Derivation of Ecological Protective Concentration using the Probabilistic Ecological Risk Assessment applicable for Korean Water Environment: (I) Cadmium

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(Received January 13, 2012; Revised June 18, 2012; Accepted June 28, 2012)

Probabilistic ecological risk assessment (PERA) for deriving ecological protective concentration (EPC) was previously suggested in USA, Australia, New Zealand, Canada, and Netherland. This study suggested the EPC of cadmium (Cd) based on the PERA to be suitable to Korean aquatic ecosystem. First, we collected reliable ecotoxicity data from reliable data without restriction and reliable data with restrictions. Next, we sorted the ecotoxicity data based on the site-specific locations, exposure duration, and water hardness. To correct toxicity by the water hardness, EU’s hardness corrected algorithm was used with slope factor 0.89 and a benchmark of water hardness 100. EPC was calculated according to statistical extrapolation method (SEM), statistical extrapolation methodAcute to chronic ratio (SEMACR), and assessment factor method (AFM). As a result, aquatic toxicity data of Cd were collected from 43 acute toxicity data (4 Actinopterygill, 29 Branchiopoda, 1 Polychaeta, 2 Bryozoa, 6 Chlorophyceae, 1 Chanophyceae) and 40 chronic toxicity data (2 Actinopterygill, 23 Branchiopoda, 9 Chlorophyceae, 6 Macrophytes). Because toxicity data of Cd belongs to 4 classes in taxonomical classification, acute and chronic EPC (11.07 µg/l and 0.034 µg/l, respectively) was calculated according to SEM technique. These values were included in the range of international EPCs. This study would be useful to establish the ecological standard for the protection of aquatic ecosystem in Korea.

Key words: Ecological protective concentration (EPC), Probabilistic ecological risk assessment (PERA), cadmium, Statistical extrapolation method (SEM), Assessment factor method (AFM)

INTRODUCTION

Probabilistic ecological risk assessment (PERA) is a technique to overcome the limitation of Deterministic ecological risk assessment (DERA) that determines if there is potential risk or not, and it is extensive approach to qualify and quantify risk on the multispieces based on species sensitivity distribution (SSD) (George et al., 2003). Developed countries, including USA, Australia, New Zealand, Canada, and Netherland, presented criteria or guideline for protecting the ecosystem with PERA technique (ANZECC and ARMCANZ, 2000a; CCME, 1999; RIVM, 2001; USEPA, 2009). In addition, there were reports, papers, and guidelines according to PERA in Korea. For example, the report that derives the water quality criteria for protecting the ecosystem using PERA from Australia and New Zealand was suggested by Ministry of Environment and National Institute of Environmental Research of Korea (2006), and An et al. (2009) proposed PERA for Korean water environment. Especially, Korean established rule No. 415 institutionally reflected the PERA in 2010.

Along with improving the awareness to manage the chemicals with the PERA, institutionalization of the relevant guideline and the performance of the relevant project were conducted (ME, 2004, 2007). Up to now, Korean government withheld criteria, guidelines, or standards for each chemical from the public. However, environmental and health policy for focusing on receptors interests ecosystem as well as human health. The study present the case study that establishes the water quality standards for protecting the ecosystem based on PERA approach. Prior to performing the stringent guidelines or standards through technical and economical analyses, ecological protective concentration (EPC) based on the scientific data is needed to present first. Case study of EPC is needed to conduct based on the PERA applicable for Korean water environment. Our purpose in this study was to suggest EPC of cadmium (Cd) based on the PERA applicable for Korean water environment pre-
sented by An et al. (2009).

MATERIALS AND METHODS

Selection of test chemicals. We selected Cd as a test chemical to derive the Korean EPA. According to An et al. (2009), toxicity of some heavy metals (e.g. Cd, Cu, Cr3+, Ni, Pb, Ag, and Zn) is different based on water hardness. Therefore hardness correction procedure is needed to induce the accuracy of ecotoxicity data. Especially, Cd and Pb were substances for the protection of human health in Korea. Along with Integrated Risk Information System (IRIS), carcinogenic classification of Cd and Pb are B1 (Probable human carcinogen - based on limited evidence of carcinogenicity in humans) and B2 (Probable human carcinogen - based on sufficient evidence of carcinogenicity in animals), respectively. Some papers presented toxicity values of Cd were more sensitive than Pb. Ninety six hours NOECs of Cd were more sensitive than Pb. Forty eight hours LC50s of Daphnia pulex, Ceriodaphnia reticulata and Simocephalus vetulus were 0.068, 0.066 and 0.024 mg/l for Cd and 5.1, 0.53 and 4.5 mg/l for Pb (Mount and Norberg, 1984). Therefore Cd was selected as a test chemical because it is more toxic than Pb based on the human health toxicity and ecotoxicity.

