The two recently retired authors have a combined career experience of over 65 years in carrying out research directed at assessing effluent effects on marine and freshwater receiving waters. As such, their work directed at the environmental information needs of the forest products industry has represented a continually evolving research program. This paper reflects a history of issues and progress on pulp and paper mill effluent research before their careers began, the progression of issues and research during their careers, how questions have changed and evolved, and also looks forward to the remaining questions that need to be addressed concerning effluent effects.

**Key words:** pulp and paper mill effluent, experimental streams, receiving water studies, laboratory bioassays, fish reproduction

---

**Introduction**

Issues related to the discharge of wastewaters from pulp and paper mills have changed significantly over time. In the U.S., for example, the decline of the Olympia oyster (*Ostreola conchapila*) in Puget Sound in the early 1900s was attributed to the discharge from mills (Dinnel et al. 2009), as was low dissolved oxygen and the clogging of fish nets in the Columbia River (Carter 2006). Before effluent primary or secondary treatment, pulp mill effluent entering the Willamette River in Oregon was described as “an oxygen-gulping slime-making scourge. It destroys fish life, fouls fishing gear and fishing boats. Sometimes it churns at river's bottom forming into rafts that rise to the surface in sluggish, foul-smelling masses of filth – There was no oxygen at all. The Willamette River was dead.” (Walth 1995).

Most mills provided effluent treatment with the addition of primary settling to remove fibres and heavy solids, either prior to or beginning in the 1950s. Early studies by the National Council for Air and Stream Improvement (NCASI) indicated the benefits of aeration lagoons as secondary treatment for biochemical oxygen demand reduction, and these were installed at mills along the Willamette River in the 1960s. By 1972 the benefits of secondary treatment were being noted in the Willamette River (Gleeson 1972). With an understanding of the benefits of secondary treatment, the *Clean Water Act* in 1972 required secondary treatment, and most U.S. mills had met this requirement by the mid 1970s. The *Act* included other provisions designed to protect the health of the aquatic environment, including a “fishable/swimmable” goal targeted to provide for the protection and propagation of fish, shellfish, and wildlife, as well as recreation.

Although the record of U.S. mills provided clear examples of improved effluent quality following the implementation of secondary treatment, there were continued calls for further research to identify whether harmful effects to aquatic organisms remained. Some of these calls were from the science-based community while others were from the public or environmental groups with sincere, but not necessarily fact-based concerns. Recent protests regarding the construction of a new state of the art pulp and paper mill and advanced wastewater treatment facility in Uruguay provide an example of how (whether fact- or emotion-based) issues continue to be raised about possible harmful effects from pulp and paper mills. Science-based questions do continue to be proposed, however, as evidenced by the attendance of international participants to the series of seven Fate and Effects Conferences. These conferences, initiated in Saltsjöbaden, Sweden, in 1991, and held most recently in Fredericton, New Brunswick, Canada, in 2009, provide examples of how science and issues have evolved over time and how there appears certainty that new questions will continue to be raised.

The two authors over the course of their careers have experienced and participated (as industry-supported scientists) in this evolution, having begun their careers either just before or just after the implementation of the *Clean Water Act* in the U.S. Some examples of the fish-related effluent effects questions that have been raised over time are provided in Table 1. The length of this partial list suggests that as one question is answered, another will arise, given the passage of time and new ideas or tools for assessing potential effluent effects. Indeed the concept of the “Great Pulp Mill Onion” has been evoked by one researcher, suggesting that “complex effluents are like layers of an onion. As you peel back one layer of effects you reveal another” (Hodson 2008). With this perspective in place, issues of effluent effects will
undoubtedly continue to be raised over time regardless of the sophistication of research employed.

Beyond questions about direct effluent effects on fish, there have been other questions related to effluent effects on other aspects of the aquatic community, such as periphyton or macroinvertebrates. The rationale for postulating these effects is based on combinations of toxicity, added inorganic or biosolid-based nutrients, and reduced underwater light transmittance because of effluent colour.

