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Application of ecological risk assessment to establish non-human environmental protection at nuclear generating stations in Ontario, Canada

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Abstract. A screening ecological risk assessment was performed for regulatory compliance at two Ontario nuclear power generation station sites to establish design requirements for a contaminant-monitoring program and to address the need for non-contaminant stressor management. Site-specific assessments went beyond traditional contaminant risk assessment to include stressors associated with land-use change, cooling water systems and site storm water runoff. Valued terrestrial and aquatic ecosystem components were selected from species lists after stakeholder consultation, and contaminants of concern were selected based on their relative loadings, and with respect to regulatory and literature-based benchmarks. Predictive modeling was used to estimate chemical and radionuclide exposures and likelihood of effects. Potential adverse effects on biota were predicted for aqueous emissions of chlorine and storm water but not for radionuclides. Retrospective analyses of field monitoring were used to determine likelihood of effects from non-contaminant stressors. Individual-level adverse effects were observed for fish losses from cooling water intake. Depending on the site and the biological species, either beneficial or adverse effects from thermal discharge were observed. Follow-up studies include monitoring, laboratory study, computer modeling and mitigation. Field monitoring will generate more precise species-level estimates of intake fish losses, magnitude of fish response to thermal discharge and chlorine concentrations in near-field discharge waters. Laboratory study is determining the effectiveness of intake fish loss mitigation technology. Computer fish population models are being used to design field studies and interpret individual-level effects. Mitigation includes storm water controls and habitat biodiversity management projects to offset past losses from site development and construction. Contaminant monitoring is planned to collect necessary information to verify site specific risk assessment model predictions and confirm model parameters and assumptions. The updated contaminant risk assessment models will be used to adjust site monitoring programs.

1. INTRODUCTION

A screening ecological risk assessment was performed for regulatory compliance at Ontario Power Generation's two nuclear generating station sites to establish design requirements for a routine contaminant monitoring program and to address the need for non-contaminant stressor management [1-6]. The scope of our site-specific assessments went beyond traditional contaminant risk assessment typically required by regulators [7] to include additional stressors associated with land-use change, cooling water systems and site storm water runoff. This was done to respond to an internal environmental management system requirement to understand and manage all significant environmental aspects and impacts of facilities operations in accordance with the ISO 14001 Environmental Management System Standard [8].

1.1 Study sites

The two study sites are located on the northern shoreline of Lake Ontario, east of Toronto, Ontario, Canada. The Pickering site is situated 32 kilometers east of Toronto. The site includes two nuclear generating stations (2,060 MWe and 2,064 MWe) each with four reactors, housed in one building with a common shoreline surface intake and separate cooling water shoreline surface discharges. The other major facilities include switchyards, transformer stations and a used fuel dry storage facility. The Darlington site, 35 km east of Pickering, includes one four-unit nuclear generating station (3,524 MWe) with an offshore deep cooling water intake and discharge diffuser. The other major facilities include a tritium removal facility, sewage treatment plant, switchyards and transformer stations. Both Pickering and Darlington use a once-through cooling water system.

2. METHOD

The study method was based on the Canadian ecological risk assessment framework [9-11] which is similar to the U.S. Environmental Protection Agency general framework [12]. This included identification of stressors and contaminants of concern, valued receptors and habitats.

Contaminants of potential concern in air, surface water, groundwater and soil included:

- radionuclides, e.g., tritium, carbon-14, cobalt-60, strontium-90, iodine-131, cesium-134, cesium-137, noble gases;
- inorganic chemicals, e.g., copper, zinc, arsenic, lead, ammonia, hydrazine, residual chlorine;
- organic chemicals, e.g., fuel oil, PCBs, morpholine.

Other stressors included:

- temperature;
- noise;
- land use;
- impingement and entrainment;

Valued receptors included:

- fish, e.g., smallmouth bass, alewife, round whitefish, northern pike, brown bullhead;
- aquatic and terrestrial birds, e.g., lesser scaup, double-crested cormorant, trumpeter swan, ring-billed gull, great horned owl;
- mammals, e.g., muskrat, red fox, meadow vole;
- aquatic and terrestrial plants;
- benthic invertebrates;
- earthworms.

Valued receptors were selected from species lists based on scientific arguments and stakeholder consultation, and contaminants of concern were selected based on their relative loadings and concentrations with respect to regulatory and literature-based benchmarks. Receptors and contaminant stressors were integrated into a conceptual pathways model of exposure in space and time. Predictive models of contaminant transport and fate yielded environment exposure concentrations. These were compared to literature benchmark toxicity values to determine potential risk to the receptor. Retrospective analyses of past field monitoring were used to determine likelihood of effects from non-contaminant stressors (e.g. site construction land-use change, cooling water intake and thermal discharge). The scientific approach was tiered with more complex analyses if initial screening could not adequately characterize risk to a receptor to an acceptable degree of certainty to support a decision. The risk characterization summarized the assumptions, uncertainties and estimated population-level significance of any potentially adverse effect. The site assessments ended with recommendations for follow up mitigation of unacceptable effects or monitoring where data was not yet adequate to support a decision.

