



ROYAL ROADS UNIVERSITY

APPLIED RESEARCH DIVISION

Ron MacDonald
President and CEO
Council of Forest Industries
Vancouver

via e-mail

23 August 1999

Dear Mr. MacDonald;

Re: Scientific Overview of AOX Discharge Limits and Current Regulatory Approaches

The attached report provides a review of the existing science on ‘AOX’ discharge and its impact on the environment. The report was prepared by Dr. Matt Dodd, an environmental chemist, and Dr. Doug Bright, an aquatic toxicologist, both of Royal Roads University - Applied Research. **We comment on the underlying rationale for a zero AOX emission policy, based on the current scientific understanding of aquatic effects of final treated pulp and paper effluents.**

This is an issue that merits a clear understanding of the underlying science regardless of the technical background of those involved. We have attempted, therefore, to provide a technical summary based on the current state of knowledge, as well as a non-technical summary. The former is intended to support the latter.

We hope that this brief review will serve as a catalyst to stimulate renewed discussion regarding AOX as a monitoring and regulatory tool. There is little doubt that AOX effluent discharge limits had value in helping to guide improvements in pulp mill technologies, and – hence - curtail dioxin and furan environmental impacts in the late 1980s/ early 1990s. It is important, however, to re-visit the use of AOX beyond the year 2000, now that dioxins and furans have been eliminated as contaminants of concern. We will be happy to provide further clarification for COFI or other interested parties. We are very much interested in the next generation of environmental policies for the pulp and paper sector in British Columbia, and look forward to following the events of the next few years.

Sincerely yours,

Doug A. Bright, Ph.D.

Matthew Dodd, Ph.D.

NON-TECHNICAL SUMMARY

Royal Roads University, Applied Research, conducted an independent scientific/technical review of the current state of knowledge on AOX as it applies to pulp and paper discharges. Adsorbable Organic Halogen (AOX) is a measure of a complex suite of halogenated compounds, including chlorine-containing toxicants such as dioxins and furans. At the start of this decade, it was widely believed that the measurement of AOX was a measure of the potential of pulp and paper effluents to cause impacts to aquatic receiving environments.

The B.C. Pulp and Paper Mill Liquid Effluent Control Regulation was introduced on December 13, 1990, in direct response to concerns over dioxins and furans. This paralleled a Federal initiative to regulate the discharge of dioxins and furans to “non-measurable” levels. The B.C. Regulation required all mills to reduce AOX liquid discharges to below 2.5 kg per air-dried tonne (ADt) of pulp produced. Subsequent amendments, effective January 17, 1992, required a further reduction of AOX to less than 1.5 kg AOX/ADt by December 31, 1995, with a further requirement for a complete elimination of the AOX produced in the bleaching process by 31 December 2002.

The B.C. pulp and paper industry in the intervening years has been able to consistently achieve a zero measurable dioxins/furans discharge record as well as the regulated target of 1.5 kg AOX/ADt by December 1995 or earlier. The average AOX discharge on a province-wide basis declined progressively from around 2.7 kg/ADt in 1991 to around 0.65 kg/ADt in 1996. At the present time, the great majority of mills in B.C. have less than 0.5 kg AOX/ADt in their final effluent. For the majority of mills, the improvements were made through the elimination of elemental chlorine (Cl_2) as a bleaching agent, and the complete substitution with chlorine dioxide (ClO_2).

Chlorinated organic substances which make up AOX in a modernized pulp mill are more water soluble and less fat soluble than dioxins and furans. Therefore, such substances will not appreciably bioaccumulate or biomagnify, and are much more likely to degrade in the water and sediment of treatment facilities and natural ecosystems. The fact that few compounds have the necessary properties to undergo biomagnification is perhaps one of the least understood concepts in environmental toxicology and chemistry by the general public. The vast majority of inorganic and organic compounds undergo dilution up the food web, not biomagnification. The misconception about potential for the biomagnification of all organochlorines appears to be the primary driver behind the invocation of the precautionary principal in the case of the B.C. Pulp and Paper Mill Liquid Effluent Control Regulation, and a call for zero AOX discharge by December, 2002. While there was an earlier correlation between the reduction in dioxins and furans or higher chlorinated phenolics and a decrease in AOX, a continued relationship is not expected between AOX in general and for the toxicants of concern for ecosystem function and for higher, often keystone predators. In addition, the focus of studies completed in the last one to five years on pulp mill effluent effects has shifted away from chlorinated compounds to primarily non-chlorinated plant extractives and their transformation byproducts. These are not included in the measurement of AOX.

