# 16.0 Ecological Risk Module

## 16.1 Purpose and Scope

The Ecological Risk Module calculates the hazard quotient (HQ) for species of mammals, birds, and herpetofauna and, through inference, for communities of organisms that live in close contact with soil (including plants and soil invertebrates), sediment (benthic invertebrates), and surface water (e.g., fish, aquatic invertebrates, algae, and aquatic plants). The HQ is the ratio of the annual average exposure (in units of concentration or dose) to a benchmark for ecological effects (in units of concentration or dose) and quantifies the potential for contaminants to elicit an adverse ecological response once released into the environment. To calculate the HQs, the Ecological Risk Module uses input concentrations from the Surface Water and Terrestrial Food Web Modules, as well as applied doses calculated by the Ecological Exposure Module, and compares those values to ecotoxicological benchmarks (EBs, in units of dose) and chemical stressor concentration limits (CSCLs, in units of concentration), as appropriate. The module calculates an HQ for every ecological receptor assigned to habitats within the area of interest (AOI) for a given site. Detailed information on the Ecological Risk Module can be found in the background document (U.S. EPA, 2000). Figure 16-1 shows the relationship and information flow between the Ecological Risk Module and the 3MRA modeling system.

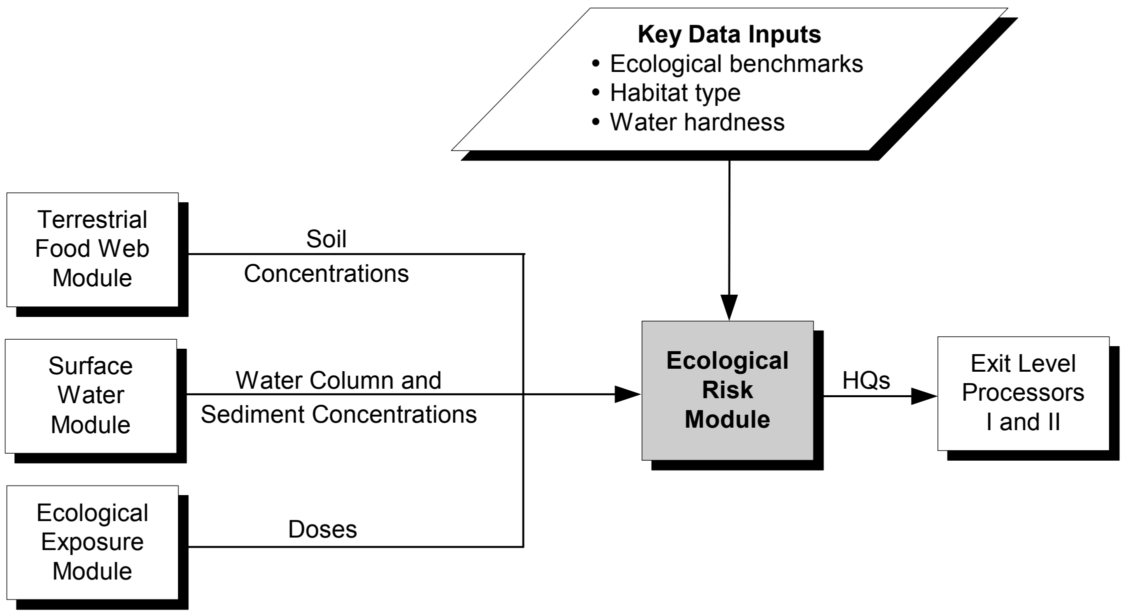


**Figure 16-1. Information flow for the Ecological Risk Module in the 3MRA modeling system.**

The conceptual approach to characterizing the potential for adverse ecological effects depends on the assessment endpoints used. Assessment endpoints are explicit expressions of the actual environmental values that are to be protected (U.S. EPA, 1998). Candidates for assessment endpoints often include threatened or endangered species, functional attributes that support food sources or flood control, or aesthetic values such as the existence of charismatic species (e.g., eagles) that have special value to society (U.S. EPA, 1998). The assessment endpoints must be defined with respect to the valued ecological entity (e.g., a particular species), and an attribute of that entity that is to be protected (e.g., reproductive fitness). For the 3MRA modeling system, the assessment endpoints were selected to represent multiple levels of biological organization (e.g., populations, communities), key functional elements of natural communities (e.g., primary producers), and biota throughout the trophic continuum. Although the 3MRA modeling system does not restrict the selection of assessment endpoints for future applications, the Ecological Risk Module and supporting databases were developed to evaluate three primary assessment endpoints:

- Survival of species that comprise key structural and functional elements of soil, freshwater, and benthic (sediment) communities;
- Reproductive fitness and survival of mammalian, avian, and herpetofaunal wildlife populations; and
- Growth and survival of primary producers (e.g., plants) in terrestrial and freshwater systems.

These endpoints are ecologically relevant to the habitat types used to represent ecological variability in the 3MRA modeling system (see Section 15.2) and are sensitive to a broad range of chemical stressors.

Table 16-1 describes the specific assessment endpoints addressed by the 3MRA modeling system in terms of: (1) the significance of the ecological entity (i.e., the reason EPA wants to protect it), (2) the ecological receptor(s) that represent that entity, (3) the characteristic(s) of the entity that is important to protect, and (4) the measure of effect used to quantify the potential for an adverse response. Measures of effect such as fecundity and mortality were chosen to support the development of the EBs and CSCLs based on their relevance to the assessment endpoints.

The Ecological Risk Module performs two major functions:

1. **Calculate Hazard Quotients (HQs).** The Ecological Risk Module calculates HQs for each receptor at each site according to spatial, temporal, and environmental characteristics of the site.

2. **Process the HQ Results for Decision Making.** The Ecological Risk Module tracks various attributes such as taxa and habitat type to process the HQ results for decision making. This processing includes placing results in bins and determining the timing of maximum risks.