3. RESULTS

The stressors that were assessed for risk after screening at one or more sites included 38 contaminants, temperature, direct losses and land-use change. Direct losses included intake of aquatic organisms, thermal discharge fishing and road kills. The stressors remaining after risk assessment for additional follow-up included eight contaminants, direct losses, temperature and land-use change.

3.1 Contaminants

Results common to both sites were the predicted risk from chlorine and the lack of predicted risk from radionuclides. Chlorination was necessary to control cooling water system fouling by dreissenid mussel larvae. Chlorine measurements taken inside the generating stations gave risk quotients to zooplankton slightly above 1.0 so follow-up monitoring and analysis of receiving environment concentrations was planned at each site. The results of follow-up monitoring and a probability-based analysis completed at Pickering showed no acute or chronic chlorine or chloramines effects in the near-field lake environment [6].

The assessment result for radionuclides was not unexpected since estimated radiation dose rates were well below international [13] and Canadian [14] biological effects benchmark levels and an earlier federal regulatory agency assessment of impact of radionuclide releases on non-human biota came to a similar conclusion [14]. The assessment of radionuclides included a geometry correction for the dose coefficients of trumpeter swans. These aquatic birds were assessed in detail because they used to have a vulnerable status in Ontario.

Spill and stormwater runoff events were a source of predicted ecological risks. The Darlington assessment predicted ecological risk to fish from oil and grease and total suspended solids in stormwater runoff. Since storm-water management was a significant environmental aspect in the site environmental management system, there was a remediation, control and monitoring program ongoing concurrent with the assessment. The planned follow-up is to review monitoring results to verify the performance of control actions and any need for further remediation.

The Pickering assessment identified potential localized effects on earthworms from historical spills of standby generator fuel oil to soil and groundwater. This receptor was also potentially at risk from sand blast/paint shop heavy metals emissions to soil. A follow-up analysis determined that planned remediation of groundwater and soil would eliminate concerns and the area of soil affected was too small to significantly affect earthworm populations [6]. The assessment also identified potential adverse effects from copper and zinc emissions to Lake Ontario from corrosion and erosion of Admiralty brass condenser tubes in the cooling water system. Mitigation has been to shut down reactors and change over to titanium or stainless steel condensers. There was also a prediction of low level adverse effects of metals in an adjacent marsh. The current source of metals in the marsh is from urban runoff. Historically, there was a discharge into the marsh from a fish farm that once received the Admiralty brass condenser cooling water system discharge water via a pipeline from Pickering. The metal emissions were caused by condenser corrosion combined with copper supplements in the fish feed used at the fish farm. This source term to the marsh was eliminated by disconnecting the pipeline in 1997. A special study involving a benthic invertebrate survey and habitat mapping is planned to evaluate current conditions at the marsh. It will also serve to link the assessment results to ongoing marsh biodiversity management actions. The study will help to bring closure to the issue of potential impact of copper emissions from Pickering which has been of high interest to community stakeholders.

A common knowledge gap for all sites was the lack of predictions of chemical and radionuclide air concentrations inside the site fences. The existing human pathway monitoring and modeling programs were based on protecting the public outside the fence line whereas the prediction of air concentrations close to emission sources poses technical challenges. The Pickering assessment included air dispersion modeling within the fence line [20] and recommended follow-up confirmatory monitoring at receptor locations on-site. The Darlington assessment predicted potential adverse effects from atmospheric contaminants (nitrogen oxides, hydrazine, ammonia) on any vegetation occurring in the near-field area within 300 m of the generating station. However, follow up site reconnaissance showed there were no valued plant receptors or habitat located that close to the station due to the paved and graveled surfaces.

3.2 Direct losses and temperature

Past field studies showed a common effect of cooling water system intake fish losses. Computer fish population model studies showed fish species of lake-wide geographic distribution, such as alewife and rainbow smelt, were unlikely to be adversely affected [15]. However, observational field sampling in the intake screenhouses showed the losses of individual fishes were high enough at each facility that further monitoring and population analysis was recommended as follow-up in order to determine the need for mitigation for fish species populations of local geographic distribution. Since intake fish impingement at Pickering has been historically large and it is a significant environmental aspect in the environmental management system, a laboratory study was also started to test the effectiveness of sound and strobe lights to deter local species of fish from intake impingement.

