# ENVIRONMENTAL EFFECTS MONITORING

An environmental effects monitoring (EEM) program is intended to gauge the environmental impacts of our hypothetical KL pulp and paper mill effluent discharge over time. At a minimum, the mill's EEM program should be designed to protect fish, fish habitat and the use of fisheries resources. The mill's EEM program should be adaptive; in other words, it should be flexible enough to respond to changes in observed receiving environment impacts over time. If a new parameter needs to be examined in order to better understand a newly observed effect in the EEM study area, then the program should incorporate the new parameter into the scheduled monitoring.

A typical EEM program consists of two parts:

1. A pre-design requirement
2. The sampling program – EEM studies with a field monitoring component and laboratory testing.

## PRE-DESIGN REQUIREMENTS

The KL mill might only need to address this requirement once, unless additional mill expansions are planned in the future. If the mill pulping process effluent loadings, discharge location or receiving environment conditions do not change significantly over time, then the following information should only be required as part of the environmental impact assessment (EIA) completed for the currently proposed mill expansion. Information required in the pre-design phase includes:

- The spatial extent of the study area, including the zone of effluent mixing and representative reference sites
- A description of the receiving aquatic habitat in sufficient detail for the selection of appropriate fish and benthic invertebrate sampling stations
- The quality and use of fisheries resources in the receiving environment (e.g., fishing by local people)
- Information on the relative abundance of fish in the study area and selection of two sentinel fish species
- Documentation of any potentially confounding or influencing factors that must be considered in the study design and interpretation of results
- Effluent quality and characterization.

Delineation of the zone of mixing is important to ensure that sampling stations are located within this zone and that reference stations are well beyond any potential zone of impact. In most receiving waters, the dilution zone will vary depending on changes in the river flows and the effluent discharge rate and quantity. Overall, the zone of effluent mixing should be delineated for conditions of minimum dilution, maximum extent of the effluent plume and long-term average conditions. Points within the minimum dilution region are most affected by effluent discharges. Points outside the maximum extent boundary are not affected by the discharge and may be suitable as reference stations. The long-term average condition defines any long-term effects of the effluent discharge.

Once the zone of mixing has been determined, depositional areas can be identified. When water velocity decreases, particles settle out, with the finest particles settling in the areas of slowest current speed. Analysis of benthic community structure in the depositional areas will be useful in determining effluent-induced effects in the aquatic environment.

The features to be identified and mapped for the habitat inventory and classification are included in Table 1. This information will assist in the identification of potentially confounding factors, such as discharges from other projects or activities that may be impacting the study area – important in designing the monitoring program and in interpreting monitoring results. Information from habitat inventory and classification is used to locate sampling stations within similar habitats in the exposure and reference areas.

A review of the mill's history and operations should include information on mill processes, effluent treatment and any accidental spills that may have occurred. Review of current and past operations can be useful for identifying environmental concerns resulting from existing operating practices. In addition, available information on the mill's effluent characteristics should be included, such as:

- pH, flow and conductivity
- biochemical oxygen demand (BOD)
- total suspended solids (TSS)
- dioxin concentrations.

## The Sampling Program

The study area for our KL mill EEM monitoring program encompasses eight individual sampling locations called stations as shown in Figure 1. The stations can be recognized, re-sampled and located quantitatively (i.e., using longitude/latitude coordinates). The study area is sub-divided into reference and exposure areas The overall intent of the sampling program is to gather data from exposure areas and unimpacted areas in order to determine whether significant effects are occurring in response to mill effluent discharges.

In most cases, the boundary of exposure is the zone of effluent mixing, and within this exposure area there should be both near-field and far-field stations. At least one of the near-field stations should be located as close as possible to the effluent discharge point, but just outside of the initial discharge zone. Far-field stations should be located close to the downstream boundary of the zone of effluent mixing. In general, multiple sampling stations in each defined area should be selected to determine spatial variation in impacts.