From an industry perspective there is disappointment that changes in mill process and treatment technologies have not resulted in a lessening of public and regulatory concern regarding whether effects in receiving waters are still taking place. This may be, in part, due to the dilemma that although good science has been carried out over the past several decades, there are still substantial differences in the conclusions which have been reached by investigators. In Canada, for example, data collected through the Environmental Effects Monitoring (EEM) program has provided sufficient cause to state that “Scientists know these effluents adversely affect fish populations” and that “Pulp mill effluents affect the ability of fish to reproduce and sustain their populations.” (Envirozine 2004). Conversely, Hall et al. (2009c) reported that “following 8 y of monitoring the weight of evidence suggests an absence of instream population/community effects downstream of the mill discharges” on four U.S. receiving waters. The differences in conclusions may not be reflective of whether research for these two respective programs was good or bad, but rather that different approaches were taken to identify whether and the extent to which effluent effects were present. The remaining portions of this paper recount, through the experiences of the now retired biologist authors, how effluent effects were studied and how issues evolved over the four decades since the early 1970s. Additionally the authors provide some career-based perspectives on remaining and future information needs and a view on forests as a unique renewable resource.

**Early NCASI Aquatic Biology Research**

NCASI was founded by representatives of forest products companies in 1943 as a nonprofit research organization whose purpose was to provide science-based environmental technical support to the industry. Early major efforts at addressing effluent effects concerns constituted an expression that the industry recognized the need to improve effluent quality in order to preserve the abundance and diversity of receiving water communities, and that a shared funding approach through NCASI was a means to accomplish this. Some of the earliest NCASI studies were related to assessing receiving water conditions as they were influenced by pulp and paper mill effluent discharges. One of the first technical bulletins issued by NCASI related to aquatic biology research and questions about the effects of mill effluent on fish food organisms (NCASI 1947). The early studies focused on and embraced the concept of the “web of life” with research addressing both fish and the supporting food web. The earliest studies were based on acute bioassays carried out in laboratory aquaria, but these evolved by 1971 into studies carried out in large outdoor experimental stream channels.

**Experimental Stream Studies**

NCASI’s experimental streams studies were undertaken out of a desire to expand the knowledge of effluent responses from observations of direct effects on individual organisms in the laboratory to assessments in a larger more natural outdoor setting where effects could be ascertained under more realistic conditions with respect to the functioning of the “web of life.” The test systems included flowing water and stream channels that were intended to mimic either coldwater faster flowing riffle/pool stream channels or warmwater meandering streams. The streams were stocked with representative fish species, and their resulting growth, survival, and production were dependent on the health of the fish based not only on their direct effluent exposure, but also on the health of...
Evolution of Effluent Effects Knowledge and Issues

The first of these studies initiated by Isaiah Gellman and Russell Blosser of NCASI, was carried out at an unbleached kraft mill in Albany, Oregon, through a cooperative agreement with Oregon State University. These studies focused on trout and salmon in the experimental streams, as well as the continued use of laboratory bioassays. The Albany experimental streams were supervised by Charles Warren from Oregon State University (Warren 1971), who was joined by Dennis Borton who later became NCASI’s first aquatic biology employee. The Albany studies spanned five years which included a period before and after initiation of secondary treatment of effluent at the host mill.

The focus of NCASI experimental stream research shifted in 1975 to a bleached kraft mill effluent, with Dr. Borton initiating new studies at the Southern Experimental Streams Facility in New Bern, North Carolina (Fig. 1). These studies included exposures in the streams to effluent before and after the mill completed process changes to chlorine dioxide substitution bleaching (Borton et al. 1996), and then to oxygen delignification. The studies involved year-long exposures of warmwater fish species (largemouth bass [Micropterus salmoides], bluegill sunfish [Lepomis macrochirus], golden shiner [Notemigonus crysoleucas]) and the supporting food web to biologically treated effluent at concentrations up to 13% vol/vol (NCASI 1983). No adverse effects were reported for fish based on survival, growth, production, reproduction, liver somatic index (LSI), gonadal somatic index (GSI), or condition factor (CF), or for the supporting macroinvertebrate community.