## Table 16-1. Assessment Endpoints and Measures of Effects for the 3MRA Modeling System

| Assessment Endpoint | Ecological Significance | Example Receptors | Characteristic(s) | Measure(s) of Effect |
|---|---|---|---|---|
| survival and reproductive fitness of mammalian wildlife populations | ■ multiple trophic levels and apex predators<br>■ multiple exposure pathways represented<br>■ species with large foraging ranges<br>■ charismatic species (e.g., eagles)<br>■ sensitive species (e.g., mammals and dioxins) | deer mouse, meadow vole, red fox | reproductive success in adult animals; survival and development of offspring | chronic/subchronic MATL for physiological effects relevant to reproductive success (e.g., gonadotoxicity; number of viable offspring; egg production) and development (e.g., malformations; growth rate) |
| survival and reproductive fitness of avian wildlife populations | | red-tailed hawk, northern bobwhite | | |
| survival of amphibian populations | ■ unique habitat niches (e.g., partially aquatic and terrestrial)<br>■ includes species that are particularly sensitive to chemical stressors, particularly metals | frog, newt | lethality and deformity | primarily acute $LC_{50}$s for lethality resulting from early life stage exposures; $EC_{20}$s for developmental effects used when available |
| reproductive success and survival of reptile populations | | snake, turtle | reproductive success in adult animals; survival and development of offspring | none identified for chemical stressors of concern |
| survival of species that comprise key structural and functional elements of the soil community | ■ high levels of exposure through direct contact<br>■ base of the food web in terrestrial systems<br>■ vital habitat for decomposers, soil aerators<br>■ essential for nutrient cycling | nematodes, arthropods, springtails, annelids, mites | mortality, growth, survival, reproductive success | 95% of soil species below low effects concentration at 50th percentile confidence interval; when data were insufficient, LOEC values for earthworms, microbes used |
| growth and survival of terrestrial plants | ■ primary producers of energy<br>■ food base for herbivores<br>■ essential habitat for many wildlife species<br>■ large fraction of the earth's biomass | soy beans, alfalfa, rye grass | plant growth and yield | 10th percentile from data on LOEC from studies on plant growth, seed germination; when data were insufficient, lowest LOEC value was selected |
| survival of species that comprise key structural and functional elements of the freshwater aquatic community | ■ high levels of exposure through direct contact<br>■ includes several species that are very sensitive to chemical stressors (e.g., daphnids)<br>■ important food source for wildlife that live in waterbody margin | fish, aquatic invertebrates | mortality, growth, survival, reproductive success | National Ambient Water Quality Criteria (NAWQC) for aquatic life (95% of aquatic species); alternate water quality criteria developed using abbreviated data sets |

*(continued)*

**Table 16-1. (continued)**

| Assessment Endpoint | Ecological Significance | Example Receptors | Characteristic(s) | Measure(s) of Effect |
|---|---|---|---|---|
| survival of species that comprise key structural and functional elements of the sediment community | ■ sediment serves as sink for persistent contaminants, resulting in high levels of exposure<br>■ habitat for early life stages (e.g., midge larvae)<br>■ nutrient processing and decomposition | protozoa, flat worms, ostracods | mortality, growth, survival, reproductive success, and community measures such as abundance, diversity | *metals* - threshold effects levels from LOEC data associated with community endpoints (e.g., species abundance)<br>*organics* - water quality criteria adjusted for sorption to organic carbon in sediment |
| growth and survival of aquatic plants and algae | ■ primary producers of energy<br>■ base of food source in the aquatic system<br>■ substrate for other organisms in the water column<br>■ essential habitat for developing organisms | algae and vascular aquatic plants (e.g., duckweed) | growth, cell numbers, mortality, biomass, root length | algae - $EC_{20}$ and $EC_{50}$ for growth, decreased cell numbers, reduction in carbon fixation<br>vascular plants - lowest LOEC for endpoints relevant to growth, biomass, root number |

MATC maximum allowable toxicant level
LOEC lowest observed effect concentration
$LC_{50}$ lethal concentration to 50 percent of the organisms
$EC_{50}$ effective concentration to elicit a response in 50 percent of the organisms
$EC_{20}$ effective concentration to elicit a response in 20 percent of the organisms

Because the assessment endpoints evaluated include both populations of wildlife species and assemblages of species that represent communities, the calculated HQs for different receptors represent different measures of effect at several levels of biological organization. As a result, it is critical to understand the rationale behind the development of the EBs and CSCLs included in the current 3MRA sample data base. Therefore, although these benchmarks are not calculated by the Ecological Risk Module, the development of these benchmarks is discussed in this section.

## 16.2 Conceptual Approach

The Ecological Risk Module quantifies the potential for adverse ecological effects by calculating HQs for individual receptors such as raccoons, aquatic plants, or the soil community. The HQs provide a "bright line" metric for risks to the individual organisms that represent wildlife populations and, based on statistical inference, the risks to narrowly defined communities (e.g., the sediment community). The Ecological Risk Module does not estimate population-level risks, defined as the likelihood that some percentage of the individuals in a population will sustain an adverse effect, nor does it characterize the risks to communities. Although population-level models have long been used by ecologists to evaluate the response of species populations to certain types of stressors, the data requirements and implications on model run time prohibited such an approach in this version of the 3MRA modeling system. Thus, the Ecological Risk Module uses specific measures of effect (e.g., a reduction in viable offspring) to generate HQs that may be used to *infer* whether the potential for an adverse ecological response is above levels of concern. That is, a target HQ of 1 serves as the indicator for adverse ecological responses; a value greater than 1 indicates that the ecological response is above a level for concern, and a value less than 1 indicates that the potential for adverse ecological effects is at a *de minimis* level for the receptor for which the HQ was calculated. The implications of this approach underscore the importance of developing EBs and CSCLs that reflect the assessment endpoints for the modeling application, tracking the attributes of each HQ that is calculated, and processing the HQ results in a transparent manner to support decision making.

### 16.2.1 Development of EBs and CSCLs

Receptor-specific benchmarks[1] (EBs and CSCLs) were developed for use in the Ecological Risk Module. As indicated previously, these benchmarks were based on measures of effects considered appropriate to support risk inferences for ecological receptors at various levels of biological organization, including individual organisms, wildlife species populations, and communities. In identifying appropriate studies from which to develop EBs and CSCLs, study selection criteria were developed to ensure consistency in the interpretation of study results and to satisfy data quality objectives. The study selection criteria address the desire for consistency across EPA programs as well as within the representative national data set, the appropriateness of the study given the assessment endpoints used in the 3MRA modeling system; and the quality

[1] The term " benchmarks" is used in this discussion to refer to both EBs for mammalian and avian species and CSCLs for selected receptors (e.g., amphibian species) and communities.

of the study with respect to endpoint selection, dose-response information, and appropriate use of extrapolation techniques (e.g., tools for statistical inference).