Overall, the call for a “zero AOX discharge” limit by 2002 is poorly conceived, since –

1. There is no way to define a single toxicological threshold for such a complex mix of potentially toxic and virtually non-toxic compounds, especially where the mix is likely to be different for each mill, each pulping/bleaching process, and over time;
2. Many compounds found in the environment and measured as AOX are produced and released naturally such that some non-zero background concentration would be expected in various terrestrial and aquatic ecosystems. Totally chlorine-free bleaching technologies have been demonstrated to produce effluents with detectable AOX concentrations.
3. There has been no consistent relationship in laboratory toxicological or field studies between levels of biological response and AOX concentrations in effluent or water; and
4. Other non-chlorinated compounds in effluent and the receiving environment, not measurable as AOX, are presently of greater scientific concern for resident fish populations, through endocrine disruption or mixed function oxygenase induced effects.

The assessment of organismic and ecological effects in the receiving environment around individual mills is relatively straight forward for compounds and mixtures which exert their effects at the point of immediate exposure. The Federal pulp mill EEM program helps in this regard. Also, provincial permits require the routine conductance of acute toxicity tests. Finally, some of the aquatic effects of contemporary concern such as MFO induction or endocrine disruption in aquatic animals are most amenable to resolution through specific detailed studies around those mills with known or suspected outstanding problems. This helps to focus regulatory and scientific attention on those specific mills with effluent discharges that continue to pose serious outstanding risks to the receiving environment.

Overall, we advocate that an environmental management policy for the pulp and paper sector should increasingly be applied on a performance basis to individual pulp mills and the associated ecosystems (i.e., be site specific). It should further provide incentives for embracing environmental management systems to further reduce outstanding impacts and tie environmental improvement specifically to mill processes. This would also allow a more wholistic approach to environmental management, based not only on liquid effluents and the aquatic receiving environment, but also on atmospheric emissions, energy and water conservation, and other important aspects of sustainability within the industry.

TECHNICAL REVIEW

Objectives

This review addresses the following five questions:

1. Is there a definable toxicity threshold for aquatic populations and communities for levels of AOX in effluent or the receiving environment beyond which environmental risks might occur?
2. At contemporary, low levels of AOX discharge into aquatic environments, is there evidence that AOX is produced by technologies employing ClO₂ but not by the so-called TCF or totally chlorine free technologies?
3. Recognizing that AOX also includes some naturally occurring chlorinated organic compounds, is there adequate information on expected background concentrations of AOX in a range of aquatic receiving environments, or in wood extractives before bleaching?
4. Does AOX correlate with any meaningful measure of environmental impact; for example, fish population effects, single species toxicity, or any toxicological endpoint such as mortality, MFO induction or endocrine disruption?
5. Are there more scientifically defensible tools for ensuring environmental quality in receiving waters?

There is a substantial body of scientific information that is useful for addressing these questions that has arisen since around 1995, much of it available in an already compiled form.

Review Methodology

We evaluated compilations of recent reviews in addition to the underlying source studies to address the above-mentioned questions. Our overall intent was to conduct an independent scientific/technical review of the current state of knowledge on AOX as it applies to pulp and paper discharges. We attempted to identify important studies that reinforce or allay any concern about AOX in final effluent, and suggest in what context AOX as an environmental management tool might be considered, or possibly curtailed.

Background

Adsorbable Organic Halogen (AOX) is a measurement based on laboratory analytical techniques of a complex suite of halogenated compounds (chlorides, bromides, iodides¹) than can be adsorbed from water or effluent onto an activated carbon column. Brominated

¹ Fluorides tend to be excluded since fluorinated compounds are primarily inorganic as opposed to organic compounds.

and iodated compounds are not generally of interest, as opposed to chlorinated organic compounds, based on public and regulatory perceptions. In pulp mill effluents, however, brominated and iodated compounds are thought to comprise an insignificant portion of the overall AOX concentration. AOX measurements, therefore, are taken to be chlorine equivalent concentrations. There is an additional, relatively small subset of halogenated organic compounds that are excluded from analysis as AOX.