Another potential source of fish mortality was sport fishing harvest in the thermal discharge areas based on earlier studies published for another nuclear generating station situated on Lake Huron [16]. In those studies, investigators used predictions of a bio-physical computer model and field monitoring to test for the cumulative impacts of the two adjacent nuclear generating stations on a local spawning smallmouth bass population and showed the species harvest was large enough, at 30% of the adult bass population per year, to have an adverse effect [17]. Aside from sport fishing, the direct effect of temperature on smallmouth bass was positive, contributing to increased growth, survival and reproduction [17].

In contrast, the observational field studies at the two Ontario Power Generation sites on Lake Ontario showed there was no possibility of a similar effect since sport harvest of vulnerable locally-occurring fish populations did not occur. In the absence of a biologically significant sport harvest, a positive effect of thermal discharge on fish growth was judged likely for the commonly sought sport fish species (e.g. salmon, trout, walleye) occurring at Pickering and Darlington [1-5].

There was historical regulatory concern during initial operations of all sites about thermal plume effects on egg survival for fall-spawning non-sport fish species of round and lake whitefish. Combined field experiments (egg incubation chambers) and computer modeling showed the natural effects of siltation were the major cause of mortality, not thermal discharge [18].

3.3 Land-use change

Historical alterations of the physical landscape and shoreline from site development and construction were judged large enough in magnitude and extent to cause long-lasting adverse ecological effects at all sites. Site development required leveling and vegetation clearing in areas within half a kilometer of the shoreline, as well as extensive lake filling in areas of littoral zone fish habitat. At Darlington the net ecological effect on the terrestrial uplands may have been beneficial since the site was changed from over 80% human use (intensive agriculture) before development to less than 35% human use during operations. Biodiversity management programs were initiated at both sites in response to a 1998 Ontario Power Generation biodiversity policy. The risk assessment recommended continued site biodiversity restoration and enhancement projects to help offset the physical impact of historical habitat loss in shoreline and upland areas.

4. CONCLUSION

Ecological risk assessments determined the likelihood of adverse effects by combining model predictions for contaminants with retrospective observational studies for non-contaminants at two nuclear generating stations situated on the Canadian shoreline of the Lake Ontario. Site-specific assessments went beyond traditional contaminant risk assessment to also include stressors associated with land-use change, cooling water systems and site storm water runoff.

Direct mortality at the individual level was predicted or known to occur only from non-contaminant stressors. The source term at the two Ontario Power Generation Lake Ontario sites was cooling water system intake water withdrawals of fish and aquatic macro-invertebrates. An additional stress of fish mortality from thermal discharge fishing has been reported in the scientific literature elsewhere, but it was not significant at the Lake Ontario sites due to the absence of small local populations of angler-sought sport fish species. The only predicted or known source of habitat loss was changes in site land use associated with original site development and construction. The need to address these non-contaminant effects was clearly established. These are being addressed through monitoring, modeling and mitigation and managed as a biodiversity significant aspect according to the individual site environmental management systems.

For contaminants, few non-radiological risk quotients exceeded one after screening, and upon further review, the actual receptor exposure was deemed unlikely either due to a mismatch of exposure area to habitat or the reduced exposure after remediation and control programs. The specifications for short-term follow-up monitoring were established by the results at each site. Routine contaminant monitoring for the longer term is also being planned to collect necessary information to verify site specific risk assessment model predictions and confirm model parameters and assumptions. The updated contaminant risk assessment models will be used to adjust site monitoring programs. The scope of long term monitoring will be determined in consultation with the regulator once draft regulatory guidance [19] currently under public review has been finalized.

The scope of risk assessment follow up monitoring was modified by community stakeholder concerns and will likely continue to be. At both sites locally valued receptors and habitats that formed the focus of the assessments were determined by combining community stakeholder input with scientific judgment. A special study of metal concentrations in the marsh at Pickering was initiated in follow-up to the assessment, even though the source term had been eliminated, to satisfy long-term stakeholder and regulatory concerns about potential impacts from the site.

The overall purpose of internal governance (e.g., environment management system, biodiversity policy) and regulatory requirements is to foster improved understanding of our interaction with the natural environment, so we can take informed actions to prevent harm and demonstrate that environmental protection measures are adequate. The risk assessments are a tool that allows us to integrate information from various monitoring programs and update predictions of risk to provide ongoing direction and improvements in impact management. An adaptive approach is needed to have monitoring programs flexible enough to respond to new regulatory requirements, new findings and new science. The future challenge for industry and their regulators is to develop reasonable, balanced and cost-effective biota compliance monitoring programs that take into account stakeholder concerns. The scope of monitoring must deal with a whole suite of stressors (biological, physical, chemical and radiological) affecting the site in accordance with known or anticipated risk.

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