When compared to data from exposure stations, data obtained from reference stations can indicate impacts to aquatic life, identify stressors and illustrate temporal and spatial trends.

**Figure 1** Location of EEM sampling stations for the KL pulp and paper mill

**Table 1** Resource and habitat inventory requirements for an EEM program

| PARAMETER | INFORMATION TO BE REPORTED |
|---|---|
| *Major tributaries and river mouth* | Locations to be shown on map. |
| *Fish spawning grounds and nursery areas* | Locations of all known areas to be shown on map. |
| *Fishing grounds and aquaculture operations* | Locations of all known areas to be shown on map. |
| *Water intakes, effluent discharges, stormwater discharges, sewer overflows and disposal sites at the mill* | Locations of all known areas to be shown on map. |
| *Dams and other barriers to fish* | Locations of all known areas to be shown on map and fish movement restrictions indicated. |
| *Riparian vegetation* | Aquatic and riparian vegetation types to be shown on map. |
| *Zones of plant growth* | Identify and map any areas in the near-field effluent plume where aquatic plant growth appears to be reduced or enhanced relative to reference areas. |
| *River gradient* | Gradient profile produced from topographic maps or study area survey. |
| *Discharge* | Summary water discharge statistics ($m^3/s$). |
| *Water chemistry* | Table of available historical water quality data. |

Reference stations should have zero mill effluent exposure and have natural habitat features similar to those of the exposure area. Sometimes it is difficult to select areas of little impact that would be suitable as reference stations, as other activities (e.g., logging or fish farms) near the study area may already be degrading the aquatic environment. In such cases, reference stations can be selected in unimpacted areas with similar habitat characteristics and aquatic species that are located within the same watershed.

The intent of the sampling program is to collect synoptic data (i.e., measured at the same place and same time) for both exposure (i.e., sediment and water chemistry) and effects endpoints (i.e., benthic invertebrates and fish) in order to characterize the effects of the pulp mill effluent. For our KL mill example EEM program, we have selected a total of eight sampling stations: two reference sites (R1 and R2), two near-field stations (NF1 and NF2), two far-field stations (FF1 and FF2), one station in the central portion of plume (CP) and one station downstream of zone of effluent mixing (DZ). The main tasks involved in an EEM sampling program are detailed in the following sections.

### *Water Chemistry*

The purpose of the water quality survey is to characterize conditions in the river environment both upstream and downstream of the mill's effluent discharge. This will allow a general assessment of any significant changes in water quality that could be attributed to the mill.

Water quality analysis should include:

- dissolved oxygen
- pH
- temperature
- conductivity
- total suspended solids.

### *Effluent Quality*

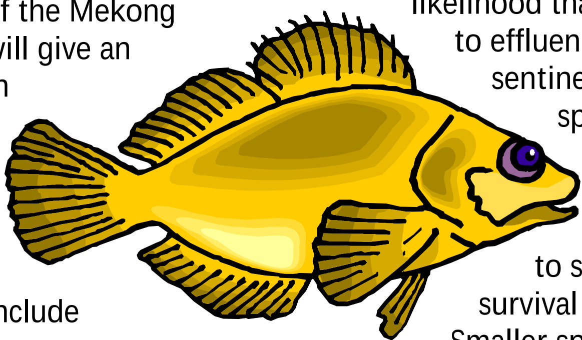
In order to determine whether the KL mill effluent is likely to cause acute toxicity to aquatic organisms in the receiving environment, the following parameters should be analyzed:

- pH, conductivity, temperature
- total suspended solids and biochemical oxygen demand
- total and residual chlorine
- ammonia
- nitrogen
- resin and fatty acids
- AOX.

### *Sediment Chemistry*

The purpose of the sediment quality assessment is to characterize the conditions of the benthic environment upstream and downstream of the mill's effluent discharge. As dioxins tend to readily partition to the organic matter in sediments, knowledge of the organic matter content of the Mekong River substrate will give an idea of the dioxin available for uptake by the benthos. Sediment chemistry analysis should include these parameters:

- nutrients
- metals
- resins and fatty acids
- dioxins
- sediment grain size and total organic carbon.



