Toxics **2014**, *2*, 346-363; doi:10.3390/toxics2020346

OPEN ACCESS

toxics

ISSN 2305-6304

www.mdpi.com/journal/toxics

Article

Environmental Risk Communication through Qualitative Risk Assessment

Sabre J. Coleman [†,*] and David M. Zalk [†]

Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94551, USA;
E-Mail: zalk1@llnl.gov

[†] These authors contributed equally to this work.

* Author to whom correspondence should be addressed; E-Mail: coleman2@llnl.gov;
Tel.: +1-925-422-3430; Fax: +1-925-423-8049.

Received: 21 February 2014; in revised form: 13 May 2014 / Accepted: 29 May 2014 / Published: 19 June 2014

Abstract: Environmental analysts are often hampered in communicating the risks of environmental contaminants due to the myriad of regulatory requirements that are applicable. The use of a qualitative, risk-based control banding strategy for assessment and control of potential environmental contaminants provides a standardized approach to improve risk communication. Presented is a model that provides an effective means for determining standardized responses and controls for common environmental issues based on the level of risk. The model is designed for integration within an occupational health and safety management system to provide a multidisciplinary environmental and occupational risk management approach. This environmental model, which utilizes multidisciplinary control banding strategies for delineating risk, complements the existing Risk Level Based Management System, a proven method in a highly regulated facility for occupational health and safety. A simplified environmental risk matrix is presented that is stratified over four risk levels. Examples of qualitative environmental control banding strategies are presented as they apply to United States regulations for construction, research activities, facility maintenance, and spill remediation that affect air, water, soil, and waste disposal. This approach offers a standardized risk communication language for multidisciplinary issues that will improve communications within and between environmental health and safety professionals, workers, and management.

Keywords: environmental risk assessment; risk communication; control banding; environmental analyst; environmental and occupational risk management; qualitative risk assessment; risk level based management system

---

1. Introduction

The Environmental Analyst (EA), who is responsible for ensuring that facilities comply with environmental regulations for air, water, wastewater, hazardous materials and hazardous waste by providing guidance and support to the facility's staff, is often hampered in communicating the risks of the effects of substances on the environment due to the myriad of regulatory requirements. The environmental regulations in each of the 50 states in the United States (US) must be as stringent as the federal environmental regulations; however, these regulations can be more stringent than federal regulations and different from those in other States. The same is true for local environmental regulations. EAs must take into consideration the intertwined federal and state regulations, multiple local jurisdictions, as well as internal requirements and sustainability goals. At Lawrence Livermore National Laboratory (LLNL), which is one of the Department of Energy's National Nuclear Security Administration's research and development (R&D) laboratories, the variety of activities that occur on the one square mile main site and an approximately 17 square mile remote site provides an opportunity to demonstrate the applicability and effectiveness of novel approaches for environmental compliance communication. LLNL has an Environment, Safety, and Health (ES&H) directorate that provides comprehensive support directly to its workforce through its two ES&H teams that offer the services of industrial safety, industrial hygiene, radiation protection and environmental professionals and technicians working together in a multidisciplinary format. Each of the ES&H disciplines also has a working group that develops procedures, protocols, and regulatory documentation necessary to ensure compliance.

The Industrial Hygiene working group at LLNL uses a qualitative, risk-based control banding strategy for the assessment and control of all hazards that are tied to regulatory requirements. The development of a comparable strategy for a standardized approach to environmental contaminants could provide the necessary improvement of risk communication for EAs, even within LLNL, which is fraught with overlapping and complicated requirements that affect multiple environment, safety, and health (ES&H) disciplines. The variety of activities and consistently changing hazards at LLNL requires an easy, logical, and consistent method of communicating environmental risk within R&D, facility operation and maintenance (O&M), construction, demolition, and emergency response work processes. In addition, LLNL is ISO 14001 and OHSAS 18001 certified and is currently working toward ISO 9001 certification. A multidisciplinary ES&H risk management would complement these certifications. Integrating this qualitative environmental component with the LLNL occupational health and safety management system (OHSMS), which uses similar qualitative control banding, is a logical step.

1.1. Control Banding

Control banding (CB) is a qualitative occupational risk assessment strategy developed as a simplified approach to reduce work-related injury and illness [1,2]. This model presents a complementary, graded approach that provides an effective means for determining standardized responses and controls for common work-related issues, including environmental issues that take into account the level of risk. The banding of occupational risks began in the 1980s for explosives events, radiation, lasers, and biological agents and in the early 1990s the qualitative risk assessment process of CB was developed to control potential chemical exposures to workers in the pharmaceutical industry [1,3]. Beginning in the 2000s, CB models for chemical agents became internet-based and their popularity grew in the Industrial Hygiene profession internationally. Towards the end of that decade, CB became an essential component for assessing and controlling exposures in the nanotechnology industries, as it was a logical and proven approach to utilize in the absence of occupational exposure limits and regulations [4,5]. In this decade, multidisciplinary CB strategies have begun being designed for integration within a proven OHSMS with the goal of providing an environmental and occupational risk management (EORM) approach [6,7]. This environmental CB strategy has been designed to complement an existing Risk Level Based Management System (RLBMS) that is currently implemented for occupational safety, hygiene, and health [6].