The EBs represent a *de minimis* level of effect for mammals and birds exposed through the ingestion of contaminated media, plants, and prey. In order of importance, the study selection criteria considered the following:

1. Relevance of study endpoints to population-level effects;

2. Whether the study contained adequate data to demonstrate a dose-response relationship;

3. Appropriateness of study design with respect to the exposure route (e.g., gavage versus dietary exposure) and duration (e.g., acute versus chronic);

4. Quality of the study as determined by the use of appropriate dosing regimes, statistical tools, etc.; and

5. Consistency with other EPA programs, such as Superfund and the Office of Water.

The CSCLs (except those for amphibians and plants) are intended to represent a *de minimis* level of effect for communities that live in close contact with the soil, sediment, or surface water. The study selection criteria for these receptors considered the following:

1. Acceptance of the benchmark by other EPA programs (e.g., National Ambient Water Quality Criteria);

2. Consistency with EPA guidelines on study selection for aquatic toxicity data;

3. Relevance of study to species identified as key functional elements of the community;

4. Relevance of study endpoints to address community-level effects (e.g., growth, survival, abundance);

5. Whether the study contained adequate data to demonstrate a dose-response relationship; and

6. Quality of the study data with respect to the design (e.g., field versus laboratory), and appropriate use of statistical tools to characterize effects (e.g., confidence levels).

For amphibians, the extensive database on acute and subchronic aqueous exposures to developing organisms was used to derive CSCLs for surface water contact at sensitive life stages over short durations (e.g., less than 7 days). For terrestrial plants, studies on growth, seed germination, and other relevant endpoints were used to derive CSCLs for exposure durations that roughly correspond to a typical growing season (e.g., 3 months). The study data on vascular aquatic plants was very limited, and short-term studies on algal growth were frequently selected to evaluate primary producers in aquatic systems.

The following subsections provide a brief description of benchmark development for the following receptor groups:

- Mammals and birds,
- Amphibians,
- Reptiles,
- Soil community,
- Terrestrial plants,
- Freshwater aquatic community,
- Sediment community, and
- Aquatic plants and algae.

The discussions highlight the minimum requirements for data used to support benchmark development and the calculation methods used. To provide the context of each description, the assessment endpoint and measure of the effect for each receptor group is presented at the beginning of each subsection. A comprehensive description of the data collection efforts and methodology developed to derive ecological benchmarks may be found in Volume II of this report.

**Mammals and Birds.**

- <u>Assessment Endpoint</u>: *survival and reproductive fitness of mammalian and avian wildlife populations.* The characteristics to be protected are: (1) the reproductive success of adult animals, and (2) the growth and development of offspring.

- <u>Measure of Effect</u>: *a de minimis threshold for developmental and reproductive toxicity in mammalian and avian wildlife species.* The threshold was calculated as the geometric mean of the No Observed Adverse Effect Level (NOAEL) and the Lowest Observed Adverse Effect Level (LOAEL), defined as the maximum acceptable toxicant level (MATL) in the 3MRA database. Implicit in this calculation is the assumption that the toxicological sensitivity is lognormal.

For mammals and birds, ecotoxicological data were evaluated to identify the most appropriate studies to support EB development. Studies meeting the data quality objectives summarized above (e.g., sufficient dose-response data), were reviewed and the study with the most sensitive endpoint was selected to derive receptor-specific benchmarks. Once the MATL was calculated from the NOAEL and LOAEL, the MATLs for mammals and birds were scaled for each receptor species using the relative body weights of the test and receptor species. The scaling equation is based on the default methodology EPA proposes for carcinogenicity assessments and reportable quantity documents for adjusting animal data to an equivalent human dose (U.S. EPA, 1992), and is widely used in ecological risk assessments (see, for example, Sample et al., 1998). Research indicates that the cross-species scaling equation for mammals is inappropriate for direct application to birds (Mineau et al., 1996). Therefore, an avian scaling factor developed by Mineau was used to derive EBs for birds.

**Amphibians.**

- *Assessment Endpoint: survival of amphibian populations.* The characteristics to be protected were the survival, growth, and development through early life stages.

- *Measure of Effect: an acute $LC_{50}$ for lethality or developmental effects resulting from early life stage exposures.*

For amphibians, the available data on toxicity were limited almost exclusively to acute studies on lethality and, in some cases, growth and developmental effects. Amphibians appear to be highly sensitive to a number of toxicants (e.g., trace metals) during the developmental stages of their life cycle. After a review of several compendia presenting amphibian toxicity data (e.g., U.S. EPA, 1996; Power et al., 1989) as well as primary literature sources, it was determined that the lack of standard methods on endpoints, species, and test durations would preclude the development of a CSCL for chronic exposures. Available data typically involved aqueous exposure during early life stages and, as a result, the only exposure pathway that could be evaluated for amphibians was direct contact with contaminated surface waters. The CSCL for early life stage effects was calculated as the geometric mean of acute $LC_{50}$ data (lethal concentration to 50 percent of the organisms). A few general guidelines were followed in selecting acute studies for developing the CSCL: (1) test duration was usually less than 15 days, (2) only studies on lethality were included to calculate the geometric mean, and (3) exposure occurred during early life stages (i.e., embryo, larvae, and tadpole).

**Reptiles.**

- *Assessment Endpoint: survival and reproductive fitness of reptile populations.* The characteristics to be protected are: (1) the reproductive success of adult animals, and (2) the growth and development of offspring.

- *Measure of Effect: a de minimis threshold for developmental and reproductive toxicity to reptile species.* The threshold is calculated using the same approach as that taken for mammals and birds.

Toxicity data relevant to reptile exposures could not be identified for the chemical stressors in the representative national data set. Additional research is needed to: (1) identify more recent data for applicability to reptile exposures and (2) determine whether methods can be developed to extrapolate benchmarks across species.

**Soil Community.**

- *Assessment Endpoint: survival of species that comprise key structural and functional elements of the soil community.* The characteristics to be protected include mortality, growth, survival, and reproductive success of selected taxa.

- <u>*Measure of Effect*</u>*: concentration in soil that, for 95 percent of the species, will be below the low effects concentration at the 50$^{th}$ percentile confidence interval.* The CSCLs for the soil community were typically derived at a 95 percent protection level using primarily low effects data for the endpoints of interest.

Ecotoxicological data on lowest observed effects concentrations (LOECs) were reviewed for soil biota for a number of functional categories in soil systems (e.g., decomposers, predators) to derive the soil community CSCLs. Thus, criteria were required both for individual study reviews as well as to evaluate the entire data set for completeness. Criteria developed for study selection included four categories of exposure: (1) topical application; (2) surface-soil application, in which the soil organisms are placed onto a treated surface; (3) mixed-soil application, in which the soil organisms are placed into a soil that was mixed with a contaminant; and (4) food application (i.e., contaminant mixed with organic food source). The endpoints for soil species were selected based on relevance to species populations and, in order of preference, included reproduction, growth, mortality, population increase/decrease, sexual development, mobility, and regeneration.