Measured AOX 'concentrations' might include the concentrations of pulp and paper derived toxicants of concern such as polychlorinated dibenzo-*p*-dioxins, polychlorinated dibenzofurans, and chlorophenolics, among the over three hundred individual chlorinated compounds likely to be present. In fact, it was believed that quantification of AOX was a reasonable measure of the potential of pulp and paper mill effluents to cause adverse environmental effects, since "the same basic changes to the industrial process are required to reduce both AOX and dioxin and furan levels" [1].

The "B.C.s Pulp Mills: Effluent Status Report" [1] further states -

"Because of the impracticality of measuring and regulating all components of pulp mill effluent, a select few have been widely adopted by regulatory authorities for use in controlling impacts from pulp mill effluents. They were selected not only because they can be easily measured, but because their impacts on receiving waters are known. Perhaps equally important, these parameters are believed to reflect the amounts of other pollutants in the waste waters."

Polychlorinated dioxins and furans in the B.C. coastal and inland environment have been linked to [2]-

1. use and presence of elemental chlorine in pulp bleaching, which combines with non-chlorinated dioxin and furan precursors, as well as a range of phenolic substances derived from hardwoods and softwoods;
2. formation from chlorophenol precursors when tetra- and pentachlorophenol-treated wood chips have been used as pulp mill feed stock;
3. a wide variety of urban and municipal incinerator emissions such as municipal waste incineration, hospital waste incineration, and the discharge into the aquatic environment of combined and sanitary sewer flows.
4. quantitatively very minor contributions from other sources.

The B.C. Pulp and Paper Mill Liquid Effluent Control Regulation was introduced on December 13, 1990, in direct response to concerns over dioxins and furans. This paralleled a Federal initiative to regulate the discharge of dioxins and furans to "non-measurable" levels. The B.C. Regulation required all mills to reduce AOX liquid discharges to below 2.5 kg

per air-dried tonne (ADt) of pulp produced². Subsequent amendments, effective January 17, 1992, required a further reduction of AOX to less than 1.5 kg AOX/ADt by December 31, 1995, with a further requirement for a complete elimination of the AOX produced in the bleaching process by 31 December 2002.

The B.C. pulp and paper industry in the intervening years has been able to consistently achieve a zero measurable dioxins/furans discharge record as well as the regulated target of 1.5 kg AOX/ADt by December 1995 or earlier. The average AOX discharge on a province-wide basis declined progressively from around 2.7 kg/ADt in 1991 to around 0.65 kg/ADt in 1996. At the present time, the great majority of mills in B.C. have less than 0.5 kg AOX/ADt in their final effluent. **For the majority of mills, the improvements were made through the elimination of elemental chlorine (Cl₂) as a bleaching agent, and the complete substitution with chlorine dioxide (ClO₂).** Chlorine dioxide and elemental chlorine exhibit fundamentally different chemical behaviour during the bleaching process [3]. Elemental chlorine tends to chlorinate wood-derived lignin and phenolic substances derived from lignin, in addition to oxidizing it. Conversely, chlorine dioxide is a much stronger oxidant and tends to more completely oxidize lignin, leaving fewer residual aromatic compounds. These remaining aromatic compounds, when reacted with ClO₂ and its derivatives, produce five to ten times less chlorine attached to soluble organic compounds. In addition the chlorinated organic compounds have much lower degree of chlorine substitution: For example, ClO₂ bleaching overwhelmingly produces mono- and dichlorinated phenolics (such as 6-chlorovanillin or dichlorosyringaldehydes) as opposed to the much more environmentally persistent and bioaccumulative tri-, tetra- and pentachlorinated phenolics found in Cl₂-derived bleached kraft effluent.