The experimental streams effort was expanded in 1980 to include a coldwater ecosystem counterpart to the Southern Experimental Streams. Tim Hall joined the NCASI staff in 1979 for the initiation of these studies at a Northern Experimental Streams Facility constructed at the site of a bleached kraft mill in Lewiston, Idaho (Fig. 2). Lewiston stream studies carried out between 1980 and 1994 focused on rainbow trout (Oncorhynchus mykiss) as a representative salmonid, with research with other salmonid species carried out in the laboratory. Studies were carried out both before (Hall et al. 1991) and after the mill underwent conversions to first increased chlorine dioxide substitution (Haley et al. 1995), and then to oxygen delignification. The Lewiston studies involved effluent exposures up to 5% vol/vol. Based on exposure periods ranging from 9 months to 3.5 years, greater levels of fish production were reported for effluent exposed fish, a likely product of similar increases noted for macroinvertebrate production. Effluent exposed rainbow trout did not, however, have significant differences in LSI or CF, and they reproduced successfully (Hall et al. 1991).

The two experimental streams studies indicated an absence of effluent effects on fish production or reproduction at concentrations considerably higher than the supporting macroinvertebrate food webs as they might be influenced by effluent exposure.

Fig. 1. The NCASI Southern Experimental Streams (New Bern, North Carolina) operated from 1975 to 2000 with warmwater fish species at effluent concentrations up to 13% vol/vol.

Fig. 2. The NCASI Northern Experimental Streams (Lewiston, Idaho) operated from 1980 to 1994 with rainbow trout at effluent concentrations up to 5% vol/vol.
the median instream effluent concentration (0.4% vol/vol) for U.S. pulp and paper mills (Beebe et al. 2004). This finding justified the conclusion of work at the Northern Streams in 1994 and the Southern Streams in 2000 with a refocus of NCASI’s aquatic biology research toward fish reproduction and endocrine disruption studies by Dr. Borton at the New Bern facility. Also at this time a research effort directed at assessing U.S. EPA (U.S. Environmental Protection Agency) whole effluent toxicity marine chronic bioassay methods, and both marine and freshwater sediment toxicity test methods, was undertaken by Mr. Hall following facility relocation to a coastal laboratory location in Anacortes, Washington.

Technical Assessment of Whole Effluent and Sediment Toxicity Test Methods

The experimental streams studies had been supported by the physical/chemical assessment of biologically important water quality parameters, the detailed characterization of the organic chemical components of the effluents tested, and newer whole effluent toxicity (WET) tests. The U.S. pulp and paper industry looked to NCASI to assist in the understanding and technical evaluation of the acute as well as newer chronic effluent WET tests being required by the U.S. EPA under the National Pollution Discharge Elimination System (NPDES) permit program. These assays included both freshwater and marine plant, invertebrate, and fish species (U.S. EPA 1995, 2002a, 2002b), NCASI’s test evaluation studies, as well as the earlier laboratory and experimental stream studies, included 7-d Pimephales promelas and Ceriodaphnia dubia freshwater growth or reproduction bioassays, and Dendraster excentricus and Mytilus edulis marine egg fertilization and embryo development bioassays. NCASI staff also became involved with the early development and interlaboratory precision testing of some of these same tests (DeGraeve et al. 1989 and Environment Canada 1992). Similar activities were also undertaken to develop practical experience with methods the U.S. EPA was developing for assessing the toxicity of both marine and freshwater sediments.

A primary theme in NCASI’s technical evaluation of bioassay methods has been to assess the adequacy of inter- and intra-laboratory precision data, and to assist in studies to fill these important information gaps when it has been found to be lacking. Substantial improvements have been made in this area as U.S. EPA and other methods have become better defined, precision tested, and more frequently used.

