compatible with the historic TGP regimes may be appropriate.
- One issue that should be kept in mind when developing site-specific guidelines for TGP is that little is known about the effects of external signs of GBT (skin blistering, exopthalmia, occlusion of the lateral line, etc.) and other sub-lethal effects (reduced disease resistance, changes in blood chemistry, etc.) on the survival of fish. The presence of external signs clearly indicates exposure to high TGP, but the long term effects are, for the most part, unknown. This is especially true for conditions involving dynamic exposures. External signs and sub-lethal effects can occur at TGPs below those that produce mortality (i.e., below 115% in shallow water). If exposure regimes involve prolonged periods of low level TGP (i.e., between 100% and 115%), extra caution is warranted in the guideline development.

The above criteria for establishing site-specific DGS guidelines are not intended to be comprehensive or complete. Some water bodies may have unique characteristics that are not fully addressed by the above criteria. In these cases, special studies may be required. For example, there may be threats to fish other than from DGS (e.g., high levels of predation, dam spillway or turbine passage, disease, high fishing pressure, low population numbers, etc,). In these situations, a site-specific guideline significantly less than 110% may be required.

6.3 Experimental Studies to Address Uncertainties Associated with Guideline A and to Facilitate the Development of Site Specific Guidelines

Based on the above discussions, there are two general areas of research that are needed to facilitate the implementation of the revised TGP guidelines. These include a re-examination of the GBT response of fish to water TGPs between 110% and 115% and the need to develop predictive tools that can assist in the development of site-specific guidelines. Of the two, the development of predictive GBT response relationships is the more urgent.

Given the uncertainties that must be addressed when developing site-specific guidelines for TGP, there is a need for predictive tools that can be used over a range of water bodies and exposure conditions. To date, the data from the literature have not been particularly useful for predictive purposes. As noted, there are questions regarding the accuracy of some of the data and in many cases there are conflicting results between studies. This is not to say that all of the data are of no use, but the data that are consistent are too few to build predictive analytical relationships.

Ideally, one would like to have a relationship that expresses time to X% GBT mortality in a population of fish as a function of TGP, temperature, species, life stage, and water depth. However, after over 40 years of experimental work, such relationships have not appeared, even for a single species or life stage. With the completion of the Fisheries and Oceans Rosewall Creek experiments, the situation has been improved somewhat. However, there is still a need for additional data before these relationships can be completed. To advance the development of these data, it is recommended that additional experimental work be conducted that will build on the Rosewall Creek experiments and expand the time to mortality information over an extended range of TGPs and temperatures. For data consistency, the proposed work should start by use the same rainbow trout stock and sizes that were used in the original Rosewall Creek studies. It will important to use rainbow trout initially because, as noted, they appear to exhibit the highest sensitivity to GBT. The research should focus on developing time to X% mortality data ranging from initiation of mortality up to 50% mortality. With these data, the original Rosewall Creek data, and what reliable data exists in the literature, it should be possible to develop the desired time to mortality functions. From these functions, risk models can be derived that will provide guidance in developing site specific TGP guidelines

The issue regarding Guideline A is the uncertainty as to the threshold for mortality in fish exposed to TGPs in the range of 110% to 115% and the cause of this mortality. To resolve these uncertainties, it is recommended that an experimental program examine juvenile rainbow trout exposed to a range of TGPs between 110% and 115% to establish the thresholds for mortality, rates of mortality and specific causes. The studies should examine a range of temperatures between 5° C and 20° C and involve primarily juvenile life stages

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