There are other ways of reducing AOX emissions, in addition to the total elimination of elemental chlorine use. Several totally chlorine free (TCF) technologies are being tried, more so in European countries than in North America. As noted below, however, even many TCF mills produce in their final effluent measurable AOX levels. Another way to theoretically achieve zero AOX emissions is through the adoption of complete closed-loop technologies, where there is no environmental discharge whatsoever. In this case, however, the justification for a zero AOX discharge would be to force a closed-loop architecture, not to curtail known problems with the environmental discharge of chlorinated organic substances. We deem this to be an issue that is within the policy and political arenas as opposed to scientific arena and, therefore, consider it to be beyond the scope of a science-based review. As an aside, it has been noted by several people that such an approach is problematic unless it embraces a pollution prevention (P2) planning perspective, where the likely effects on energy consumption, greenhouse gas and other atmospheric emissions, water use, and other aspects of pulp and paper production are simultaneously considered. There are clearly no specific provisions within the existing B.C. Pulp and Paper Mill Liquid Effluent Control Regulation for such an approach.

The net result of a complete substitution with ClO₂ during bleaching is that the AOX formed has a much lower chlorine content (approximately 1 chlorine atom per 100 carbon atoms) than was

² Each air dried tonne (ADt) of pulp produced by a typical mill results in the generation of 25,000 to 100,000 litres of wastewater. This waste water is further required to be subjected to secondary treatment prior to release.

previously found with Cl₂ (10 to 15 chlorine atoms per 100 carbon atoms). **The individual chlorinated organic constituents found in AOX in a modernized pulp mill, therefore, are more water soluble and less fat soluble (lipophilic) and therefore will not appreciably bioaccumulate or biomagnify, and are much more likely to degrade in the water and sediment of treatment facilities and natural ecosystems.**

The issue of biomagnification is an important one from the perspective of public perceptions. Organochlorines such as dioxins and furans, PCB congeners and chlorinated pesticides such as p,p'-DDT or chlordane compounds are of strong concern to scientists, regulators, and the public owing to real world examples of impacts to wildlife populations and, occasionally, human beings. In all of these cases, however, the exposure regime leading to impacts has been via food-web mediated biomagnification especially in aquatic environments. Biomagnification is a very well understood phenomenon that occurs only for a small subset of chemicals based on a few key properties. **For a chemical to biomagnify** - to increase in tissue concentration from lower trophic order organisms (primary producers and herbivores) to higher trophic order animals (secondary, tertiary, quaternary consumers) - **there are two basic requirements:**

1. First, the chemical must be moderately to strongly insoluble in water or aqueous media (hydrophobic) and at the same time be strongly soluble in fatty tissues (lipophilic) in the tissues.³
2. Second, the chemical must be resistant to enzymatic modification once in an organism, where enzyme-mediated biotransformation would reduce the lipophilicity and assist in the rapid elimination of metabolites from the body.

Adverse effects to living organisms in or associated with the aquatic environment can be divided into two types based on whether a chemical has the appropriate properties to undergo biomagnification:

1. **For the vast majority of limited bioavailability organochlorines found in AOX, the plausible mode of toxicology action will be based on the direct contact of an organism with the compound via water and/or sediment.** The worst-case risks would be at the point of maximum exposure, which for the most part would occur at or near the effluent discharge point. Subsidiary effects on the larger biological community and ecosystem could theoretically occur through loss of a food source or alteration of inter-species interactions, but only after significant effects on the individuals and populations directly exposed were evident.
2. **For highly lipophilic substances like 2,3,7,8-tetrachlorodibenzofuran, the primary concern is for higher predators,** particularly piscivorous fish, birds and mammals, which may be exposed to very high doses relative to the concentrations found in water or sediment within the receiving environment.

³ Compounds with an octanol-water partition coefficient (K_{ow}) of greater than 10,000 are generally deemed to be sufficiently bioaccumulative substances to undergo food-web mediated biomagnification (Mackay, 1995).

The fact that few compounds have the necessary properties to undergo biomagnification is perhaps one of the least understood concepts in environmental toxicology and chemistry by the general public. The vast majority of inorganic and organic compounds, where the primary exposure path is through the diet, undergo biodilution, not biomagnification. This misconception appears to be the primary driver behind the invocation of the precautionary principle in the case of the B.C. Pulp and Paper Mill Liquid Effluent Control Regulation, and a call for zero AOX discharge by December, 2002.