The first, and preferred, method was based on a community-level approach analogous to that used to develop the National Ambient Water Quality Criteria (NAWQC) for the protection of aquatic biota. Like the NAWQC, the soil community CSCLs are intended to protect the structure and function of the community and its critical role in the terrestrial food web (e.g., nutrient processing). A detailed discussion of the calculations used to develop a community-based soil CSCL are provided in Volume II of this report.[2] The second method used to derive soil CSCLs required the identification of LOECs for earthworms and microbial endpoints despite the obvious limitations in relying on a single species to infer adverse effects to the community. Nevertheless, earthworms have been recognized for the critical role they play in promoting soil fertility, releasing nutrients, and providing aeration and aggregation of soil, as well as being an important food source for higher trophic level organisms. In addition, their constant contact with soil media and permeable epidermis makes them more susceptible to contaminant exposures. Likewise, microbial communities play a key functional role in soil fertility, decomposition processes, and nutrient cycling, providing nutrients in available forms to plants. Microbial CSCLs were used only when they indicated a significantly higher sensitivity to a particular contaminant than the corresponding earthworm toxicity data. The earthworm/microbial CSCLs were derived using one of two approaches: (1) if more than 10 studies were identified reporting a LOEC, the 10$^{th}$ percentile value was selected as the CSCL, or (2) if fewer than 10 values were identified, the lowest LOEC was selected as the CSCL.

**Terrestrial Plants.**

- <u>*Assessment Endpoint*</u>: *growth and survival of terrestrial plants*. The characteristics to be protected include the growth and yield of terrestrial plants.

[2] The discussion in Volume II uses no observed effects concentrations (NOECs) rather than LOECs. The methodology presented is entirely accurate; however, EPA has elected to use the less conservative LOECs to derive the soil CSCLs based on a comparison between NOEC-derived CSCLs and typical background concentrations.

- <u>*Measure of Effect*</u>*: soil concentrations related to growth, yield, seedling emergence, and germination endpoints*. The lowest observed effects data on phytotoxicity were rank ordered, and the plant CSCL was estimated as the 10$^{th}$ percentile value.

The development of CSCLs for terrestrial plants primarily included endpoints relevant to growth and yield (e.g., seed germination, seedling emergence). Data collection and review activities were focused on these endpoints because they are ecologically significant responses and because the database of phytotoxicity studies provides sufficient coverage of these types of effects (Efroymson et al., 1997). However, very few contaminants have toxicity data for a sufficient number of terrestrial species to represent even a simple plant community, including short-lived and long-lived plants, flowering and nonflowering plants, high seed producers, and plants with extensive root systems (Eijsackers, 1994). Consequently, the data quality requirements presented in Efroymson et al. (1997) regarding study preferences (e.g., field studies were preferred over greenhouse studies) were adopted for development of soil CSCLs for plants. The terrestrial plant CSCLs were derived using the same approach as described previously for the earthworm/microbial CSCLs (i.e., based on the number of studies).

**Freshwater Aquatic Community.**

- <u>*Assessment Endpoint*</u>*: survival of species that comprise key structural and functional elements of the freshwater aquatic community*. The characteristics to be protected include mortality, growth, survival, and reproductive success of selected taxa.

- <u>*Measure of Effect*</u>*: surface water concentration that, for 95 percent of the species, will be below the low effects concentration at 50$^{th}$ percentile confidence interval.* Typically, the NAWQC was chosen as the CSCL for this receptor group.

The CSCLs for the freshwater community reflect endpoints ranging from mortality to growth and reproductive effects. As with the soil community, criteria for individual study selection were established, as well as criteria applicable to the data set as a whole. The minimum data requirements to derive a CSCL for the aquatic community were based on the *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (Stephan et al., 1985), and, for data sets that did not meet those requirements, the Tier II guidelines proposed in the *Water Quality Guidance for the Great Lakes System and Correction; Proposed Rule* (58 FR 20802). These methods require the compilation of appropriate acute and chronic toxicity data on adverse effects to aquatic biota for specific taxa of the freshwater community. Specifically, either the Final Chronic Value (FCV) developed using the above guidance or the criterion continuous concentration (CCC) developed for the Great Lakes Water Quality Initiative (GLWQI) was selected as the CSCL for the freshwater aquatic community. If neither a CCC nor an FCV was available, a Secondary Chronic Value (SCV) was calculated using Tier II methods developed through the GLWQI (Stephan et al., 1985; Suter and Tsao, 1996).

**Sediment Community.**

- *Assessment Endpoint: survival of species that comprise key structural and functional elements of the sediment community*. The characteristics to be protected include mortality, growth, survival, and reproductive success of selected taxa.

- *Measure of Effect: two types of measures were used, one for organics (based on the NAWQC) and one for metals (similar to the approach for earthworms and microbes).* The sediment quality criteria based on partitioning theory and the similarity in toxicological sensitivity between water column and sediment biota were used to derive the CSCLs for organic chemicals. Empirical data from field studies were used to derive the CSCLs for metals.

Two methods were applied in developing the CSCLs for the benthic community (e.g., worms, amphipods). For metals and ionic organic chemicals, CSCLs were based on either: (1) threshold effects levels (TELs) developed by the Florida Department of Environmental Protection (FDEP), which are the upper limit of the range of sediment concentrations for endpoints on survival, species diversity, and abundance; or (2) the $10^{th}$ percentile effects concentrations (ER-L) developed by National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends (NS&T) Program. The TELs were preferred over the ER-L values because: (1) the same database was used for both the NOAA criteria and the FDEP criteria development; (2) in most cases, the FDEP criteria were based on more appropriate measurement endpoints; and (3) the marine TELs developed by the FDEP were found to be analogous to TELs observed in freshwater organisms (Smith et al., 1996).

For nonionic organic chemicals, the CSCL derivation method was based on an equilibrium partitioning relationship between sediment and surface water. This method calculates the sediment CSCL based on the surface water FCV or SCV, assuming that the equilibrium partitioning between sediment and the water column is a function of the fraction organic carbon. In calculating the baseline sediment CSCL for nonionic chemicals, the fraction organic carbon was assumed to be 1, and the organic carbon partitioning coefficients were adopted as reported in Jones et al. (1997). However, because the HQs are intended to represent the ecological hazard for the environmental characteristics of each site, the Ecological Risk Module adjusts the sediment CSCL for the site-specific fraction organic carbon prior to calculating the sediment community HQ value.