### *Fish Survey*

The purpose of the fish survey component of the KL mill's EEM sampling program is to assess the effects of effluent on fish survival, growth and reproduction. The fish survey focuses on monitoring whole organism parameters for two sentinel fish species; fish often are good indicators of overall ecosystem health. The selection of appropriate sentinel species is based in large part on the degree to which it is exposed to the effluent. Species that are resident in the lower Mekong River for most or all of their life cycles and exhibit limited mobility relative to the size of the study area are preferred because these species reflect local environmental conditions. Species that are migratory or spend only a small portion of their life cycles in close proximity to the study area are not good sentinel species because their exposure to the effluent is minimal or transient.

In general, the greater the likelihood that a fish species is exposed to effluent, the greater its value as a sentinel species. Very large species should be avoided, since adult abundances of small species will respond more rapidly to stressors that will affect survival and reproduction. Smaller species of important forage fish may serve as excellent sentinel species. Species that are heavily fished are also not appropriate, as significant harvesting can mask effects related to environmental stress in fish populations being monitored.

Ideally, 40 fish of each sentinel species (i.e., 20 males and 20 females) will be collected at each sampling location and their abundance, size, weight, age, gonad weight and general body condition will be recorded.

Data analysis and interpretation will involve comparison of data from impact sites to reference sites. Significant differences in fish abundance and condition relative to reference stations can be interpreted as possible effluent-related effects.

### *Tissue Analysis for Chlorinated Dioxins*

Because the KL pulp and paper mill uses chlorine bleaching in their pulping process, analysis of dioxin tissue levels on edible portions of fish should be undertaken. In general, the species selected for analysis and that portion of the fish constituting the edible portion should be decided on a site-specific basis. In the case of the KL mill, the Shortbarbel pangasius (*Pangasius micronemus)* could be used for tissue analysis. Tissue testing should also be undertaken to determine dioxin bioavailability to higher-trophic level organisms such as predatory fish and birds.

### *Benthic Invertebrate Survey*

The invertebrate community survey is intended to provide a detailed characterization of benthos in the study area so that potential effects of KL mill effluent on biological conditions in the receiving environment can be assessed. We are seeking to determine whether benthic community structure differs among locations within the study area, as compared to reference sites. If differences do exist, we want to know if they are related to distance from the KL effluent outfall (i.e., to establish a gradient of effects). Benthic invertebrate samples should be analyzed for:

- Species richness
- Total abundance
- Presence of sentinel species that are indicative of healthy invertebrate communities
- Absence of species known to be indicative of disturbed conditions, such as species that are known to be invasive or pollution-tolerant
- Sediment grain size and total organic carbon
- Tissue analysis to determine exposure to dioxins.

Changes in the benthic community structure can be a strong indicator of habitat degradation, either due to a biological or chemical pollutant (e.g., dioxins) or a physical disturbance. High invertebrate abundance (i.e., many organisms) and diversity (i.e., many different species) is essential to a healthy aquatic environment. This ensures an adequate food source for resident fish species, and thus, sufficient food for local people.

Various indices can be used to help gauge the health of the aquatic environment through analysis of the benthic community. For example, the EPT index uses abundance of the Ephemoptera (mayflies), Plecoptera (stoneflies) and Tricoptera (caddisflies) to indicate good water and sediment quality. These species are considered sentinel species; sensitive to pollution and indicative of the overall health of the aquatic environment. Reduced numbers of EPT are indicative of degraded aquatic habitat quality. Pollution-tolerant species have also been identified, including some midges and blackflies (*Chironomidae*, *Simulidae*), leeches (*Hirudinea*) and aquatic worms (*Oligochaeta*). Based on the above designations of benthic species, biotic indices have been created that determine a weighted average of the tolerance values for various species within a sample. The tolerance values are quantified on scale of zero to 10, with 10 indicating greatest pollution tolerance. Indices similar to the EPT or benthic species pollution sensitivity used in North America and Europe should ideally be developed for the specific aquatic environment of the Mekong River.