The available scientific studies provide a strong weight-of-evidence with regard to pulp mill derived organochlorines in contemporary liquid effluents. Changes in technologies and practices implemented in the early 1990s have virtually eliminated the higher chlorinated organic compounds with the potential to undergo biomagnification [4]. While there was an earlier correlation between the reduction in dioxins and furans or higher chlorinated phenolics and a decrease in AOX, a continued relationship is not expected between AOX in general and for the toxicants of concern for ecosystem function and for higher, often keystone predators.

The more recent focus for environmental improvements has shifted away from compounds that biomagnify, since these have already been eliminated in pulp mill final effluents, with few exceptions. This leaves concerns around direct exposure to the residual suite of chlorinated organic compounds and various toxicological modes of action. Direct exposure and toxic action at the point of exposure from water or sediment is more amenable to detection through the application of traditional toxicological principles (e.g. - a synoptic dose-response model) as well as via direct observation in field populations and laboratory exposed plants and animals. The compounds contributing to this later category of possible risks are also less likely to create long-term and large scale ecological effects.

In addition, studies completed in the last one to five years on pulp mill effluent effects have shifted away from a focus on chlorinated compounds to primarily non-chlorinated plant extractives and their transformation byproducts. These compounds are implicated in two major toxicological responses of contemporary concern:

1. the induction or impairment of Mixed Function Oxygenase detoxification enzymes in field-caught or laboratory exposed fish, and
2. endocrine-disruption type effects in fish populations as evidenced by changes in circulating sex hormones, and/or masculinization of female fish in wild populations.

Compounds from pulp mill effluent implicated to the present time in these two types of responses in fish include stilbenes, terpenes such as juvabione and dehydrojuvabione, retene - a microbial transformation product of a di- and triterpene, and natural plant sterols such as β -sitosterol [4]. These are all either natural plant products or products formed through the microbial conversion of such products. They are not chlorinated organic compounds, and are not included in the measurement of AOX. Furthermore, they may be derived from a large number of natural and anthropogenic sources. The potential for adverse effects varies as a function of the extent to

which a variety of pulp mill activities, not just bleaching, contribute to a flux of these compounds into aquatic environments at rates well beyond what has occurred naturally. Overall, such compounds can exhibit an enhanced flux into adjacent aquatic environments in specific instances where log harvesting, storage, chipping, pulping, or other processes enhance the leaching from wood, without adequate potential for a diminution of concentration prior to entering a fish-bearing water body.

Is There a Definable Toxicological Threshold for AOX?

AOX is a 'bulk' parameter which includes a wide variety of chlorinated organic compounds (more than 300 individual compounds). The important toxicological and chemical properties for the protection of aquatic life include bioavailability and potential for bioaccumulation, persistence, and the threshold - if any - beyond which various chronic or acute toxicological effects are likely. The problem with defining an environmentally safe but not overly restrictive concentration for any bulk parameter is as follows: The key properties of individual compounds that might contribute to the mix may differ by many orders of magnitude. An individual mix might include varying portions of virtually non-toxic compounds and - at least prior to 1995 - small quantities of what is often deemed to be one of the most toxic compounds identified to the present time (2,3,7,8-TCDD). **While it makes sense to define a toxicological threshold for each individual compound, it is challenging to define a scientifically defensible threshold for the entire suite.** This is especially true where the composition of individual compounds within AOX vary as a function of the individual mill, type of feed stock used, short term variations in mill processes, type of secondary treatment employed, black liquor carry over, changes over time, and a wide range of other factors.

One approach to deriving an environmentally protective discharge or ambient quality threshold is to make certain assumptions about the relative composition of different classes of constituents, each with its own known toxicological threshold, and then calculate an overall threshold through the use of a weighted average approach. This implies, however, that there is a reasonably good understanding of a substantial portion of the compounds present as well as their individual toxicological properties. This is clearly not the case for AOX. This approach is perhaps a viable option for future consideration, and would be more in line with trends towards risk-based environmental standards setting exercises. The approach could also be refined by a better subdivision of the entire AOX suite along lines that have direct relevance for ecological risks. The presently defined AOX limits, however, are not rooted in such an approach. Instead, the AOX discharge levels were initially defined through policy decision by what was deemed by regulatory officials to be achievable as of 1994.