**Aquatic Plants and Algae.**

- *Assessment Endpoint*: *growth and survival of aquatic plants and algae in freshwater systems*. The characteristics to be protected are different for aquatic plants and algae, and include root length and biomass, and growth and cell numbers, respectively.

- *Measure of Effect*: *surface water concentrations related to gross measures of health (e.g., biomass) for the algal community and a variety of endpoints for aquatic plants (e.g., number of fronds, root number, plant number, root length).*

For algae, the effective concentration to 20 percent of the population ($EC_{20}$) was selected as the threshold for an adverse response. For plants, the lowest LOEC for endpoints of interest was chosen as the CSCL because of the paucity of data and the importance of vascular plants to maintain a healthy aquatic ecosystem.

The CSCLs developed for primary producers in aquatic systems include data on both vascular aquatic plants and algae. Algae were included in this receptor group because they have a relatively long history of toxicity testing and have often been shown to be more sensitive than vascular aquatic plants to chemical stressors (Klaine and Lewis, 1995). For algae, the measure of effect was based on the $EC_{20}$ and $EC_{50}$ values related to growth inhibition, decreased cell numbers, and reduction in carbon fixation as common responses measured in algal toxicity tests. For aquatic plants such as duckweed (e.g., *Lemna minor*), the endpoints included LOECs for development of fronds, biomass, root number and length, and plant number. The toxicological data relevant to this receptor group were identified in the open literature and from data compiled in *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision* (Suter and Tsao, 1996).

### 16.2.2 Calculate Hazard Quotients

The Ecological Risk Module calculates an HQ for receptors assigned within the AOI for a given site. The module may calculate more than one HQ for a receptor if the receptor is assigned to more than one habitat; however, the module calculates only one HQ per habitat for any receptor.[3] In calculating an HQ, the Ecological Risk Module checks first to determine whether an EB or CSCL (as appropriate) is available for a particular receptor. An HQ is not reported for a receptor if no benchmark is available; however, the lack of an ecological benchmark does not indicate the lack of ecological risk.

The Ecological Risk Module calculates HQs for each year, habitat, receptor, and site. Annual average media concentrations and applied doses are used to represent chronic, long-term exposures to chemical stressors released from waste management units. Although the HQ calculation is essentially the same for any receptor, the spatial scale and environmental characteristics relevant to the HQ calculations are handled differently for different habitat/receptor/constituent combinations. Therefore, it is useful to organize the discussion of HQ calculations around three basic groups of receptors:

1. **Freshwater Receptors (freshwater aquatic community, sediment community, amphibians, and aquatic plants and algae).** The module calculates HQs for these receptors based on appropriate CSCLs, determines the average concentration across the habitat or ephemeral water body, and adjusts certain CSCLs for environmental conditions prior to calculating the HQ.

2. **Soil receptors (soil community and terrestrial plants).** The module calculates HQs for these receptors based on the depth-averaged soil concentration and the

[3] There is one exception to this rule: more than one HQ can be calculated and reported for the soil community and terrestrial plants. This exception is explained in Section 16.2.2.2.

soil CSCLs, and reports an HQ for each receptor with a unique spatial definition (based on the receptor home ranges) in each habitat.

3. **Mammals, birds, and reptiles.** The module calculates HQs for mammals and birds using the applied doses calculated by the Ecological Exposure Module and the receptor-specific EBs. The spatial scale for each mammalian and avian HQ calculated by the module is based on the home range of the species. As noted earlier, insufficient data were available for the current 3MRA data set to calculate reptile HQs.

**Freshwater Receptors.** By definition, freshwater habitats (i.e., waterbody and wetland margins) include at least one fishable surface waterbody. Prior to calculating HQs for these receptors, the Ecological Risk Module identifies which habitats are waterbody margin or wetland, determines the number of reaches that are connected in each habitat,[4] and calculates the average surface water and sediment concentration for the habitat. For surface water, the module calculates average concentrations for both the total (i.e., dissolved plus bound fraction) and freely dissolved phases for each constituent.

For metals, the module adjusts the surface water CSCL to account for the effect of water hardness on toxicity. This adjustment is made only for cationic metals for which toxicological sensitivity has been shown to correlate with water hardness *and* for which a quantitative expression of that relationship has been developed by EPA. For nonionic organics, the module adjusts the sediment CSCL for the site-specific fraction organic carbon to ensure that the partitioning reflects the site conditions.

Using the average surface water and sediment concentrations and the adjusted CSCLs (if appropriate), the Ecological Risk Module calculates HQs for the aquatic community, aquatic plants or algae, amphibians, and the benthic community as follows:

$$HQ_{receptor_{habitat\ i}} = \frac{C_{medium_{habitat\ i}}}{CSCL_{receptor}} \tag{16-1}$$

where

| | | |
|---|---|---|
| $HQ_{receptor\_habitat^i}$ | = | hazard quotient for receptor in habitat i (unitless) |
| $C_{medium\_habitat^i}$ | = | concentration in surface water or sediment in habitat i (mg/L or mg/kg) |
| $CSCL_{receptor}$ | = | chemical stressor concentration limit for receptor (mg/L or mg/kg). |

The Ecological Risk Module uses two conventions that pertain to the use of surface water CSCLs to calculate HQs. First, the Ecological Risk Module uses the freely dissolved chemical

[4] The 3MRA modeling system treats all waterbodies, including streams, lakes, ponds, and permanently flooded wetlands, as reaches.

concentration if the corresponding CSCL also reflects freely dissolved chemical. The total water concentration is used to calculate the HQ if no freely dissolved CSCL is available (typically, surface water CSCLs are available only for total surface water concentrations). Second, the module calculates HQs for amphibians in intermittently flooded wetlands, reach order 2 streams, or any other transitory bodies of water that can serve as a breeding ground for amphibians. Indeed, an estimated 30 percent and 50 percent of all species of caudates (salamanders) and anurans (frogs), respectively, use temporary ponds for breeding, and many of these species reproduce in them exclusively (Freda, 1991).