### *Laboratory Toxicity Testing*

Toxicity tests are used to expose test organisms to a medium (e.g., water, sediment or soil) and evaluate the effects on survival, growth, reproduction and/or behavior of the organisms. These tests may help to determine whether contaminant concentrations in water and/or sediments are high enough to cause adverse effects in organisms.

Generally, toxicity tests involve collecting samples from a project site and sending them to a toxicity laboratory where the tests can be performed. For our example KL mill EEM program, we could collect water and sediment samples from the eight sampling stations and test them to determine potential toxicity to aquatic life in the receiving environment. Toxicity tests are a useful component of EEM programs because they can:

- Demonstrate whether contaminants are bioavailable – the presence of a contaminant does not itself indicate a potential for adverse effects on aquatic life. A contaminant can have toxic effects only if it occurs in a bioavailable form (i.e., a form that organisms can take up).
- Evaluate the aggregate effects of all contamination in a medium – many industrial sites present a complex array of contaminants, with a mixture of potentially harmful substances present in the water and sediment. In these cases, chemical data alone cannot accurately predict the toxicity of the contaminants. Instead, toxicity tests are used to measure the aggregate effects of contaminated media on organisms.
- Characterize the nature of a toxic effect – toxicity tests can reveal whether contaminant concentrations have lethal or sublethal effects. Sublethal effects include reduced growth, impaired reproduction and behavioral changes.
- Characterize the distribution of toxicity at a site – toxicity tests can be performed on samples from a variety of locations on a site, such as our near-field and far-field sampling stations. For the purposes of the KL mill's EEM program, toxicity testing can be a cost-effective way to determine the spatial extent of toxicity and identify areas with high effluent-induced effects.

#### *Acute Toxicity Tests*

A typical acute toxicity test exposes test organisms to a series of contaminant dilutions and records deaths over a specified period of time, usually 24 to 96 hours. For example, samples of effluent from the KL mill could be tested at several concentrations including zero and 100%. Results can then be analyzed by comparing percent mortality of organisms exposed to the effluent to organisms exposed in a control treatment (i.e., clean water or sediment containing no contaminants). Acute toxicity test results are often analyzed to determine the dilution of the effluent at which 50 percent of the test organisms died. This dilution is referred to as the LC50, or lethal concentration for 50 percent of the organisms.

Sometimes, rather than seeking the LC50 for a particular test organism, tests can be performed to determine the concentration at which 50 percent of the organisms exhibit a specific effect, such as reduced reproduction or reburial into clean sediments within a certain time frame. The EC50, or the effect concentration for 50 percent of the test organisms, is the endpoint for such tests.

Additionally, test results can be evaluated to determine the LOEC, or lowest observable effects concentration, which is the highest dilution causing statistically significant toxic effects. The no observed effects concentration (NOEC) also can be calculated from the data. The NOEC is the lowest dilution at which no statistically significant toxic effects occurred.

### *Chronic Toxicity Tests*

Chronic toxicity tests expose organisms to a series of dilutions of a specific medium, such as sediment, and measures sublethal effects, and in some cases, lethal effects as well. Sublethal effects may include growth reduction, reproductive impairment, lack of mobility and development of structural abnormalities. Data analysis generally involves a direct comparison between percent effect occurring in organisms exposed to site media and those exposed to uncontaminated media. The LC50, NOEC and LOEC can all be calculated.

While it is an oversimplification to extrapolate the outcome of chronic toxicity tests to the natural environment, sublethal effects measured in the laboratory help to indicate the potential for ecologically significant effects to occur in nature. For example, reduced growth of a fish species can lead to decreased production, smaller size, increased predation and lower overall health of a given population. Reproductive impairment can reduce the population size and can also bring about changes in a population’s age structure. Individuals that develop structural abnormalities can affect the population because these organisms have a lower growth rate and are generally unable to reproduce.