Collection of ecotoxicity data. Reliable ecotoxicity data was collected from reliable data without restriction (e.g. toxicity data based on the Good Laboratory Practice) and reliable data with restrictions (e.g. SCI(E) papers), according to Klimesch et al. (1997) and An et al. (2009). These references were from the US EPA’s ECOTOXicology Database (ECOTOX; http://www.epa.gov/ecotox), Australia and New Zealand’s TOX-2000 Database, ECB’s International Uniform Chemical Information Database (IUCLID), USEPA’s ambient water quality criteria reports (ANZECC and ARMCANZ, 2000b; ECB, 2000; USEPA, 1980, 1985, 1996, 2001, 2005).

Sorting of ecotoxicity data based on the site-specific locations, exposure duration, and water hardness. To induce Korean aquatic ecosystem through consideration of mutual relation among Korean organisms, we sorted the ecotoxicity data based on the site-specific locations. We utilized the research papers and illustrated books of Korean organisms (An et al., 2007a, 2007b, 2008; Kim, 1982; Kim and Park, 2002; KIWE, 2000; ME, 1968, 1996; Nam et al., 2007; NIER, 2004). Ecotoxicity data included domestic species that live in the Korean aquatic ecosystem and introduced species that settle down in the Korean water environment but excluded domestic species that locally live in the Korean aquatic ecosystem. Also, we sorted the acute and chronic exposure duration with life cycle of species based on the papers (An et al., 2007a, 2008; Nam et al., 2007). According to Nam et al. (2007), fish toxicity data included lethality, embryo and sac-fry stages, early-life stage, and juvenile growth toxicity test, and these data were classified by the endpoints. Acute and chronic duration of lethality toxicity test was categorized as 14 days, and duration of embryo and sac-fry stages test was maintained with the time from embryo to sac-fry. Chronic duration of early-life stage test was the time from embryo to adult, and chronic duration of juvenile growth toxicity test was until adult appears. Cladoceran reproductive toxicity data were assessed in the time that they reproduce at least third broods and lethality and immobilization toxicity test data were different according to life cycle of species (An et al., 2007a). Along with An et al. (2008a), acute and chronic duration of green algae growth inhibition toxicity data were divided by 72 hours. Aquatic toxicity of some heavy metals differs according to water hardness. So, correction of water hardness is needed to replace water hardness presented in the test with the benchmark of water hardness. In this study, we corrected the toxicity values from the EU’s hardness corrected algorithm; hardness corrected toxicity value = toxicity value presented in the test X (the benchmark of water hardness/ water hardness presented in the test) slope factor (EU, 2007). At this time, 0.89 is used as a slope factor (ANZECC and ARMCANZ, 2000a) and 100 are used as a benchmark of water hardness (An et al., 2008b).

Calculation of ecological protective concentration. We utilized the domestic PERA techniques (e.g. Statistical extrapolation method (SEM), Statistical extrapolation method_acute to chronic ratio (SEM_ACR), and Assessment factor method (AFM) presented by An et al. (2009). It is based on the PERA techniques to protect the ecosystem in developed countries (e.g. USA, Australia, New Zealand, Canada, and Netherlands). These techniques are used as related sufficiency of toxicity data. SEM is applied to sufficient acute median lethal concentration (LC50) values, acute median effective concentration (EC50) values, or chronic no-observed-effective concentration (NOEC) values and used the fifth percentile hazard concentration (HC5) from species sensitivity distribution (SSD) presented by E<sub>5</sub>X program. At this time, the data should include at least 4 classes in taxonomical classification (e.g. Actinopterygill, Branchiopoda, Chlorophyceae, Maxillapoda, Insects, Bivalvia, Gastropoda, Secernentea, Polychaeta, Monocotyldoneae, Chanophyceae, and etc.). SEM<sub>ACR</sub> is applied to the case where chronic toxicity data were insufficient but acute toxicity data were sufficient. At this time, HC5 calculated from the acute LC50 and EC50 was divided by acute to chronic ratio (ACR), and ACR was derived from the acute and chronic toxicity values of the same species. AFM is applied to the insufficient acute and chronic toxicity data. The lowest acute LC50,
EC50, or chronic NOEC were divided by assessment factor (AF) presented in Table 1.