In addition to the RLBMS, there is another national ES&H initiative emerging in the US that can also benefit from an environmental CB strategy. The US Occupational Safety & Health Administration (OSHA) has adopted the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) that resulted in the replacement of the Material Safety Data Sheet with the more comprehensive Safety Data Sheet (SDS) that is being used worldwide [8]. There are standard pictograms and text within a SDS; provided in 16 sections. Section 12 is entitled "ecological information" and section 13 is entitled "disposal considerations." All of the information on a SDS is very useful, but the information in sections 12 and 13 is particularly useful to EAs. The new SDS format and the international standardization of hazard identification that GHS is bringing to the global workforce is an excellent start toward simplifying risk communication. The EAs at LLNL also see the more recent GHS implementation in the US as an opportunity to improve the interdisciplinary communication in a manner that is beneficial to its workforce. The overarching goal of developing a holistic EORM at LLNL is the development of a process for delineating environmental risk as part of a qualitative risk assessment that affords clear and consistent risk communication as part of its output. The accomplishment of this goal at a highly regulated large facility, like LLNL, would demonstrate that the development of an environmental CB model is flexible and can be implemented both nationally and internationally.

1.2. Banding the Components of Environmental Risk

Banding environmental risk requires delineating a graded approach for the factors that are tied to regulatory expectations of controlling this risk. The RLBMS model consistently addresses this within four levels of risk for each of the ES&H disciplines. There are some US OSHA requirements in the Code of Federal Regulations (CFR) that lend themselves well to delineating these four risk levels (RLs), such as asbestos (29 CFR 1910.1001) and lead (29 CFR 1910.1025), but other hazards might require the combination of multiple factors to provide a method for identifying appropriate controls for these RLs [2,6]. This method treats risk as an outcome of the combination of probability of occurrence with the severity of the hazard. In a commonly utilized risk management approach, the probability and severity (or environmental consequence) is graded and put into a risk matrix model that has as the outcome a commensurate RL and control (as demonstrated in Table 1).

Table 1. Three factors affecting the probability of contamination of the environment.

Probability Level	Quantity		Location		Hazardous Characteristics		
	<RQ	≥RQ	Controlled	Inadequate & Uncontrolled	Regulated Material/Waste	Environ. Permit	EMP Goal
P1	✓		✓				✓
P1	✓			✓			✓
P2	✓		✓		✓		
P2	✓		✓			✓	
P2		✓	✓				✓
P2		✓		✓			✓
P3		✓	✓		✓		
P3	✓			✓	✓		
P3		✓	✓			✓	
P3	✓			✓		✓	
P4		✓		✓	✓		
P4		✓		✓		✓	

Groupings of Severity: Long-term environmental damage (reportable), e.g., large amounts of bio-accumulative material or contamination of groundwater—extensive remediation with high cost, multi-agency involvement; Short-term environmental damage or short-term effect (reportable), e.g., small fish kill—minor remediation with low cost, single-agency involvement; Short-term environmental effect (non-reportable event)—not immediately reportable to a federal, state or local regulatory agency), e.g., discharge of chlorinated potable water into storm drain system that discharges into navigable waters—no remediation; Minimal environmental damage, e.g., discharge of potable water or low conductivity water onto soil—event is considered a nuisance event and with minimal to no damage to the environment.

By using a CB approach in environmental risk management within the same RLBMS framework utilized by the health and safety professionals, EAs can more quickly identify which activities require more scrutiny and provide additional time and resources to those with a higher risk [6,9]. Those activities with a lower risk can be controlled and managed through documented ES&H training and established procedures. Like many other large facilities, LLNL has a comprehensive long-standing program to document and provide reminders for ES&H Training and there are standard operating procedures in place to set expectations in field practice. By using a graded approach and banding environmental risk with commensurate control outcomes, there is the potential to optimize the use of all the ES&H resources available. The intent is to present an effort toward developing an overall CB strategy that is a balanced and consistent approach that does not increase day-to-day costs of environmental oversight, while simultaneously providing a qualitative methodology for EAs to consistently assess hazards and ensure better communication of environmental risk. This approach is useful in the compliance with US regulations. CB modeling is allowed by regulation to be used for Industrial Hygiene application in a Tier 1 exposure assessment as a first step in the prioritization or filtering of projects in compliance with the European Union regulation on Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) requirements and in identifying problematic activities with substances of very high concern. Similarly, an environmental risk-based prioritization can be utilized as part of a decision analysis with multiple input criteria as part of a decision analysis that yields the higher risk activities that require further quantitative risk assessment evaluation for authorization and restriction requirements under REACH, waste stream issues outside of REACH requirements, and with other regulations that mandate a quantitative assessment. In this manner, CB modeling would help bin those projects that require more extensive EA involvement from those that can be initially addressed by others using procedures, checklists, and examples that have been prepared by a given facility's EAs. The EAs then could incorporate their professional input for higher risk activities during the review of the final results. In total, the intent is to put forward a qualitative risk management tool to increase the efficiency of the available ES&H resources.

2. Methods

Risk, as a two-dimensional concept, involves probability and consequence [10]. Therefore, the initial steps for developing an environmental CB strategy require consideration for each given hazard of the probability of an adverse outcome and the factors that delineate the levels of severity for the hazard. In order to develop this CB strategy for environmental hazards, our method first begins with a clarification of probability of occurrence in an environmental context and the resulting input parameters. The probability of contamination of the environment is based on three factors (as shown in Figure 1):

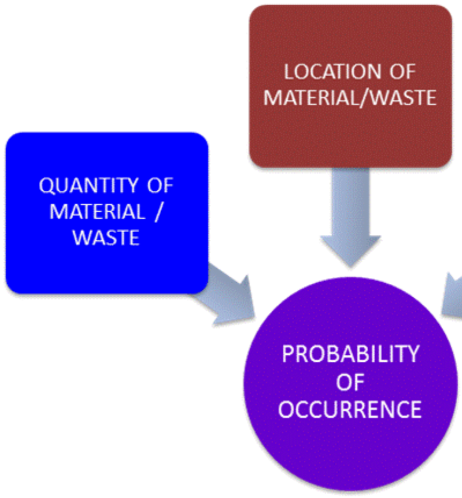
(1) The quantity of the material used in the specific activity or R&D project (quantity);
(2) The location of the activity using the material/waste, and the engineered controls and/or administrative controls in place to protect the environment (location);
(3) The hazardous characteristics of the material, including radioactive characteristics.