**Soil Receptors.** For the soil community and terrestrial plants, the Ecological Risk Module calculates an HQ for each unique home range in each habitat delineated at the site. Four possible unique home ranges are currently implemented in the 3MRA modeling system (although, as indicated in Section 15, the 3MRA modeling system can process a unique home range for *every* receptor). For terrestrial habitats at many sites, the two largest home range sizes are larger than the habitat delineated within the AOI. As discussed in Section 15, these home ranges were constrained by the size of the habitat and, therefore, have identical spatial characteristics. In these instances, the HQs for these home ranges would be identical and reflect the same spatial averaging within the habitat and reporting them all would be redundant. Therefore, for most receptors, only one HQ is calculated per habitat, with the exception of plants and soil community receptors. This exception accounts for the fact that wildlife are tightly coupled to their environment, and adverse effects to the base of the food web may be highly significant ecologically. Consequently, the HQs for the soil community and terrestrial plants are calculated for unique spatial averages (defined by the home range) within each habitat. The HQs for soil receptors are calculated as the ratio of the root zone soil concentration (depth-averaged to 5 cm) to the soil CSCL for soil biota and plants, respectively, as follows:

$$HQ_{receptor_{habitat^{\,i}}} = \frac{C_{soil_{HomeRange^{\,j}}}}{CSCL_{receptor}} \tag{16-2}$$

where

| | | |
|---|---|---|
| $HQ_{receptor\_HomeRange^i}$ | = | hazard quotient for receptor in home range i (unitless) |
| $C_{soil\_HomeRange^i}$ | = | root zone soil concentration in home range i (mg/kg) |
| $CSCL_{receptor}$ | = | chemical stressor concentration limit for receptor (mg/kg). |

For any terrestrial habitat delineated within the AOI, between 1 and 4 HQs will be calculated for the soil community and terrestrial plants, respectively, provided that the chemical database contains CSCLs for both receptor types.

**Mammals, Birds, and Reptiles.** The Ecological Risk Module calculates HQs for mammals and birds as the ratio of the applied dose from the Ecological Exposure Model to the receptor-specific EB. Thus, Equation 16-3 has the same general form as the previous two HQ equations; however, the applied dose is used to represent the environmental exposure through the ingestion pathway, and the EB is used as the ecological benchmark for endpoints relevant to population growth and survival.

$$HQ_{receptor_{habitat\ i}} = \frac{AppliedDose_{receptor}}{EB_{receptor}} \quad (16\text{-}3)$$

where

| | | |
|---|---|---|
| $HQ_{receptor\_habitat^i}$ | = | hazard quotient for receptor in habitat i |
| $AppliedDose_{receptor}$ | = | applied dose to receptor (mg/kg-d) |
| $EB_{receptor}$ | = | ecological benchmark for receptor (mg/kg-d). |

The spatial characteristics of the HQ are defined by the home range for each mammalian and avian receptor.[5] Thus, the HQ values calculated for the same receptor assigned to two different terrestrial habitats at a site are likely to reflect the differences in soil, plant, and prey concentrations associated with the respective home ranges.

### 16.2.3 Process HQ Results for Decision Making

The HQs calculated by the Ecological Risk Module provide a risk metric with essentially a binary outcome: an HQ above 1 indicates that ecological risks are above levels of concern, and an HQ below 1 indicates that ecological risks are below levels of concern. Naturally, this approach implies that an HQ much greater than 1 (say, two orders of magnitude) represents a more serious ecological threat than an HQ of 2; however, the 3MRA modeling system and data do not quantify the *probability* that an adverse effect will occur. For example, an HQ of 20 calculated for a drop in egg production for the osprey does not imply that the probability of this effect is 10 times more likely than an HQ of 2, only that the magnitude of the effect is likely to be more serious. Similarly, because the actual dose-response relationship is not used in the HQ calculations, the HQ of 20 does not imply that the effect would be 10 times more severe than for osprey with an HQ of 2. The HQ approach provides limited information on the probability and significance of ecological risks for decision-making purposes; the implications of calculated receptor-specific HQs as to the quality of ecological systems as a whole simply cannot be inferred. The sometimes unpredictable nature of community dynamics, as well as the presence of other stressors (e.g., habitat alteration), are such that the potential ecosystem effects associated with, say, a reduction in reproductive fitness of a single receptor can be difficult to predict, particularly when the modeling simulation may run hundreds or even thousands of years.

To address this limitation for national-scale applications of the 3MRA modeling system, the Ecological Risk Module processes the calculated HQs so that decision makers can answer a variety of questions about potential ecological risks. Specifically, the Ecological Risk Module (1) assigns attributes appropriate to each HQ, including the hazard bin, distance to waste management unit (WMU), receptor taxa, and habitat type, and (2) identifies the critical year in the simulation at which ecological risks (i.e., HQs) are collectively at the highest level.

[5] The Ecological Risk Module is also designed to calculate HQs for reptiles; however, insufficient ecotoxicity data were identified to support an EB for reptile species.

**Assigning Attributes to HQs.** One of the most important attributes of the HQs calculated by the Ecological Risk Module is the hazard range (referred to as a hazard "bin") to which the HQ is assigned. The HQs for all receptors assigned to habitats within the AOI are placed into one of five hazard bins identified by EPA as useful to decision-makers. The HQ bins are defined as

- **Bin 1:** ≤ 0.1
- **Bin 2:** > 0.1 to ≤ 1
- **Bin 3:** >1 to ≤ 10
- **Bin 4:** >10 to ≤ 100
- **Bin 5:** >100.

As an example, suppose that a particular site has a total of 25 mammalian receptor species assigned across the three habitats: 10 mammals in a forest habitat, 7 mammals in a grassland habitat, and 8 mammals in a stream margin habitat. For a simulation that runs three years, assume that the HQs calculated for the mammalian receptors are as shown in Table 16-2. These HQ calculations reflect the applied doses to mammalian wildlife due to the ingestion of contaminated media, plants, and prey. Notice that the hazard profile changes with each year in the simulation; in this hypothetical example, the level of exposure and resulting hazard is increasing over time.

**Table 16-2. Example HQ Counts for Mammals at Hypothetical Site**

| | Number of Mammal Species in Each HQ Range | | | | |
|---|---|---|---|---|---|
| | **Bin 1** | **Bin 2** | **Bin 3** | **Bin 4** | **Bin 5** |
| **Exposure starting in...** | **≤ 0.1** | **>0.1 to ≤1** | **>1 to ≤ 10** | **>10 to ≤ 100** | **>100** |
| Year 1 | 19 | 5 | 1 | 0 | 0 |
| Year 2 | 15 | 7 | 2 | 1 | 0 |
| Year 3 | 12 | 9 | 1 | 2 | 1 |

The Ecological Risk Module uses the HQ counts to create a cumulative frequency histogram: the results expressed as the cumulative percentile of the total number of HQs. Therefore, the conditional, cumulative frequency percentiles for mammalian risks (defined by the HQ) for each year in the simulation would be as shown in Table 16-3.