**RESULTS**

Aquatic toxicity data of Cd were collected 43 acute toxicity data (4 Actinopterygill, 29 Branchiopoda, 1 Polychaeta, 2 Bryozoa, 6 Chlorophyceae, 1 Chanophyceae) and 40 chronic toxicity data (2 Actinopterygill, 23 Branchiopoda, 9 Chlorophyceae, 6 Macrophytes) as listed in Table 2, 3 and 4. Actinopterygill toxicity data were tested with *Cyprinus carpio*, *Gasterosteus aculeatus* and *Lepomis macrochirus* and their adverse effects were lethality and vertebral column damage. Branchiopoda toxicity data were conducted with *Ceriodaphnia dubia*, *Ceriodaphnia reticulata*, *Daphnia pulex*, *Moina macrocopa*, *Simocephalus serrulatus* and *Simocephalus ventulus* and lethal and reproductive effects were tested in 2~4 and 7~70 days. Polychaeta and Bryozoa toxicity data were only assessed in acute exposure duration and lethal effect were tested with *Branchiura sowerbyi*, *Lophopodella carteri* and *Pectinatella magnifica*. Chlorophyceae toxicity data were conducted with *Chlorella vulgaris*, *Selenastrum capricornutum* and *Ankistrodesmus falcatus* and acute and chronic growth inhibition effects were assessed in 1~2 and 4~14 days. Chanophyceae toxicity data were only tested in acute exposure duration and growth inhibition effects were conducted with *Microcystis aeruginosa* for 1 day. Macrophytes toxicity data were only tested in chronic exposure duration and *Lemna paucicostata* were assessed in 7 days for investigating change of number of foids.

The EPC of Cd for acute and chronic toxicity effects was calculated according to SEM technique because of toxicity data belong to 6 classes (Actinopterygill, Branchiopoda,

| Classification      | Toxicity data | Acute | Chronic |
|---------------------|---------------|-------|---------|
| Actinopterygill     | 4             | 2     |         |
| Branchiopoda       | 29            | 23    |         |
| Polychaeta         | 1             | 0     |         |
| Bryozoa            | 2             | 0     |         |
| Chlorophyceae      | 6             | 9     |         |
| Macrophytes        | 0             | 6     |         |
| Chanophyceae       | 1             | 0     |         |
| Total              | 43            | 40    |         |