The quantity of the material used can be placed into two groups: quantities that are below the regulatory Reportable Quantities (RQ) set by the US Environmental Protection Agency (EPA) for the material or waste (40 CFR Part 302)) [11] or do not have an RQ, and quantities that meet or exceed RQ levels or exceeds an environmental regulatory permit condition. Each regulated material is assigned its own RQ. For example, the RQ for mercury is one pound (0.454 kg), the RQ for trichloroethylene is 100 pounds (45.4 kg), the RQ for sulfuric acid is 1000 pounds (454 kg), and the RQ for acetone is 5000 pounds (2270 kg). The basis for the US EPA regulations that determine RQs is similar to the mandated REACH information requirements by tonnage (≥1, ≥10, ≥100, and ≥1000). Both are based on the potential for serious adverse affects.

The location of the activity using the material/waste is either uncontrolled from an environmental risk point of view or is in an area with engineered controls and/or administrative controls that are in place to protect the environment. Engineered controls are those physical barriers or devices that are in place to protect the environment. Examples include floor drains within a building that are plugged to prevent discharge to the sanitary or storm sewers; material or waste placed within a HEPA filtered enclosure that is designed to mitigate exposure; or if outside, a non-volatile liquid material within a berm that has the capacity to hold 100% of the material and the rain from a 25-year storm.

Administrative controls include environmental training courses or certifications, general environmental guidance available through ES&H manuals or procedure, and on-the-job training.

Figure 1. The three factors affecting the probability of contamination of the environment.



Hazardous characteristics for this model are based on understanding environmental regulatory requirements (e.g., 40 CFR Part 261: Identification and Listing of Hazardous Waste and the State of California Code of Regulations (CCR) Title 22 Social Security, Division 4.5: Environment) [12], using manufacturers' prepared GHS SDSs for each specific hazardous material, using industry standard references [13,14], knowing the environmental permit requirements, and the facility's ISO 14001 Environmental Management System. The hazardous characteristics used in determining the level of risk are:

(1) Environmental hazard classification, listed from those materials or waste causing the most negative risks to the environment to those that there is some scientific debate whether there is a negative risk to the environment. Nonetheless, for each of these materials or waste, their management and disposal are regulated in the United States.

   a. Classification as an acutely or extremely hazardous material/waste by the federal government, *i.e.*, the Resource Conservation and Recovery Act P-List published by the US EPA (Title 40 CFR Part 261, Subpart D, Section 261.33) [15] or a State (e.g., 22 CCR Division 4.5: Environment) [15];
   b. Classification as a hazardous material/waste by the federal government, *i.e.*, the US EPA (40 CFR Part 261, Subparts C and D) [15] or the State, e.g., California, including:

      i. Classification as a material that bio-accumulates in the environment, e.g., lead, as noted in Section 12: Ecological information given in a GHS SDS;
      ii. Documented aquatic toxicity that has a lethal concentration of 50 percent, e.g., in a 96-hour period as noted in Section 12: Ecological information of a GHS SDS;

   c. The material is classified as a greenhouse gas (e.g., sulfur hexafluoride).

(2) Use of the material or generation of the specific waste requires an environmental permit (e.g., asbestos removal from the local air regulatory agency)

(3) The use of the material is noted within an Environmental Management Plan (EMP) of the Environmental Management System (EMS) for the facility and a goal within an EMP is a decreased use or generation over time

Taken together, as seen in Figure 1, these three factors—quantity, location, and hazard characteristic—determine the methods necessary to address the probability of occurrence within an Environmental CB model. In order to line-up this approach with other existing CB models in use at LLNL, four input categories emerge, which results in four environmental Probability Levels. Delineating the probability of environmental contamination in this implementation of the graded approach requires an appropriate weighting of each of the probability input factors in each of the four Probability Levels (as shown in Table 1).

Probability Level 1 (P1) denotes extremely unlikely—the quantity of material/waste does not have a RQ or is less than its RQ, it is in either a controlled or uncontrolled location, and has a quantitative value within an EMP that dictates its use and/or disposal or there is no known or suspected adverse effects to the environment.

Probability Level 2 (P2) denotes less likely—the quantity of material/waste is less than its RQ, it is in a controlled location, and/or its management is explicit within an environmental permit or the quantity of material/waste is greater than its RQ, it is in either a controlled or uncontrolled location, and the quantitative value within an EMP that dictates its use and/or disposal is also greater than its RQ.

Probability Level 3 (P3) denotes likely—the quantity of material/waste is equal to or greater than its RQ, it is in an inadequately controlled or uncontrolled location, and its management is explicit within an environmental permit; or the quantity of material/waste is less than its RQ, it is in a controlled location, and has a specific environmental hazardous regulation governing its use and/or disposal.

Probability Level 4 (P4) denotes extremely likely—the quantity of material/waste is equal to or greater than its RQ, it is in an inadequately controlled or uncontrolled location and has a specific environmental hazardous regulation or permit condition governing its use and/or disposal.

The aforementioned Probability Levels are used to demonstrate the probability of contamination of environment risk. The three input factors, and how they are considered within each of the Probability Levels, are shown in Table 1 for each combination of the three input factors. Once the three input factors are assessed in Table 1, the outcome Probability Level will become the input on the probability axis in the environmental CB risk matrix in Table 2.