Fish Reproduction Research

Additional NCASI research to address questions about the possible direct effects of effluents on fish survival, growth, and particularly reproduction began in 1979 with the first of a series of fathead minnow life-cycle tests. The life-cycle bioassays began with the exposure of P. promelas eggs from laboratory cultures to various concentrations of effluent with exposure continued for an additional 5 to 6 months. Upon reaching maturity, fish were reduced to spawning “trios” with resulting egg production and other endpoints recorded (Fig. 3). The final phase of the studies were to record the hatching success and early growth and survival of the resulting offspring. Since the first of these studies was completed in 1979 (NCASI 1985), 24 fathead minnow life-cycle assays have been completed with effluents from 12 different mills, including unbleached kraft, bleached kraft, thermomechanical, deinking recycle, and cardboard container recycle mills, as well as with exposures to wood leachates, lignin, and stigmastanol (a phytosterol originating with the wood furnish). Additional multigenerational studies were also completed, including some tests before and after mill modernization. Egg production was generally the most sensitive of the reproduction metrics measured and, depending on the effluent tested, was not affected until effluent exposure reached from 8 to >100% vol/vol (NCASI 2006; Borton et al. 2009), a concentration substantially higher than the 0.4% vol/vol median concentration for U.S. pulp and paper mills (Beebe et al. 2004). Other results indicated that multigenerational exposure did not increase effects (Borton et al. 2000), mill modernization decreased effluent effects (Borton et al. 1997), effects noted were dependent on continuous exposure thus diminishing the probability of bioaccumulation (Borton et al. 2004), and that some chemical compounds originating from the wood furnish could contribute to reproduction effects, although resin acids were ruled out as contributing compounds (Borton et al. 2006). Of over 50 components measured during the life-cycle assays, polyphenols, a group of secondary metabolites naturally produced by trees, provided the highest correlation with reduced egg production (Borton et al. 2009). Also of note is that several commonly used bioindicators (e.g., GSI, LSI, CF) measured during life-cycle assays have been completed in 1979 (NCASI 1985), 24 fathead minnow life-cycle assays have been completed with effluents from 12 different mills, including unbleached kraft, bleached kraft, thermomechanical, deinking recycle, and cardboard container recycle mills, as well as with exposures to wood leachates, lignin, and stigmastanol (a phytosterol originating with the wood furnish). Additional multigenerational studies were also completed, including some tests before and after mill modernization. Egg production was generally the most sensitive of the reproduction metrics measured and, depending on the effluent tested, was not affected until effluent exposure reached from 8 to >100% vol/vol (NCASI 2006; Borton et al. 2009), a concentration substantially higher than the 0.4% vol/vol median concentration for U.S. pulp and paper mills (Beebe et al. 2004). Other results indicated that multigenerational exposure did not increase effects (Borton et al. 2000), mill modernization decreased effluent effects (Borton et al. 1997), effects noted were dependent on continuous exposure thus diminishing the probability of bioaccumulation (Borton et al. 2004), and that some chemical compounds originating from the wood furnish could contribute to reproduction effects, although resin acids were ruled out as contributing compounds (Borton et al. 2006). Of over 50 components measured during the life-cycle assays, polyphenols, a group of secondary metabolites naturally produced by trees, provided the highest correlation with reduced egg production (Borton et al. 2009). Also of note is that several commonly used bioindicators (e.g., GSI, LSI, CF) measured during life-cycle tests did not correlate well to egg production (Borton et al. 2003).

Long-Term Receiving Water Studies

The NCASI Long-Term Receiving Water Studies (LTRWS) were a logical extension of the experimental streams. Although the experimental streams offered an important step forward with respect to understanding the potential for long-term effluent exposure effects at the aquatic community/food web level, they represented rather simplified conditions compared with more complex natural streams. The concept of the LTRWS was developed by NCASI through its industry steering committee, and from this a series of scope and framework objectives was developed (Hall and Miner 1997). These objectives included the general purpose of addressing the compatibility of effluents with healthy receiving water communities, and understanding any related changes
following mill process modifications. The studies were designed based on their long-term timeframe (10 to 20 year) and detailed field and laboratory bioassessment to identify possible subtle effluent effects that may not have been previously identified, as well as to serve as a real world framework to assess the significance of these effects if they were identified. In addition, the length of the study and the inclusion of a watershed-scale distribution of sample sites were intended to put potential responses within the context of natural upstream/downstream variability, and variability over time. The studies, managed by Mr. Hall, were initiated in 1998/1999 at Codorus Creek (Pennsylvania), the Leaf River (Mississippi), and the Willamette/McKenzie rivers (Oregon) (Fig. 4) to represent a blend of bleached and unbleached mills, both coldwater and warmwater stream ecosystems, and a range of representative effluent concentrations (Table 2).

A key component of the study was the inclusion of a Science Advisory Panel (SAP). The six member independent panel consisted of representatives from both academia and industry with expertise in stream ecology, toxicology, and bioindicators, as well as pulp and paper mill processes. During the formative years of the LTRWS, the SAP consisted of John Rodgers (Clemson University), Wayne Landis (Western Washington University), Wayne Minshall (Idaho State University), Tibor Kovacs (FP Innovations/Paprican), Barry Firth (Weyerhaeuser), and Tom Deardorff (International Paper). Carroll (Skip) Missimer (Glatfelter) and Monique Dubé (University of Saskatchewan) joined the SAP in more recent years to fill vacancies created by the departures of Firth and Deardorff. Twice yearly meetings with NCASI staff provided direction in program development, internal quality assurance assessment, assessment of findings, and peer review of publications.