**Table 2.** The present condition of aquatic toxicity data for cadmium selected in this study

| Scientific name (Common name) | Exposure duration (d) | Endpoint | Hardness (mg CaCO₃/l) | Toxicity value (µg/l) | Hardness corrected toxicity value (µg/l) | Species mean acute value (µg/l) | References                      |
|-------------------------------|-----------------------|----------|-----------------------|----------------------|------------------------------------------|--------------------------------|--------------------------------|
| *Cyprinus carpio* (Common carp) | -                     | L(E)C50  | 100                   | 4,300                | 4,300                                    | 8,575                          | USEPA(1980, 1985, 1996, 2001) |
| *Cyprinus carpio* (Common carp) | -                     | L(E)C50  | 100                   | 17,100               | 17,100                                   |                               | USEPA(1980, 1985, 1996, 2001) |
| *Gasterosteus aculeatus* (Threespine stickleback) | -                     | L(E)C50  | 115                   | 6,500                | 5,740                                    | 11,149                         | USEPA(1980, 1985, 1996, 2001) |
| *Gasterosteus aculeatus* (Threespine stickleback) | -                     | L(E)C50  | 107                   | 23,000               | 21,656                                   |                               | USEPA(1980, 1985, 1996, 2001) |
| Scientific name (Common name) | Exposure duration (d) | Endpoint | Hardness (mg CaCO₃/l) | Toxicity value (µg/l) | Hardness corrected toxicity value (µg/l) | Species mean acute value (µg/l) | References |
|-------------------------------|-----------------------|----------|------------------------|----------------------|------------------------------------------|--------------------------------|------------|
| **Class Branchiopoda**       |                       |          |                        |                      |                                          |                                |            |
| Ceriodaphnia dubia (Water flea) | 4                     | LC₅₀     | 17                     | 17                   | 82                                       | Suedel et al.(1997)           |            |
| Ceriodaphnia dubia (Water flea) | 2                     | LC₅₀     | 83                     | 50                   | 59                                       | Diamond et al.(1997)          |            |
| Ceriodaphnia dubia (Water flea) | 2                     | EC₅₀     | 90                     | 54                   | 59                                       | Bitton et al.(1996)           |            |
| Ceriodaphnia dubia (Water flea) | -                     | L(E)C₅₀ | 80                     | 55                   | 66                                       | USEPA(1980, 1985, 1996, 2001)  |            |
| Ceriodaphnia dubia (Water flea) | -                     | L(E)C₅₀ | 90                     | 56                   | 61                                       | USEPA(1980, 1985, 1996, 2001)  |            |
| Ceriodaphnia dubia (Water flea) | 2                     | LC₅₀     | 17                     | 63                   | 305                                      | Suedel et al.(1997)           | 114        |
| Ceriodaphnia dubia (Water flea) | 2                     | LC₅₀     | 83                     | 107                  | 127                                      | Diamond et al.(1997)          |            |
| Ceriodaphnia dubia (Water flea) | 2                     | LC₅₀     | 83                     | 160                  | 190                                      | Diamond et al.(1997)          |            |
| Ceriodaphnia dubia (Water flea) | 2                     | LC₅₀     | 83                     | 213                  | 253                                      | Diamond et al.(1997)          |            |
| Ceriodaphnia dubia (Water flea) | 2                     | LC₅₀     | 290                    | 220                  | 89                                       | Schubauer-Berigan et al.(1993)|            |
| Ceriodaphnia dubia (Water flea) | 2                     | LC₅₀     | 290                    | 560                  | 217                                      | Schubauer-Berigan et al.(1993)|            |
| Ceriodaphnia reticulata (Water flea) | 2                     | LC₅₀     | 45                     | 66                   | 134                                      | Mount and Norberg.( 1984)     |            |
| Ceriodaphnia reticulata (Water flea) | -                     | L(E)C₅₀ | 120                    | 110                  | 94                                       | USEPA(1980, 1985, 1996, 2001)  | 98         |
| Ceriodaphnia reticulata (Water flea) | -                     | L(E)C₅₀ | 240                    | 184                  | 84                                       | USEPA(1980, 1985, 1996, 2001)  |            |
| Ceriodaphnia reticulata (Water flea) | 2                     | EC₅₀     | 230                    | 184                  | 88                                       | Elnabarawy et al.(1986)       |            |
| Daphnia pulex (Water flea)      | -                     | L(E)C₅₀ | 57                     | 47                   | 78                                       | USEPA(1980, 1985, 1996, 2001)  |            |
| Daphnia pulex (Water flea)      | -                     | L(E)C₅₀ | 85                     | 66                   | 76                                       | USEPA(1980, 1985, 1996, 2001)  |            |
| Daphnia pulex (Water flea)      | 2                     | LC₅₀     | 45                     | 68                   | 138                                      | Mount and Norberg.( 1984)     | 102        |
| Daphnia pulex (Water flea)      | -                     | L(E)C₅₀ | 85                     | 70                   | 81                                       | USEPA(1980, 1985, 1996, 2001)  |            |
| Daphnia pulex (Water flea)      | -                     | L(E)C₅₀ | 54                     | 70                   | 122                                      | USEPA(1980, 1985, 1996, 2001)  |            |
| Daphnia pulex (Water flea)      | -                     | L(E)C₅₀ | 120                    | 80                   | 68                                       | USEPA(1980, 1985, 1996, 2001)  |            |
| Daphnia pulex (Water flea)      | -                     | L(E)C₅₀ | 85                     | 99                   | 114                                      | USEPA(1980, 1985, 1996, 2001)  |            |
Table 3. Continued

