# COEUR D'ALENE BASIN RI/FS
# TECHNICAL MEMORANDUM

# A PREDICTIVE ANALYSIS FOR POST-REMEDIATION METAL LOADING

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**October 1, 2007**

United States Environmental Protection Agency

REGION 10

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October 2007

URS

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## ABSTRACT

The predictive analysis is a risk management tool intended to inform decision making for remedy selection in the Coeur d'Alene Basin. It does so by quantifying best estimates of cleanup outcomes along with the uncertainty with which a proposed remedy leads to meeting cleanup goals. The analysis focuses on the six remedial alternatives identified in the Coeur d'Alene Basin feasibility study for the upper and lower Coeur d'Alene Basin, providing forecasts for two specific locations. The first location at Pinehurst reflects remedial activities in the upper basin, and the second at Harrison reflects remedial activities in the lower basin. These forecasts are engineering approximations based on an interpretation and synthesis of available data and informed by expert opinion. Best (mean) estimates of dissolved zinc load ratio at Pinehurst (without the Bunker Hill "Box" included), i.e., zinc load relative to ambient water quality criteria (AWQC), for 100 years after remediation are 7.0, 4.8, 2.2, 1.7, 6.0, and 6.2 for remedial alternatives 1 through 6, respectively. At Harrison, the corresponding load ratios for 100 years are 3.5, 2.6, 1.6, 1.25, 3.2, and 3.1 for remedial alternatives 1 through 6, respectively. Best (median) estimates for meeting AWQC for dissolved zinc (without the Bunker Hill Box included) at Pinehurst are 890, 700, 400, 280, 820, and 845 years for remedial alternatives 1 through 6 and at Harrison are 720, 570, 270, 170, 650, and 675 years for remedial alternatives 1 through 6.

# EXECUTIVE SUMMARY

This memorandum documents the predictive analysis developed to forecast post-remediation metal loading in the Coeur d'Alene River Basin of Idaho. The objective of the predictive analysis is to assess the effect of specific upstream remedial alternatives on downstream metal loadings and to use available information to quantify the certainty with which remedial goals can be met. The predictive analysis also is used to assess the downstream effect of hypothetical metal load reductions in tributary streams and thus to identify the remedial effectiveness required to meet target metal loadings.

This risk management tool is intended to be used in the remedy selection process to compare cleanup efforts. The analysis focuses on the six ecological remedial alternatives identified in the Coeur d'Alene Basin feasibility study for the upper and lower Coeur d'Alene Basin to Harrison. This includes Conceptual Site Model Units 1, 2, and 3, but excludes the Lake Coeur d'Alene (Unit 4) and the Spokane River (Unit 5).

The analysis provides outcome forecasts for two specific locations in the basin (without the Bunker Hill "Box" included): on the South Fork Coeur d'Alene River at Pinehurst, and on the mainstem of the Coeur d'Alene River at Harrison. The former includes remedial activities in the upper basin to Pinehurst, while the latter also includes remedial activities in the lower basin from Cataldo to Harrison. Harrison estimates include all upstream sources and remedial actions, not including the Bunker Hill Box or any remedial actions in the North Fork Coeur d'Alene River.

The results are engineering approximations based on an interpretation and synthesis of available information. While there is a great deal of information on the Coeur d'Alene Basin, the basin is large and complex. Therefore, the results are conditional on the hypotheses and assumptions made in the modeling.

The predictive analysis combines existing information on the basin with scientific understanding of environmental processes, but neither the existing information nor our scientific understanding of environmental processes is perfect. Detailed historical monitoring data on stream flows, levels of contamination, and other environmental conditions are limited for the purposes of analyzing and predicting natural conditions in the basin. This situation is no different from most large river basins. As a result, the scientific and professional judgment of experts is called on to interpret data and to help estimate parameter values, which is now standard practice in scientific and regulatory modeling. This process also introduces uncertainties that the predictive analysis attempts to capture and quantify. However, as the monitoring program continues and a more extensive data base is compiled, the present model and parameter estimates will be refined.