Another approach would be to make a worst-case assumption that the adverse effects of the entire AOX mixture can be defined by an extrapolation of the toxicity threshold of the most toxic single constituent to the entire AOX concentration. In fact, by assuming the entire mix is 2,3,7,8-TCDD, it might be assumed that any concentration of AOX is unacceptable. 2,3,7,8-TCDD is regarded by the majority of toxicologist to be a non-threshold acting compounds which is capable of exerting adverse biochemical effects at any exposure concentration There are other

mechanisms, however, based on environmental fate and transfer, prior to internalization, which may contribute to a bioaccumulation threshold and indirectly to a toxicity threshold [5].

Even if one assumes that 2,3,7,8-TCDD is a threshold acting toxicant, it is clear that the AOX measured in B.C. pulp mill effluents within the last few years do not contain any measurable 2,3,7,8-TCDD at the analytical detection limits dictated by Federal regulations. **Therefore, an AOX threshold, as presently embraced in the regulation, is not justifiable based on toxicological and environmental chemistry principles.**

Is AOX produced by technologies employing ClO₂ but not by the so-called TCF or totally chlorine free technologies?

The short answer to this question is a simple “No”. It is clear that elemental chlorine free (ECF) technologies using 100% ClO₂ substitution generally produce more AOX in final effluent/ADt, but that totally chlorine free technologies (TCF) based on oxygen delignification or other techniques still produce AOX. For example, Dahlman *et al.* [6] measured AOX levels in Swedish mill effluents. The AOX ranged from 0.2 to 0.7 kg/ADt in ECF mills, and from less than detection to 0.01 kg/ADt in TCF mill effluents (detected in 3 of 5 samples).

Some minimum concentration of AOX can be detected in final effluent from mills where neither Cl₂ nor ClO₂ are employed. Some studies, in fact, have demonstrated an increase in AOX concentration from the primary effluent to the secondary treated effluent – an indication that microbial and or chemical processes in treatment lagoons are capable of producing chlorinated organic compounds.

Is there adequate information on expected background concentrations of AOX?

Grimvall *et al* [7] in 1994 reviewed information on naturally occurring chlorinated organic compounds in surface water and precipitation, which were measurable as AOX. For example, naturally produced chlorinated fulvic acids in aquatic water have been characterized in detail. Background water samples from “relatively unpolluted” rivers in Sweden and Finland contained between 1 and 58 µg Cl as AOX per liter of water (µg Cl/L). A rainfall samples contained up to 11 µg Cl /L. Average concentrations of trichloroacetic acid, one constituent of AOX at different sites in Germany varied form 0.5 to 1.0 µg/L. The AOX constituents in rainfall were not very volatile.

Nystrom et al [8] demonstrated that two trichlorinated phenolics, 2,4,6-trichlorophenol and 2,4,6-trichloroanisole are ubiquitously found in humus-rich waters, most likely due to a natural, biogenic origin.

Around 2000 different halogenated compounds have been identified as entering the environment from biogenic sources (plants, marine organisms, insects, bacteria, fungi, and mammals) [4].

Other natural sources include active volcanoes, forest fires, and chemical reactions within the atmosphere.

It is worthwhile to place these natural AOX concentrations in context. A water sample with a natural AOX concentration of around 10 µg Cl/L would be directly comparable to a sample of pulp mill effluent with an AOX concentration of 0.6 kg/ADt assuming that the production of each kg dry wt of pulp generated around 60,000 liters of effluent.

For the majority of water quality and soil quality guidelines and standards in British Columbia and Canada, there are provisions that do not require a responsible party to take action to reduce contaminant levels to below background concentrations, in recognition of the impracticality of this approach. If this is a sound philosophy, then it will be worthwhile for regulators to accurately define for a range of receiving environments the probability distribution of naturally occurring AOX in the environment and revise the regulated AOX target threshold accordingly.

Does AOX correlate with any meaningful measure of environmental impact?