| Scientific name (Common name) | Exposure duration (d) | Endpoint | Hardness (mg CaCO₃/l) | Toxicity value (µg/l) | Hardness corrected toxicity value (µg/l) | Species mean acute value (µg/l) | References |
|------------------------------|-----------------------|----------|-----------------------|----------------------|------------------------------------------|-------------------------------|------------|
| Daphnia pulex (Water flea)  | -                     | L(E)C50  | 120                   | 100                  | 85                                       | USEPA(1980, 1985, 1996, 2001) |
| Daphnia pulex (Water flea)  | 2                     | EC50     | 230                   | 319                  | 152                                      | 102                           | Elnabarawy et al. (1986) |
| Daphnia pulex (Water flea)  | -                     | L(E)C50  | 240                   | 319                  | 146                                      | USEPA(1980, 1985, 1996, 2001) |
| Moina macrocopa (Water flea) | -                     | L(E)C50  | 82                    | 71                   | 85                                       | USEPA(1980, 1985, 1996, 2001) |
| Simocephalus serrulatus (Water flea) | -                     | L(E)C50  | 11                    | 7                    | 50                                       | USEPA(1980, 1985, 1996, 2001) |
| Simocephalus serrulatus (Water flea) | -                     | L(E)C50  | 44                    | 25                   | 51                                       | USEPA(1980, 1985, 1996, 2001) |
| Simocephalus ventulus (Water flea) | 2                     | LC50     | 45                    | 24                   | 49                                       | USEPA(1980, 1985, 1996, 2001) |
| Branchiura sowerbyi (Tbificid worm) | -                     | L(E)C50  | 5                     | 240                  | 3,278                                    | USEPA(1980, 1985, 1996, 2001) |
| Lophopodella carteri (Bryozoan) | -                     | L(E)C50  | 205                   | 150                  | 79                                       | USEPA(1980, 1985, 1996, 2001) |
| Pectinatella magnifica (Bryozoan) | -                     | L(E)C50  | 205                   | 700                  | 370                                      | USEPA(1980, 1985, 1996, 2001) |
| Chlorella vulgaris (green algae) | 2                     | EC50     | -                     | 5,100                | -                                        | USEPA(1980, 1985, 1996, 2001) |
| Chlorella vulgaris (green algae) | 2                     | EC50     | -                     | 15,720               | -                                        | USEPA(1980, 1985, 1996, 2001) |
| Selenastrum capricornutum (green algae) | 2                     | EC50     | -                     | 109                  | -                                        | USEPA(1980, 1985, 1996, 2001) |
| Selenastrum capricornutum (green algae) | 1                     | EC50     | 16                    | 341                  | 1,845                                    | USEPA(1980, 1985, 1996, 2001) |
| Selenastrum capricornutum (green algae) | 1                     | EC50     | -                     | 341                  | -                                        | USEPA(1980, 1985, 1996, 2001) |
| Selenastrum capricornutum (green algae) | 1                     | EC50     | -                     | 2                    | -                                        | USEPA(1980, 1985, 1996, 2001) |
| Microcystis aeruginosa (Blue-green algae) | 1                     | EC50     | -                     | 1                    | -                                        | USEPA(1980, 1985, 1996, 2001) |

Polychaeta, Bryozoa, Chlorophyceae, Chanophyceae) and 4 classes (Actinopterygill, Branchiopoda, Chlorophyceae, Macrophytes) in taxonomical classification. Species mean acute (chronic) value (SMA(C)V), geometric mean calculated from toxicity values of same species, was used as input data to run program, and SMAV and SMCV of Cd were calculated from 12 and 7 species, respectively. Acute and chronic SSD of Cd was presented in Fig. 1 and Fig. 2, and acute and chronic HC5 were calculated as 11.07 (1.3~40.2) µg/l and 0.034 (0.0002~0.4) µg/l, respectively.
Table 4. List of chronic toxicity data for cadmium