The graded approach for the four levels of severity, or environmental consequence, is therefore tied directly to potential damage to the environment and is based on the effects of the material or contaminant on the environment. This component is assessed and the appropriate selection of the four levels will become the input on the severity axis in the environment CB risk matrix in Table 2. For this model, severity is grouped into four categories:

Table 2. Environmental risk matrix.

Severity (Consequence to the Environment)		**PROBABILITY**			
		Extremely Unlikely (P1)	**Less Likely (P2)**	**Likely (P3)**	**Extremely Likely (P4)**
	Long-term damage (reportable)	**RL3**	**RL3**	**RL4**	**RL4**
	Short-term damage (reportable)	**RL2**	**RL2**	**RL3**	**RL4**
	Short-term damage (non-reportable)	**RL1**	**RL1**	**RL2**	**RL3**
	Minimal damage/Nuisance/Not immediately reportable event	**RL1**	**RL1**	**RL1**	**RL2**

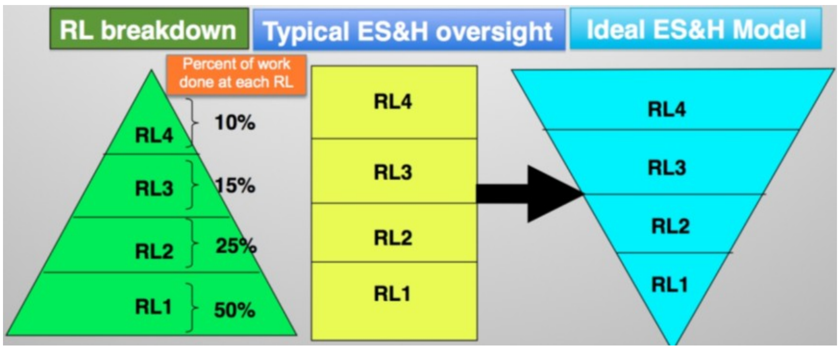
Control Outcomes: **RL1**: Administrative controls (e.g., policies, procedures, checklists, *etc.*) only; **RL2**: Basic Engineering (e.g., physical barriers like secondary containment, filtration systems, *etc.*) and Administrative controls; **RL3**: Requires EA involvement for a documented review and signature with controls specified; **RL4**: Complex work for EA evaluation, often requiring other ES&H disciplines.

Environmental Risk Matrix

This method for using the input factors for both the probability of contaminating the environment and the severity, or consequence to the environment, affords the necessary criteria for developing an environmental CB risk matrix presented in Table 2. It employs a relative ranking approach across the four RLs, with RL4 denoting the highest risk and RL1 the lowest risk. In keeping with the CB models used at LLNL, the graded approach for this standardized environmental risk matrix is also stratified over four RLs to correspond with the Control Outcomes necessary for ensuring regulatory compliance.

Even though LLNL's R&D focus would appear to contraindicate the utility of a simplified risk matrix process, due to its high variability in day-to-day operations, the application of a CB approach has been found to be appropriate for Industrial Hygiene. As seen in Figure 2, the RL breakdown on the left side presents the approximate percentage of work activities performed for each RL at LLNL. Therefore, it can be estimated that approximately 25% of the activities performed are in the highest risk categories, RL3 and RL4. The need for an environmental CB approach is the same as for the other ES&H disciplines. In the absence of this standardized CB methodology, the ES&H disciplines tend towards prioritizing each RL the same. The outcome is that events with very different consequences and probabilities receive the same amount of ES&H effort.

Figure 2. Risk level approach to EA oversight *vs.* current EA oversight.



Prioritization using the RLBMS approach maximizes ES&H resources, including EA effort and time to focus on the highest RL outcomes. Moving away from the typical approach that randomly spreads resources by regulatory demands and deadlines, a more efficient ES&H model emerges that benefits the workplace as a whole.

3. Results

The environmental CB methods described above have been applied at LLNL in various areas to determine the utility of an environmental risk matrix. This banding of environmental risk and control outcomes has been assessed using a variety of traditional environmental scenarios to investigate its applicability for environmental RL implementation and effectiveness for use in the workplace.

3.1. Examples of Generic Environmental RL Implementation

To demonstrate the implementation of the environmental RL concept using a CB approach, two common scenarios follow: soil disturbance and waste generation.

3.1.1. Soil Disturbance

The characteristics of the soil and the material involved with a project will determine the environmental RL of disturbance. The first example is the installation of a utility vault in uncontaminated soil using established procedures. The soil is controlled and there is no contamination. This project has a Probability Level of 1 (P1). The severity, or consequence, of the project as managed is expected to have minimal damage. Using the Environmental Risk Matrix shown in Table 2, the Risk Level is RL1. Thus, the existing administrative controls can govern the activity and oversight and review by an EA is not warranted.

The second example is a project that removed an abandoned underground leaking chemical processing pipeline. The leaking material was characterized as hazardous. In this example, the project is controlled; however there is contamination. Using the probability input factors, this project would be considered a P3. In considering the severity input, the fate and transport of the leaking material is such that there is potential for long-term damage. The control outcome is RL4 and this complex work would require an EA to work with other ES&H disciplines as well as the project management team.

3.1.2. Waste Stream Generation

Most projects generate some type of waste and the types and quantities are as varied as the projects. For the first waste stream example, spent gloves were worn in an analytical laboratory for protection from small quantities of solvents (isopropyl alcohol and acetone). The spent gloves are uncontaminated. The probability outcome would be P3 because the experimenters are working in a controlled location with a hazardous material. However, the severity consequence would be considered minimal damage. Thus, the control outcome is RL1—administrative controls.