LTRWS monitoring included the assessment of fish at the whole organism and population/community level as well as similar assessments of the periphyton and macroinvertebrate communities (Fig. 5). Similar to the approach used in the experimental streams studies, instream monitoring was accompanied by the analysis of water and effluent for over 100 physical/chemical parameters, effluent chronic bioassays, streamside mesocosm studies, and fathead minnow life-cycle studies.

A series of papers was published in 2009 reporting on findings from the first eight years of the LTRWS (Borton et al. 2009; Flinders et al. 2009a, 2009b, 2009c; Hall et al. 2009a, 2009b, 2009c; Landis and Thomas 2009). Conclusions reached during this initial period of the study provide a “weight of evidence” founded on both instream and laboratory-based assessment for an absence of effluent effects for the four mill discharges studied (Table 2). That this may be more broadly applied to the larger population of mills is supported since all but one of the effluents studied was present in its receiving water at greater than the 50th percentile distribution of U.S. mills (0.4% vol/vol) (Beebe et al. 2004). One of the effluents studied (Codorus Creek mill, Pennsylvania) was actually in the >95th percentile of the distribution (33% vol/vol) and was selected as a way to address the “margin of safety” possible for other mills. Effluent chronic bioassays included in the study suggested that the “margin of safety” may have been from 2 to 3 times for Codorus Creek and from 25 to 321 times for the other three study sites.

The conclusions drawn here are substantially different from those reported in the Canadian EEM program (EnviroZine 2004; Lowell et al. 2005) where it has been stated to a high degree of certainty that paper mill effluent exposures adversely affect fish populations through metabolic disruption or reproductive impairment. The nature of the differences in conclusions may relate to the use of long-term (i.e., multiyear, multiseason) population/community-based metrics in the LTRWS (e.g., species type and relative abundance, community structure metrics such as richness and diversity, and structure and function metrics) versus less frequent (single year or periodic) individual sentinel fish.
Fig. 4. The Long-term Receiving Water Study sites at which work was initiated in 1998 to assess effluent effects on representative U.S. receiving waters. Codorus Creek (upper left), Leaf River (upper right), McKenzie River (lower left), and Willamette River (lower right).

<table>
<thead>
<tr>
<th>TABLE 2. Overview of LTRWS findings after the first decade: the “weight of evidence”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mill type</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Mean effluent concentration</td>
</tr>
<tr>
<td>- edge of mixing zone</td>
</tr>
</tbody>
</table>

**Were there significant differences downstream of the mill discharge?**

<table>
<thead>
<tr>
<th>Water quality</th>
<th>Colour</th>
<th>Conductivity</th>
<th>Total phosphorus</th>
<th>Total nitrogen</th>
<th>Light attenuation</th>
<th>Periphyton</th>
<th>Chlorophyll</th>
<th>Macroinvertebrate</th>
<th>Hilsenhoff Biotic Index</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Inc b</td>
<td>No</td>
<td>Community structure</td>
<td>Inc b</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Inc b</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**What was the “margin of safety”?**

<table>
<thead>
<tr>
<th>Species</th>
<th>Effect</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Selenastrum capricornutum</em></td>
<td>Growth</td>
<td>96 h</td>
</tr>
<tr>
<td><em>Ceriodaphnia dubia</em></td>
<td>7-d Reproduction</td>
<td>3x</td>
</tr>
<tr>
<td><em>Pimephales promelas</em></td>
<td>7-d Growth</td>
<td>3x</td>
</tr>
<tr>
<td><em>Pimephales promelas</em></td>
<td>6-month reproduction</td>
<td>3x</td>
</tr>
</tbody>
</table>

---

*a* Effluent contribution could not be differentiated from adjoining tributary.

*b* Inc = inconclusive; downstream sites differed from some but not all upstream sites.

*c* Downstream differences for 2 of 16 metrics.