| Scientific name (Common name) | Exposure duration (d) | Endpoint | Hardness (mg CaCO₃/l) | Toxicity value (µg/l) | Hardness corrected toxicity value (µg/l) | Species mean chronic value (µg/l) | References |
|-------------------------------|-----------------------|----------|-----------------------|----------------------|------------------------------------------|----------------------------------|------------|
| **Class Actinopterygill**     |                       |          |                       |                      |                                          |                                  |            |
| *Lepomis macrochirus* (Bluegill) | -                    | Chronic value | 207                  | 50                   | 26                                       | 26                               | USEPA(1980, 1985, 1996, 2001) |
| *Cyprinus carpio* (Common carp) | 47                   | LOEC (vertebral column damage) | 18                  | 10                   | 46                                       | 46                               | ECB(2000)  |
| **Class Branchiopoda**        |                       |          |                       |                      |                                          |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 8                     | NOEC (Reproduction) | -                    | 0                    | -                                        |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 7                     | NOEC (Reproduction) | 17                  | 1                    | 5                                        |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 10                    | NOEC (Reproduction) | 17                  | 1                    | 5                                        |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 14                    | NOEC (reproduction) | 17                  | 1                    | 5                                        |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 7                     | NOEC (Survival) | 17                  | 10                   | 48                                       |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 10                    | NOEC (Survival) | 17                  | 10                   | 48                                       |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 14                    | NOEC (Survival) | 17                  | 10                   | 48                                       |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 10                    | LOEC (survival) | 17                  | 13                   | 63                                       | 27                               |            |
| *Ceriodaphnia dubia* (Water flea) | 10                    | LOEC (reproduction) | 17                  | 4                    | 19                                       |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 7                     | LOEC (survival) | 17                  | 13                   | 63                                       |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 7                     | LOEC (reproduction) | 17                  | 4                    | 19                                       |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 14                    | LOEC (survival) | 17                  | 13                   | 63                                       |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | 14                    | LOEC (reproduction) | 17                  | 4                    | 19                                       |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | -                     | Chronic Value | 20                  | 14                   | 58                                       |                                  |            |
| *Ceriodaphnia dubia* (Water flea) | -                     | NOEC (survival) | 22                  | 19                   | 73                                       |                                  |            |
| **Daphnia pulex (Water flea)** | 21                    | NOAEL (reproduction) | -                   | 0.003                 | -                                        |                                  | USEPA(1980, 1985, 1996, 2001) |
| **Daphnia pulex (Water flea)** | 14                    | LOEL (reproductive impairment) | 230                | 0.2                   | 0.1                                      | 0.1                              | Elnabarawy et al.(1986) |
| **Daphnia pulex (Water flea)** | 70                    | NOEC (GRO) | -                    | 2                    | -                                        |                                  | ANZECC and ARMCANZ(2000b) |
| **Daphnia pulex (Water flea)** | 70                    | NOEC (Mortality) | -                   | 2                    | -                                        |                                  | ANZECC and ARMCANZ(2000b) |
DISCUSSION

The EPCs of Cd were presented by US EPA, Australia, New Zealand, Canada, EC, and the Netherlands. The acute EPC was only suggested 2 µg/l in national recommended water quality criteria of US EPA (USEPA, 2009). Other
international EPCs was presented as chronic value including 0.25 µg/l for US EPA, 0.2 µg/l for Australia and New Zealand, 0.017 µg/l for Canada, 0.19 µg/l for EC and 0.34 µg/l for the Netherland (ANZECC and ARMCANZ, 2000a; CCME, 1999; EC, 2007; USEPA, 2009). EPCs of Canada are derived by multiplying LOEL of 0.17 µg/l for D. magna by safety factor of 0.1 (CCME, 1999). EPC of EC is 0.09 µg/l; derived from 44 chronic toxicity data at 95% protection by EtX software, dividing by assessment factor of 2. These toxicity data were tested with 19 fish and amphibians, 22 invertebrates and 8 primary producers. The standard value of hardness is 50 mg/l as CaCO3 (EC, 2007). Dutch EPC were derived from statistical distribution method at 95% protection by EtX software and 45 NOEC values includes 14 pisces, 6 crustaceans, 1 annelids, 2 molluscs, 1 rotifera, 2 protozoa, 6 macrophyta, 9 algae, 2 cyanophyta and 2 bacteria (RIVM, 2001). The confidential limits (0.0002–0.4 µg/l) of chronic EPC (0.034 µg/l) calculated in this study were included the range of international chronic EPC (0.017–1.79). However chronic EPC (0.034 µg/l) calculated in this study were more sensitive than US EPA, Australia and New Zealand, EC and the Netherland using the statistical distribution method, except for Canada. Chronic toxicity data of Cd selected from this study were mainly included sensitive crustaceans while these countries have a variety of chronic toxicity data. Therefore we expected lower toxicity value for crustaceans affected deduction of HC5. Recommended technique for deriving the EPC can be applicable to hazardous chemicals. This study would be useful to establish the ecological standard for the protection of aquatic ecosystem in Korea.

ACKNOWLEDGMENTS

This work was funded by the project of Ministry of Environment (MOE) entitled “Implementation of risk assessment (Pb, Hg and Cd) and preparation of establishment plan for risk management”.

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