For the second example, a small 16-ounce container of an adhesive, which is permitted by an air regulatory agency, is used to repair a piece of equipment located outdoors. Not all the adhesive is used for the project and the remainder must be disposed. The activity is performed under a standardized operating procedure. The probability outcome is P2 because it is a controlled activity with a permitted material. The severity consequence would be a reportable event because if the adhesive is not managed properly, a report must be made to the environmental oversight agency. In this case, the control outcome is RL1. Again, the administrative controls that are mandated are sufficient environmental controls.

3.2. Research and Development Applications

As indicated above in Figure 2, approximately 75% of the projects at an R&D facility that affect the environment can be considered standardized work as determined by the Industrial Hygiene working group. Nonetheless, this standardized estimation can be challenging for EAs as experiments are often short-term, have unique processes, formulate new materials, and the activities constantly change. This differs greatly from manufacturing and production facilities, where standard processes are necessary to ensure the quality of the product during the production of a steady quantity of materials.

Thus, R&D provides unique challenges for determining both probability and severity for an environmental contaminant because of the aforementioned attributes and because there may not be an SDS, or toxicological data available. However, by using the information used for materials with similar characteristics an estimation of environmental risk can be ascertained. Two examples follow: the first is for a relatively new material and the second is for a material commonly used in analytical laboratories.

3.2.1. Explosive Waste Residue

Small amounts of explosive waste residue may not be reactive, but in some cases less than 1% is characterized as an aquatic toxin, which can cause short-term damage to the environment. When generated in small quantities in a controlled location, using the CB approach, this scenario has a Probability Level of P2. This scenario was initially classified as an RL3 and required EA review. However, once the bounds of the severity potential were better understood, it was classified as an RL2 with the establishment of basic engineering and administrative controls. Even with an RL2 classification, it still warranted the EA working closely with the researchers at the start of the project to ensure that there is an understanding of the environmental risk and the necessary controls. However, once the project was underway, there was still need to have periodic oversight of the experimental activities to ensure the established engineered and administrative controls to protect the environment remained consistently in place.

3.2.2. Isopropyl Alcohol Used for Wipe Cleaning

Many R&D laboratories use isopropyl alcohol in small squeeze bottles for wipe cleaning. A small amount spilled would have minimal damage to the environment. When generated in small quantities in a controlled location, e.g., wipes used with a small amount of isopropyl alcohol and are dry at the end of wipe cleaning (*i.e.*, not characterized as hazardous waste due to damp or saturated wipes), using the CB risk matrix approach, this scenario has a Probability Level of P2. This scenario is an RL1. In this case, the EA can rely on the administrative controls since the risk to the environment is at the lowest level. Now that the bounds are clearly understood by the workers for this commonly performed task, this activity can be considered RL1 wherever and whenever it occurs at LLNL.

3.3. Facility Operation and Maintenance Applications

There are a variety of hazardous materials used and waste generated during O&M activities. Petroleum products and synthetic oils are used as fuel and lubricants in equipment and controls for their use need to be clearly understood and applied wherever they are used.

Oil-Filled Equipment

Many large pieces of equipment used outdoors for O&M have large reservoirs of hydraulic oil (e.g., wood chippers, or reservoirs of oil in a large transformer). If during O&M, a hose broke or a gasket cracked, there could be long-term damage to the environment. If there were inadequate or no controls in place and more than 42 gallons could be released, then the Probability Level would be P4. This scenario is a RL4. If the O&M staff were to work with the EAs and engineered and/or administrative controls were put into place, the Probability Level could be reduced to a P3 and the event would be "reportable" according to the CB risk matrix. Now the scenario would be RL2. This type of activity provides a concise example of how the simplified risk communication aids both ES&H and O&M with a clear understanding of the benefit of reducing the Probability Level in advance of the activity by working proactively with the EA.

3.4. Demolition Applications

At a demolition site, there is a potential for the generation of high volumes of waste, which may be hazardous. Additionally, storm water run-off and soil contamination are always a concern. There are wastes generated that can have serious human health concerns due to long-term injury or illness, but according to literature these materials do not have the same level of risk to the environment. Additionally, environmental regulations by local enforcement agencies for the same material can differ from each other although risk to the environment is the same. This is reflected in the following example.

Asbestos Removal

Local air management regulatory agencies have varying permit requirements for asbestos removal projects and can have differing definitions of "large" projects. The CB approach can be used regardless of the specific regulation. At LLNL's Livermore Site, the Bay Area Air Quality Management District mandates permits for the removal of friable asbestos containing materials in amounts greater than 100 square feet, 100 linear feet, or 35 cubic feet; smaller projects are covered by the Bay Area Air Quality Management District site-wide umbrella permit [16]. Whereas at LLNL's Site 300, the San Joaquin Valley Air Pollution Control District mandates permits for the removal of friable asbestos in amounts greater than 160 square feet, 260 linear feet, or 35 cubic feet; smaller projects are covered by the San Joaquin Valley Air Pollution Control District site-wide umbrella permit [17]. Friable asbestos is characterized as hazardous waste; however, non-friable asbestos is not characterized as hazardous waste. If non-friable asbestos containing material enters into the environment (e.g., placed on soil), the effects on the environment would be minimal. If the demolition project was permitted and controls were in place, it would have a Probability Level of P2. This scenario would be a RL1. Now changing the scenario and instead of non-friable asbestos, friable asbestos (a hazardous waste) were placed onto soil outside of an appropriate container, the Probability Level would be P4 and it would be a Reportable Event. (The US regulatory RQ for asbestos is one pound.) The Risk Level would be RL3. Once again, this differential is much easier to discuss with construction contractors when using the input parameters of the environmental CB risk matrix than using the differing regulatory requirements for asbestos containing materials.