*d* Mean effluent bioassay IC25 effect concentration vs. mean instream effluent concentration.
measurements used in EEM (CF, GSI, LSI, age). One aspiration of the LTRWS was to help bridge the information gap between these two approaches with the hopeful target of arriving at an approach that provides for both short-term response indicators of effluent effects as desired by the regulatory community as well as an assurance that these indicators provide an accurate portrayal of the health and sustainability of fish communities over the longer course of time.

Some Career-Based Perspectives

The combined careers of the two authors represent over 65 years of research related to pulp and paper mill effluent effects questions. This long-term period of involvement has provided for the formation of a number of perspectives based both on knowledge gained from the research completed to date as well as a corresponding awareness of future research information needs. Also offered is a nontechnical but nevertheless important view of forests as a unique renewable resource.

The Need for Both Short-Term Indicators of Effect and Long-Term Validation Studies to Address Ecological Relevance

The authors feel great satisfaction in having worked in a field characterized by such dynamic change over the past three-plus decades. This has provided an opportunity not only to carry out challenging and meaningful research, but to also interact with a similarly engaged group of international researchers. There have been, however, frustrations and misunderstandings along the way in terms of the approaches used and resulting conclusions reached regarding effluent effects questions. Part of this may be a result of program-driven differences in research objectives. Regulatory programs, for example, from an environmental protection standpoint, may need to respond proactively to perceived problems or those that are thought to have an unacceptable or high risk. The Canadian EEM program and the use of WET tests in the U.S. NPDES program are examples of the use of proactive short-term or rapid response indicators in safeguarding against possible adverse effluent effects. There is also an interest, however, on the part of the associated industry, that additional process and effluent treatment costs directed toward improvements in effluent quality have a measurable return in terms of benefit to the environment. From this standpoint it is important that the short-term or rapid bioassessment approaches incorporated into environmental protection programs be ecologically relevant in terms of providing for the long-term sustainability of fish populations as well as other components of the aquatic ecosystem. The suggestion here is not that there is a right way or a wrong way to move forward with respect to effluent effects questions, but that both long-term and short-term assessment approaches have merit and those future efforts should not be exclusive to one approach or the other.

The Need for Watershed-Scale Studies

With the advent of effluent secondary treatment and refinements to the mill process, effluent effects have been markedly reduced from much earlier times when incidences of acute toxicity were not uncommon and gross examples of water fouling from fibre deposits and low dissolved oxygen occurred. Today’s pulp and paper mill effluents offer the potential for effluent effects to be assessed at more and more subtle levels. The NCASI LTRWS, for example, provides indication that biological population/community level effects, if they exist, may be below measurable detection limits and that effluent related water quality effects for nutrients and some other parameters may more likely have signatures from nonpoint agricultural or land-use activities than from mill effluent discharges (Hall et al. 2009c). The case is presented here that future studies regarding the effects from pulp and paper mill effluents be carried out at the watershed level scale so that effluent effects can be placed in context with other water quality influencing factors, and so that watershed management and regulatory attention can be directed where the benefit is the greatest.
The Need to Consider a Historical Dimension in Addressing Current Effluent Effect Concerns

The pulp and paper industry is one of the older industries in North America and elsewhere. There are many mills that have been in operation and have been discharging to receiving waters for well over 100 years. Codorus Creek, one of the LTRWS study streams, has actually had a mill in active operation for over 150 years. An argument is not being made that premodern technology mill operations and discharges of untreated effluent were not without adverse effect, but rather, based on Codorus Creek and evidence from the LTRWS, that there has not been a lingering effect or long-term degradation carried forward to modern mill practices and properly treated effluents. This note of optimism is contradicted directly in the print media where dire predictions of adverse effects are sometimes stated. For example, Weinhold (2009) cautions “If you’re reading this on paper, you may want to thank fish populations around the world for their sacrifices,” and that “effluent from pulp and paper mills discharged to nearby waters is linked to plummeting fish populations...” Even in the absence of contemporary comprehensive studies such as the LTRWS, there should be reason for questioning such dire predictions (e.g., plummeting fish populations), owing the contrary evidence provided from streams which have demonstrated long-term sustainable fish populations in the presence of pulp and paper mill discharges over periods of time spanning many decades.