**Table 16-3. Example Cumulative Frequency HQ Histogram for Mammals at Hypothetical Site**

| | Percent of Mammal Species in this HQ Range or Lower | | | | |
|---|---|---|---|---|---|
| **Exposure starting in...** | **Bin 1** | **Bin 2** | **Bin 3** | **Bin 4** | **Bin 5** |
| Year 1 | 76 | 96 | 100 | | |
| Year 2 | 60 | 88 | 96 | 100 | |
| Year 3 | 48 | 84 | 88 | 96 | 100 |

Aggregating the HQs into hazard ranges serves two important functions in the 3MRA modeling system. First, converting the results to cumulative hazard allows the module to greatly reduce the amount of data that it produces. Because the Ecological Risk Module calculates HQs for every receptor in every year in the simulation, the system produces a tremendous amount of data. Second, the use of hazard ranges recognizes that the state of ecological risk assessment science (for national applications) lacks the data to validate the level of accuracy in risk estimates. Accumulating the ecological hazard quotients implicitly acknowledges the limitations in predicting ecological risks using the HQ approach. EPA developed these bin ranges to be meaningful in terms of decision making, increasing from below levels of concern to high levels of concern.

In addition to the hazard bin, each HQ is associated with a series of attributes that allow ecological risks to be characterized in different ways. EPA identified five attributes considered relevant to interpreting the potential significance for adverse ecological effects within the context of regulatory decision making. These attributes support analyses at different scales of organization with respect to space as well as trophic position, and include:

- Habitat type (e.g., forest, grassland, pond, stream, permanently flooded forest),
- Habitat group (i.e., terrestrial, freshwater, and wetland),
- Receptor group (e.g., mammals, amphibians, soil community),
- Trophic level (i.e., producers, TL1, TL2, TL3, top predators), and
- Distance to WMU (e.g., within 1 km of WMU).

The maximum HQ across the site is also reported, along with its ecological risk attributes. This metric was added for use in pass/fail analyses that may be needed to prioritize sites for further refinement or assessment.

In summary, for each year in the simulation, the Ecological Risk Module does all of the necessary accounting to construct cumulative frequency histograms, expressed as a percentile of the total HQs across all receptors or by attribute. The cumulative frequency data contain the HQ values for each attribute of interest (e.g., receptor group, habitat type) so that the results may be accumulated to respond to different questions (e.g., what are the risks to mammals at a site). The cumulative frequency data on HQs across all sites serves as the input data set for the Exit Level Processor (ELP) of the 3MRA modeling system. As described in the overview in Section 1.0, the ELP is a system level tool used to develop cumulative frequency distributions of ecological risks for national analyses.

**Identifying the Critical Year in the Simulation.** Having produced the time series of cumulative frequencies for HQs, the Ecological Risk Module identifies the year during which the total hazard is a maximum for each of the ecological attributes listed above (i.e., habitat type, habitat group, receptor group, and trophic level; all HQs are specific to a distance from the WMU). This is the critical year in the simulation (referred to as TCrit); in processing ecological risk results for national applications, the ELP uses only the HQ results for the TCrit year for each site included in the simulation. The Ecological Risk Module identifies the TCrit year for each of the first four ecological attributes listed above as a function of distance to the WMU. For example, the module produces the cumulative frequency HQ histogram for all receptor groups (e.g., mammals, birds, aquatic community) for the entire site, and for distance intervals within

1 km of the WMU, and between 1 and 2 km of the WMU.[6] In addition, the module identifies the TCrit for the maximum HQ across all receptors assigned to the site.

The Ecological Risk Module identifies the TCrit for each attribute in three basic steps. First, the module calculates the total HQ (by attribute) for each year in the simulation by summing the HQs across all receptors that share that attribute. Second, the module rank orders the time series of total HQs. Third, the module selects the Ecological Regulatory Percentile (ERP) and identifies the TCrit year that matches the total HQ at that percentile of the rank ordering. The Ecological Regulatory Percentile is a user-specified percentile that indicates the level of protection required to select TCrit. For example, if the user specified 95 percent as the Ecological Regulatory Percentile, the Ecological Risk Module would identify TCrit as the output year when the total HQ value is greater than 95 percent of all the other total HQ values reported for the simulation. In the current implementation of the 3MRA modeling system, the default value for Ecological Regulatory Percentile is 100 percent; therefore, the module identifies the maximum total HQ and reports that year as TCrit for the appropriate attribute.

## 16.3 Module Discussion

### 16.3.1 Strengths and Advantages

The Ecological Risk Module calculates HQs for all receptors assigned to habitats within the AOI. The module offers a number advantages, including the underlying ecological benchmarks as well as site-specific adjustments to the benchmarks that reflect the environmental characteristics of the site. Examples of these advantages include the following:

- **The ecological benchmarks reflect the management goals and assessment endpoints for national-scale analyses.** The ecological benchmarks in the 3MRA modeling system were developed specifically to evaluate the ecological risks associated with long-term, low-level contaminant releases into the environment. The relevance of these benchmarks to national-scale applications of the 3MRA modeling system is a major advantage of this module. Although a variety of different benchmarks could be used by the module to calculate ecological hazard, the benchmark database ensures that the resulting HQs will be highly relevant to establishing exit levels that are protective of the environment. The rationale, confidence levels, and data quality objectives are transparent for ecological benchmarks that are incorporated into the 3MRA modeling system benchmark database.

- **Benchmarks are adjusted for site-specific conditions as appropriate.** For certain benchmarks and chemicals, environmental characteristics exert a strong influence on toxicity. For example, the water quality CSCL for certain metals is sensitive to water hardness. For each simulation, the surface water CSCL is

[6] Although the Ecological Risk Module reports hazard quotients for all three distance intervals, EPA has determined that distance to WMU is of limited value in characterizing ecological risks. The vast majority of habitats delineated for sites of interest overlap the 1 km distance from the WMU. As a result, it would be double counting to report these risks for both the 1 km and 1-2 km distance intervals.

adjusted for the site-specific water hardness to better represent the potential toxicity given the specific environmental setting. Similarly, the sediment CSCL for organic chemicals is adjusted for the site-specific organic carbon fraction in the sediment. The ability to modify benchmarks during a simulation allows the module to be applied to virtually any site, and adjusts the toxicity according to the site conditions.