3.5. Emergency Response Applications

Using a risk-based approach would help with planning and response to a variety of scenarios. Examples of the use of this approach in preparing for small and large emergencies follow.

3.5.1. Small Scenario

Similar to the example presented in the facility discussion, consider an outdoor demolition site where friable asbestos (a hazardous waste) is generated and placed directly onto soil (*i.e.*, no container): The Probability Level would be P4 due to inadequate controls of a hazardous waste. This would be a Reportable Event if not immediately cleaned-up. The control outcome would be RL3. Prior to the start of the project, the construction manager and appropriate staff should work with the EAs to ensure that the appropriate controls are in place to mitigate the potential for this scenario.

3.5.2. Large Scenario

An isolated, large transformer has a major leak and 1000 gallons of transformer oil is released into the environment. The location of the transformer is near a storm sewer system that flows into navigable waters. The Probability Level is a P4 for the environment, even though it may be at a lower level for human health. Short-term damage is the severity input for the consequence to the environment. Thus, the control outcome would be RL4. It is cost-effective to have staff work with the EA to ensure that engineered and/or administrative controls are put into place and the established risk assessment formally documented. The monetary savings for avoiding this potential outcome can certainly be calculated, but the costs associated with damage to the facility's reputation and the trust of the nearby communities that may use the navigable waters can be thought of as equally important and should also be considered. This type of outcome consideration is one that can be deemed a differential between the bases of an OHSMS and EMS and therefore can also be seen as a value-added benefit of the inclusion of an environmental CB strategy within the RLBMS.

4. Vetting Process

In order to ensure that an Environmental CB approach would work in line with professional EA expert opinion, recent real-life examples were presented as seen in Table 3. Five EAs (out of six on staff) who are members of the ES&H teams independently reviewed each of the scenarios listed in Table 3 to determine their probability and severity input factors in the absence of the risk matrix RL outcomes. The EAs then met to verbally discuss the potential environmental severity of the event outcomes and then the probability of impact outcomes for each scenario. With each of their severity and probability components vetted, the EAs were able to utilize the risk matrix to assist in forming a consensus on which category would be considered appropriate. This consensus was achievable because the initial differences in their expert opinions were small and the severity and probability choices in the risk matrix assisted in readily calibrating each of their expert opinions. Then, the agreed severity and probability input parameters were entered into the risk matrix to reveal the RL outcomes and EAs found them in line with what would be their independently determined expert opinion. The final outcome of this vetting process was extremely positive as the resulting RLs for each of the scenarios were consistently derived from appropriately delineated risk matrix input parameters for probability and severity categories and the overall process was characterized in line with professional opinion [18].

Table 3. Scenario examples vetted by EAs.

Scenario	Severity of Consequence to the Environment *	Probability				Risk Factor
		Extremely Unlikely (P1)	Less Likely (P2)	Likely (P3)	Extremely Likely (P4)	
R&D with 100 ml hydrochloric acid (an EH) in a hood with a secondary tray under the container	Minimal	X				RL1
Chlorinated water release (violates facility's storm water permit)	Minimal		X			RL1
Outdoor grinding of aluminum	Short-term damage (non-reportable)	X				RL2
Two-gallons of hydraulic oil release from outside construction equipment	Short-term damage (non-reportable)			X		RL2
Fork-lift fire in a hazardous waste Treatment, Storage, & Disposal Facility that triggers the contingency plan	Short-term (reportable)		X			RL2
Fueling of an outside emergency generator that has a single-walled diesel fuel tank with a 100 gallon capacity (exceeds the RQ for diesel fuel)	Short-term (reportable)			X		RL3
Lead-paint removal on the outside of a transportainer—no controls	Short-term (reportable)				X	RL4
Historical contamination of mercury discovered during excavation	Long-term damage (reportable)				X	RL4

* Choices for Severity of Consequences are: Long-term environmental damage (reportable); Short-term environmental damage (reportable); Short-term environmental damage (non-reportable); Minimal environmental damage/Nuisance/Not immediately reportable event.

5. Discussion

Environmental CB is a means to collect and use all the available resources effectively to assess and communicate environmental risk consistently. The benefits of this RLBMS method for EAs include a consistent qualitative standardized approach that incorporates the applicable environmental regulatory requirements into both the risk matrix and its outcomes. In addition, it also has the benefit of including the specific facility's administrative and engineered controls as well as ES&H training into the decision-making process while simultaneously coupling with or integrating into an existing OHSMS [19–21]. At LLNL, this has a synergistic benefit in that the existing OHSMS already uses CB.

Therefore, an expansion that incorporates a complementary environmental CB risk management system would mean a holistic EORM system that in all aspects of ES&H utilize CB in a manner that provides a singular risk communication language that is beneficial for discussions within and between workers as well as our multidisciplinary ES&H teams [20,21].

The EA input helped complete the probability table and the process for vetting evolved organically. Rather than relying on each individual EA to develop their own risk level outcomes, it was more important to establish that the categories for probability and severity of the consequence were clearly delineated. The EAs ensured that the examples given ranged across the spectrum given for the severity of the consequence. The agreement was that the categories would be modified to reach consensus using the more than 100 person-years of experience and knowledge of regulations that EAs possess. The only modifications that resulted from this collaboration were the descriptor of the severity categories was changed to reflect reportable *vs.* non-reportable scenarios and additional combinations of factors are shown in Table 1. Nonetheless, the input factors for each of the categories remained the same. This process helped to confirm that environmental CB can be used to assist in EA resource allocation and communicate risk to laymen.