Some Lingering Effluent Effects May Be Due to the Natural Properties of Wood

A review by Hall and LaFleur (2003) indicated that plants produce several thousand secondary metabolites that provide protection from herbivores. Many of these metabolites are of the high molecular weight water-soluble polyphenol form, which achieve antitherbivore properties through protein binding capacities. Although primarily a defence mechanism against terrestrial herbivores, these same compounds, being water soluble, are also liberated from natural wood residue to surface waters. Concentrations of these materials along with other humic substances produce the strong tea colouration of musk, peat bogs, and many coastal and boreal forest streams, as well as pulp and paper mill effluent (Fig. 6). These natural products have been found to adversely affect the colonization settling of various benthic marine organisms, to cause gill damage in fish, and even to function as antimicrobial agents sufficient to be considered for use as a wood preservative or in dental cavity prevention. They may also provide an avenue of explanation for residual bioassay responses at higher effluent concentrations or the fact that reproductive effect indicators noted in the EEM program appear to be unrelated to mill process or treatment type (Dubé et al. 2008; Hewitt et al. 2008). The significance of polyphenols as a factor affecting fish reproduction has also been suggested in the fathead minnow life-cycle work carried out by NCASI (Borton et al. 2009). The possibility exists that residual mill effluent effects may be of similar nature and actually of a much smaller scale compared with the leachate produced by the northern latitude boreal forests.

Forests Are a Unique Renewable Resource

Forests truly represent a unique resource in today's world where many resources are recognized as being rapidly depleted and nonrenewable in nature. Forest harvest carried out with modern forestry practices provides a sustainable alternative for a wide range of currently important products, including lumber and pulp and paper, and also provides for an important future potential as a cellulose-based energy source. Forests are also being increasingly recognized as a beneficial land use, e.g., “working forests,” achieved through conservation easements and along with farming practices have been recognized as a preferable land use to development (Mapes 2009). The maintenance of timberland, in lieu of deforestation and alternative land uses, may also be essential to the availability of future supplies of high quality water (Wiegand et al. 2009). The remarkable regenerative properties of forests are also in evidence today at the locations of some previous harvest and mill discharges.

Fig. 6. A forest leachate coloured coastal tide pool and river in Washington State.
Fig. 7. Swanson Bay, the location of one of the first pulp mills in British Columbia during mill operations in 1909-1923 (left) and today (right). The stack represents the only visible evidence of the mill site which has now been reclaimed by the forest. (Photo credit: Moore 1974).

operations. A vivid reminder of the renewable nature and resiliency of forests is provided by the coastal mill at Swanson Bay in British Columbia (Moore 1974). The mill, one of the first in British Columbia, operated during the period 1909 to 1923. A remarkable reminder of forest resiliency is the single stack which today protrudes through a canopy of naturally regenerated forest at the location of the former mill and its associated town (Fig. 7).

Conclusions

The authors feel gratified in having had long productive careers in a field of rapidly advancing knowledge and continued new challenges. The series of seven “Fate and Effects” conferences has provided evidence of the advances that have been made with respect to effluent effects, and also serves to provide testimony that questions still remain and will continue to be raised in the future. It is clear, however, that the knowledge base regarding effluent effects has advanced considerably since the first conference held in 1991, and that it would be inaccurate to perceive the potential for newly discovered effluent effects to be unlimited, as suggested in the “pulp mill effluent onion” analogy (Hodson 2008). It appears clear that effluents from modern mills with secondary treatment have diminished effects from earlier process and effluent treatment technologies. Long-term studies at the population/community level have, for example, demonstrated a lack of effluent response at multiple trophic levels, and additional bioassays substantiate that this finding comes with a considerable “margin of safety” (Hall et al. 2009c). The indications of diminished effects also come with recognition that some of the residual responses may arise from the natural chemical properties of wood and not as an expression of the pulp or paper making process (Dubé et al. 2008; Hewitt et al. 2008). This finding represents a new challenge in that increasingly subtle effluent effects will require investigation not only with respect to the natural chemical properties of wood represented in effluent, but also how these same properties function naturally in aquatic ecosystems.

Acknowledgements

The authors wish to recognize the late Russell O. Blosser, and Isaiah Gellman, past NCASI vice president and president, respectively, for their efforts in sustaining the vitality of NCASI’s aquatic biology program over many decades.

References


Received: 1 September 2009; accepted: 28 December 2009.