- **HQs retain attributes critical to characterizing the nature of ecological risk estimates.** Each HQ calculated by the module retains all of its attributes such as the receptor group (e.g., mammals) and habitat type (e.g., forest). In addition, the Ecological Risk Module reports the maximum HQ calculated at each site (along with its attributes) to allow for a rapid screening function or coarse ranking of sites. This information on HQ attributes is critical to allow decision makers to evaluate the results using different kinds of ecological indicators. For example, it may be desirable to evaluate concentration levels specifically for wetlands, because of their ecological importance. Similarly, the user may want to understand the nature of the risk estimates with regard to the receptors most likely at risk, or the habitats most likely at risk. Consequently, the module reports this information to retain flexibility in the characterization of predicted ecological risks.

- **Binning HQ greatly reduces the volume of data.** Although the module calculates HQs for each receptor at a site, these HQs are binned into discrete ecological hazard bins. Because these bins are developed across each of the possible attributes (e.g., trophic level, receptor group), the binning provides a very efficient method of storing and manipulating these data without losing any of the relevant information. This approach offers a very practical solution to the potential storage issues associated with storing time series of HQs for dozens of receptors across hundreds of sites. Moreover, the use of hazard bins is a very appropriate technique to characterize ecological risk, given the current state-of-the-science for national-scale analyses.

### 16.3.2 Uncertainty and Limitations

The methodology implemented by the Ecological Risk Module to characterize the potential for adverse ecological effects carries certain assumptions and limitations, and acknowledges several important sources of uncertainty. A number of the limitations and uncertainties discussed in Section 15.3 on the Ecological Exposure Module also apply to the Ecological Risk Module. Although parts of this section are redundant with the discussion in Section 15.3, the primary focus of the following discussion is on the implications for risk estimation and characterization for all ecological receptors, not just those receptors for which ingestion exposures were calculated.

- **The HQ estimates are based exclusively on an annual time step; that is, only annual average applied doses and media concentrations are used in calculating the HQ.** The ecological HQ estimates are based on annual averages. This time step represents much longer-than-lifetime exposures for some receptors and substantially less-than-lifetime for other receptors. As indicated in Section 15.3, concentration spikes due to episodic events (e.g., rain storms) or elevated WMU source releases following waste additions are not evaluated. Even though the measures of effect often reflect critical life stage endpoints, the use of annual average doses and concentrations to predict risk may not adequately reflect effects associated with elevated, short-term exposures. This "one-time-step-fits-all" approach, although necessary to address run time issues, does limit the applicability of the HQ estimates for certain receptors.

- **The HQs are not calculated at the population or community level; ecological risks must be inferred to higher levels of biological organization**. Ecosystems are enormously complex, and our understanding of even simple community dynamics is limited. Data on chemical stressors are seldom available above the level of an individual organism; that is, the study endpoints focus on individual organisms rather than processes crucial to assemblages of organisms. Although the measures of effect are relevant to higher levels of organization, the comparison of point estimates of simulated contaminant doses or concentrations for individual receptors with ecological benchmarks does not support the quantification of population or community risks. Our ability to address community-level effects associated with contaminant releases into the environment is even more limited; the CSCLs developed to evaluate risks to communities are derived by statistical inference based on toxicity data for individual organisms. This limitation in the data and technology (i.e., the inability to run population-level models in the 3MRA modeling system) introduces significant uncertainty in the risk estimates.

- **The effects of multiple stressors (chemical and nonchemical) are not considered in developing estimates of potential ecological risk**. Given the design goals for the 3MRA modeling system (i.e., to support national-level assessment strategies of WMUs, waste streams, and contaminants), exposure to multiple contaminants, contaminant releases outside of the AOI, and effects associated with multiple stressors are not considered. In addition, background concentrations of constituents were not considered in developing exposure estimates, nor were other potential nonchemical stressors such as habitat fragmentation. Data availability on the antagonistic and synergistic effects associated with multiple stressors are extremely limited at this time (with the possible exception of narcotic contaminants in aqueous systems), and prevented the development of a multistressor analytical approach for the universe of constituents in the current data set. Data limitations notwithstanding, the inability to consider multiple stressors is a limitation in our ability to interpret the risk results generated by this module. This is a significant but unquantifiable uncertainty inherent in the HQ calculations.

- **The HQ estimates reflect different endpoints at varying levels of effect**. The ecological benchmarks address a variety of receptors (e.g., soil fauna, mammals, plants) and, because the quality and quantity of relevant data vary widely across receptors, the HQs generated by the Ecological Risk Module represent different levels of knowledge regarding the exposure and toxicity of chemical stressors. The variability in supporting data suggests that the level of confidence in the exemption criteria is dependent on the quantity and quality of available data. The HQ methodology—the ratio of an exposure to a benchmark—is applied uniformly across all ecological receptors. However, the data supporting the HQ calculation vary in that they include endpoints from lethality to reproductive fitness and address population- and community-level effects by inference. To some extent, the HQ estimates for different receptor groups represent different risk metrics. The interpretation of these HQ estimates is, therefore, limited by our understanding of the potential ecological significance of the measures of effect as well as overall confidence in the data used to support the calculations.

- **The data used to support the development of sediment CSCLs for metals have come under significant scrutiny because of concerns regarding the applicability of the tests to predict sediment effects.** The sediment CSCLs for metals are ultimately based on data from the National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends (NS&T) data. The NOAA data generally rely on observed effects to sediment biota exposed to sediment samples. The sediment samples are contaminated with mixtures of metals and, as a result, the observed effects cannot be definitively attributed to a specific metal. Thus, the effects levels reported for specific metals may in fact reflect effects of a mixture of metals. HQs based on these sediment CSCLs may overestimate the potential for adverse effects to the sediment community.

- **The HQs calculated for the aquatic and benthic communities are resolved at the habitat, rather than reach level**. There is some uncertainty associated with calculating risks to aquatic life across an entire habitat (as defined within the study area). Species of fish such as brown trout tend to use certain segments of stream habitats; therefore, HQs at the reach level may be more appropriate. Conversely, establishing artificial boundaries between stream reaches is contrary to the goals of the assessment strategy, namely, to evaluate ecological risks using the habitat as the fundamental unit. In short, the spatial scale adopted for evaluating freshwater communities of water column and sediment biota introduces uncertainty in HQ for these receptors. Risks may be underestimated for stream reaches with elevated contaminant concentrations; conversely, risks may be overestimated for a stream habitat with only a single stream reach above levels of concern.

## 16.4 References

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