Pryke (in progress) recently completed a review on the relationship between AOX levels and effluent toxicity. Based on the available scientific information, it was concluded that –

- Laboratory bioassay responses for aquatic invertebrates and fish are not correlated with AOX levels for either primary or final treated pulp mill effluents.
- Factors other than the presence or absence of chlorinated organic substances are presently deemed to be responsible for many of the biological responses of concern in aquatic receiving environments near a small subset of mills. Such responses include mixed function oxygenase (MFO) induction or inhibition, masculinization of female fish, and suppression of sexual steroid hormones. Natural compounds extracted from wood in the pulping processes and released to the environment have been identified as the likely cause.
- Model ecosystem studies have shown there is no relationship between AOX concentration and observed environmental effects.
- Field observations of environmental effects in Canadian receiving waters do not correlate with AOX concentrations.
- Adverse effects on field populations or in laboratory toxicity tests have been observed for both TCF and ECF mill effluents. For ECF mill effluents, in particular, effluent samples with very low AOX often produce toxic responses, while final effluent samples with very high AOX concentrations (equivalent to >> 0.5 kg/ADt) have proved to be non-toxic.

Having reviewed the underlying peer-reviewed scientific literature, we concur with Pryke's conclusions that there is no consistent and predictable relationship between AOX and biological responses in wild populations or in the laboratory. This stands to reason given the complex suite of compounds that AOX represents.

Are there more scientifically defensible tools for ensuring environmental quality in receiving waters?

According to the B.C. Ministry of Environment, Lands and Parks –

“Because of the impracticality of measuring and regulating all components of pulp mill effluent, a select few have been widely adopted by regulatory authorities for use in controlling impacts from pulp mill effluents. **They were selected not only because they can be easily measured, but because their impacts on receiving waters are known.** Perhaps equally important, these parameters are believed to reflect the amounts of other pollutants in the waste waters.”

Clearly, the impacts of AOX on receiving waters cannot be defined *per se*. This is a bulk parameter that provides a singular summary of a complex underlying composition of chlorinated organic compounds. The mixture is expected to vary widely across mills and periods of time. It is not theoretically possible, therefore, to define any threshold that is based on toxicological risks or impacts.

Note the earlier discussion regarding the two major exposure scenarios of concern from a risk assessment context, based on the types of compounds involved. These were (i) effects owing to food-web mediated trophic transfer (biomagnification), and (ii) direct chronic or acute effects on an organism due to the direct exposure to pulp mill derived compounds in water or sediment. Gains made in the management of pulp mill effluent environmental effects since around 1990 have resolved the vast majority of the concerns associated with the first of these two exposure scenarios. There has been a substantial decrease in polychlorinated phenols, dioxins and furans at a disproportionately high percentage relative to AOX in general.

The assessment of organismic and ecological effects in the receiving environment around individual mills is relatively straight forward for compounds and mixtures which exert their effects at the point of immediate exposure. The Federal pulp mill EEM program helps in this regard. Also, regardless of the use of AOX as a regulatory tool, provincial permits require the routine conductance of acute toxicity tests. Finally, some of the aquatic effects of contemporary concern such as MFO induction or endocrine disruption in aquatic animals are most amenable to resolution through specific detailed studies around those mills with known or suspected outstanding problems. This helps to focus regulatory and scientific attention on those specific mills with effluent discharges that continue to pose serious outstanding risks to the receiving environment.

Overall, we advocate that an environmental management policy for the pulp and paper sector should increasingly be applied on a performance basis to individual pulp mills and the associated ecosystems (i.e., be site specific). It should further provide incentives for embracing environmental management systems to further reduce outstanding impacts and tie environmental improvement specifically to mill processes. This would also allow a more wholistic approach to environmental management, based not only on liquid effluents and the aquatic receiving

environment, but also on atmospheric emissions, energy and water conservation, and other important aspects of sustainability within the industry.

Closure

The analysis provided herein is based on our present understanding of the scientific weight-of-evidence regarding the use of AOX as a tool for the protection and enhancement of environmental quality in B.C. aquatic pulp mill environments. We recognize that there is an independent set of policy decisions based on other than scientific considerations that will undoubtedly influence any final decision on AOX discharge limits.

There are a large number of papers from the open scientific literature which were used by us in addressing the objectives. Most of these have not been referenced directly in this letter report (references cited may be found on the next page), but are available should the need to provide much more detail arise. We would be happy to provide additional clarification.

References

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- [8] Nystrom et al., 1992. Drinking water off-flavour caused by 2,4,6-trichloroanisole. *Water Science Technology*, 25: 241-249.