The main strength of an environmental CB is that it is a flexible, simplistic qualitative approach that is malleable to meet the needs of a variety of projects and activities that have the potential to cause environmental damage. Specifically, it affords the users the ability to make environmental risk-based decisions regardless of the environmental regulatory arena, risk-tolerance perceptions that are in place, and public's interface with the facility—both with governmental agencies and private companies. In addition, there is an inherent benefit in using an environmental CB model that does not dictate quantitative limits; it works as well in California as in New York or anywhere else in the US. Therefore, it has the potential to present comparable benefits in other countries. So, perhaps this singular risk communication approach presented by the RLBMS can find utility with regulations implemented by the US EPA, like GHS. Its potential for assisting multinational companies should also be explored as this model presents a graded risk approach for prioritizing quantitative risk assessments utilizing limited ES&H resources in finding compliance with REACH, as well as with waste stream requirements outside of REACH, which use environmental chemical risk as a factor within the regulations. Another significant attribute is that this risk matrix approach mirrors CB for occupational risks, providing a comprehensive risk assessment process for ES&H with a common risk communication language and clear and standardized optimization of resources.

Environmental CB can also be seen as having potential weaknesses and the input and considerations of this proposed model from a broader EA national and international professional audience is essential. A potential limitation of qualitative CB is the higher degree of subjective interpretation. To decrease variability, the environmental CB model must be clearly presented, documented, and vetted by the facility's EAs. There are a number of RL outcomes that rely on the expertise and knowledge of the EAs, so having the availability of professional environmental expertise will still be necessary. Additionally, persons using the environmental risk matrix will require some aspect of training to become familiarized with the input factors and the potential workplace variations that might occur and necessitate interpretation or additional assistance. These instances can also occur with the specificity of environmental regulations and permits as well as relating to the requirements for ES&H training and as they may affect existing procedures within a given facility. Most importantly, as emphasized in the examples of potential issues described above, an environmental CB strategy should not be considered as a one-size-fits-all solutions approach for all industries and applicable to all national regulations. Environmental CB and its role within an RLBMS can be considered an important first step towards a clear and consistent risk communication strategy that, first and foremost, is a helpful assistance for workers to understand the intricacies of environmental protection in the workplace. The basis for this qualitative risk assessment process is provided so, although as the individual facility must tailor it to its needs, this can also be construed as a strength.

This environmental CB model is a new concept and future research on the topic is essential. To reach its full potential, other environmental professionals need to validate its use in real-life scenarios and provide suggestions for improvement, e.g., should extremely hazardous materials or waste be considered when evaluating the quantity input factor. The input factors and resulting outcomes need to be evaluated as part of a pilot qualitative risk assessment program and the results compared to comparable environmental quantitative models [10]. Additionally, the environmental CB model should be tested at a larger scale facility with an ISO 14001 certified EMS program to determine if it stands as is or requires modification to be in line with EMS expectations. Further, this new method should also be applied in countries outside the US and at a variety of facilities and industrial plants to ensure the method is suitable at a broader range. Ultimately, more research is necessary to confirm the appropriateness of qualitative risk assessment strategies, like the environmental CB model provided here, in the development and implementation of environmental regulations. As with most models, it is not expected to be a fit for every scenario, but it is expected to provide a cost-effective approach in communicating environmental risk.

6. Conclusions

This approach offers a standardized risk communication language for the environmental profession, which is complementary to that which is already in use for OHSMS. It also will be part of a standardized risk communication language for each of the ES&H disciplines that will increase the extent of discussions that can be had within and between material and waste handlers, ES&H professionals, and management. This RLBMS model, with the inclusion of this very necessary environmental component, has an added value in that it supports both OHSAS 18001 and ISO 14001. Although there is further research necessary on the model and its components, the inherent potential for such a model has already been proven with other applications of CB models in the Industrial Hygiene profession. There is an even more important potential within international collaborations and applications for both this environmental CB model and its utility within the RLBMS as part of the global implementation of the GHS. To begin to take advantage of these opportunities, a pilot program at facilities in the European Union could be conducted. In addition, the potential utility of a CB model could be explored as part of an initial qualitative risk assessment that filters out the higher risk processes in line with regulations that require further EA involvement. In this manner, the presented risk matrix model can also be an integral part of a multiple criteria decision analysis and quantitative risk assessment at elevated RLs that could have applications within numerous regulatory requirements. The results could be used to refine and improve the environmental CB model for expansion in the US and other countries. In summary, the opportunities globally for the implementation of a standardized environmental qualitative risk assessment process using CB model with commensurate controls for the environmental profession are significant, as well as for other potential application, implementation, and further research on its strengths and weaknesses.

Acknowledgments

This work, in part, was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, LLNL-JRNL-651186. The authors want to also acknowledge the contributions of Kat Tucker, Joseph Woods, and Vicki Salvo, Environmental Analysts at LLNL, Lisa Crawford (former LLNL Environmental Analyst) of the US Department of Energy Sandia National Laboratory and Richard Michalik (former LLNL Environmental Analyst) of the US Department of Energy Bettis Atomic Power Laboratory.

Author Contributions

Both authors collaborated on the idea that an environmental risk based control banding strategy could be implemented. Sabre J. Coleman wrote the first version of the manuscript, performed the literature review for environmental control banding strategy, lead the vetting process, and co-responded to the reviewers' comments. David M. Zalk provided the initial insight on the potential integration of environmental control banding to complement the existing occupational health and safety risk-based strategy, wrote the text on occupational health and safety risk-based control band strategy, performed the literature review for occupational health and safety control banding strategy, and co-responded to the reviewers comments.

Abbreviations

CB, Control Banding; CCR, California Code of Regulations; CFR, Code of Federal Regulations; EA, Environmental Analyst; EORM, Environmental and Occupational Risk Management; EMP, Environmental Management Plan; EMS, Environmental Management System; EPA, Environmental Protection Agency; ES&H, Environment, Safety, and Health; GHS, Globally Harmonized System of Classification & Labeling of Chemicals; LLNL, Lawrence Livermore National Laboratory; O&M, Operation and Maintenance; OHSMS, Occupational Health and Safety Management System; OSHA, Occupational Safety and Health Administration; P1-4, Probability Levels 1, 2, 3, and 4; R&D, Research and Development; REACH, Registration, Evaluation, Authorisation, and Restriction of Chemicals; RL, Risk Level; RLBMS, Risk Level Based Management System; RQ, Reportable Quantities; SDS, Safety Data Sheet; US, United States.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Zalk, D.M.; Nelson, D.I. History and Evolution of Control Banding: A Review. *J. Occup. Environ. Health* **2008**, *5*, 330–346.

2. Zalk, D.M. *Control Banding*; *A Simplified, Qualitative Strategy for the Assessment of Risks and Selection of Solutions*; TU Delft Publisher: Delft, The Netherlands, 2010; pp. 2–8.
3. Oldershaw, P.J. Editorial Control Banding Workshop, November 4–5, 2002. *Ann. Occup. Hyg.* **2003**, *47*, 531–532.
4. Zalk, D.M.; Paik, S.; Swuste, P. Evaluating the Control Banding nanotool, a qualitative risk assessment approach for controlling nanomaterial exposure. *J. Nanopart. Res.* **2009**, *11*, 1685–1704.
5. Brouwer, D.H. Control banding approaches for nanomaterials. *Ann. Occup. Hyg.* **2012**, *5*, 506–514.
6. Zalk, D.M.; Kamerzell, R.; Paik, S.; Kapp, J.; Harrington, D.; Swuste, P. Risk level based management system: A Control Banding model for occupational health and safety risk management in a highly regulated environment. *Ind. Health* **2010**, *48*, 18–28.
7. Swuste, P. Qualitative Methods for Occupational Risk Prevention Strategies in Safety, or Control Banding—Safety. *Saf. Sci. Monit.* **2007**, *11*, 1–7.
8. United States Occupational Safety & Health Administration. A Guide to the US Globally Harmonized System of Classification and Labelling of Chemicals. Available online: https://www.osha.gov/dsg/hazcom/ghs.html (accessed on 9 February 2014).
9. Zalk, D.M.; Spee, T.; Gillen, M.; Lentz, T.J.; Garrod, A.; Evans, P.; Swuste, P. Review of qualitative approaches for the construction industry: Designing a risk management toolbox. *Saf. Health Work* **2011**, *2*, 105–121.
10. Covello, V.T.; Merkhofer, M.W. *Risk Assessment Methods: Approaches for Assessing Health and Environmental Risk*; Plenum Press: New York, NY, USA, 1993.
11. United States Environmental Protection Agency. Code of Federal Regulations, Title 40, Part 302: Designation, Reportable Quantities, and Notification. Available online: http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr302_main_02.tpl (accessed on 17 February 2014).
12. California Department of Toxic Substances Control. California Code of Regulations, Title 22, Division 4.5: Environment. Available online: http://ccelearn.csus.edu/wasteclass/mod1/mod1_03.html (accessed on 17 February 2014).
13. Lewis, R.J., Sr. *SAX's Dangerous Properties of Industrial Materials*, 12th ed.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2012.
14. Bogen, K.T.; Spear, R.C. Integrating Uncertainty and Interindividual Variability in Environmental Risk Assessment. *Risk Anal.* **1987**, *7*, 427–436.
15. United States Environmental Protection Agency. Code of Federal Regulations, Title 40, Part 261: Identification and Listing of Hazardous Waste, March 4, 2005. Available online: http://www.epa.gov/wastes/hazard/transportation/manifest/pdf/manfst-fr.pdf (accessed on 17 February 2014).
16. Bay Area Air Quality Management District, Regulation 11, Rule 2: Asbestos Demolition, Renovation, and Manufacturing, October 7, 1998. Available online: http://www.baaqmd.gov/~/media/Files/Planning%20and%20Research/Rules%20and%20Regs/reg%2011/rg1102.ashx (accessed on 17 February 2014).
17. San Joaquin Valley Air Pollution Control District. Asbestos Requirements for Demolition and Renovation. Available online: http://www.valleyair.org/busind/comply/asbestosbultn.htm (accessed on 17 February 2014).

18. Hallenbeck, W.H.; Cunningham, K.M. Chapter 2: Exposure Characterization. In *Quantitative Risk Assessment for Environmental and Occupational Health*; Lewis Publishers, Inc.: Chelsea, MI, USA, 1986; pp. 9–18.
19. Ghittori, S.; Ferrari, M.; Negri, S.; Serranti, P.; Sacco, P.; Biffi, R.; Imbriani, M. *Recent Prevention Strategies and Occupational Risk Analysis: Control Banding and Sobane*; G. Ital Med Lav Ergon: Torino, Italy, 2006; Volume 28, pp. 30–43. (in Italian)
20. Zalk, D.M.; Heussen, H. Banding the World Together. *Saf. Health Work* **2011**, *2*, 375–379.
21. United States Department of Health and Human Services Centers for Disease Control and Prevention; National Institute for Occupational Safety and Health. *Occupational Hazards: Qualitative Risk Characterization and Management of Occupational Hazards: Control Banding*; NIOSH: Atlanta, GA, USA, 2009.