The predictive analysis uses a simple probabilistic approach to capturing uncertainties and propagating their combined effect through to forecasts. Best estimates, standard deviations, and correlations are assessed for the input entering the analysis, and best estimates, standard deviations, and correlations are calculated for the output. The standard deviations associated with the output allow quantitative conclusions to be drawn about the degree of uncertainty in the forecasts.

## CONCEPT OF THE ANALYSIS

The analysis uses a straightforward accounting scheme to sum up the contributions of upstream sources to metal loads in the river downstream. Metal load is taken to be the daily mass of dissolved zinc in the river passing a particular monitoring location. This is used as an index for total metal load. Individual sources contribute dissolved metal to the river system in proportion to their type and size. Ultimately, the analysis converts metal loads to concentrations for comparison with water quality standards.

Two monitoring locations are considered in the analysis: Pinehurst and Harrison. After subtraction of measured adit loads, the analysis ascribes the remaining load at the Pinehurst or Harrison locations to each source type (e.g., waste rock) based on estimates of the proportional "loading strength" and the volume of material of that source type in the basin upstream of the monitoring location.

The effect of remedial actions at the sources is taken into account by modifying the contributions of each source to metal entering the river. The combined effect of each of the six remedial alternatives of Section 1.3 is forecast by aggregating the contributions over all the sources.

Uncertainty in the analysis predictions is estimated by assessing the uncertainty in the analysis input parameters and then propagating those input uncertainties to corresponding uncertainties in the output. This calculated uncertainty in the output is expressed by best estimates (means), standard deviations, and probability distributions.

The effect of source depletion over time is addressed by allowing the loadings generated by the various sources to decay with time in proportion to the amount of remaining leachable metal at any given time in the future. As the source generates loading, the remaining metal mass decreases correspondingly. Thus, even if no remedial actions are taken, the loadings from the various sources decrease slowly.

## ASSUMPTIONS AND PARAMETERS

The principal hypotheses and assumptions of the analysis are that:

- Historical stream data are statistically representative of pre-remediation conditions; that is, data can be used to estimate how much loading is generated by various sources.

- Metal loadings to the river and its tributaries are proportional to source volumes, and load reductions are proportional to remediated volume; that is, the mass of source material is assumed to be proportional to source volume and the effectiveness of remediation in reducing source loads is assumed to be proportional to the mass remediated.

- Loading decays over time based on total remaining metal mass; that is, with or without remediation, as leaching occurs from a source volume, the remaining contaminant mass in the source slowly deplete.

- Source-type relative loading potentials represent volumetric spatial averages; that is, loading potential for a given source type reflects the aggregate effect of loadings and the mix of source types upstream of a monitoring location.

- The effectiveness of a remedial action represents volumetric spatial averages for a given source type; that is, the effectiveness of a given remedial action will vary with the specific sources remediated.

- Deeper aquifer materials are a zinc source; that is, if the zinc loading from deeper aquifer material exceeds that estimated, then for each action alternative, the expected values of the effectiveness of a remedial action may be systematically underestimated.

- Groundwater loadings are accounted for in the source type load potential estimates; that is, impacted groundwater does not affect surface water quality until it discharges to surface water.

- Ambient water quality criteria will not change; that is, it is assumed that the relationships between stream discharge and water hardness will continue into the future, and not be significantly affected by remedial action.

## RESULTS

The analysis was implemented in two versions. The first version analyzes six alternatives identified in the feasibility study based on source-by-source remedial actions. The analysis and results do not include loading contribution from the Bunker Hill Box, which is undergoing remedial action under existing Records of Decision. Post-remediation forecasts of dissolved zinc results were calculated for Pinehurst SF27 and Harrison LC60. Summary results are shown in Tables ES-1 and ES-2.

**Table ES-1**
**Levels of Zinc Load Ratio (Lr) at Pinehurst and Harrison, With Daily Load Relative to AWQC, 100 Years After Remediation**

| Location | Remedial Alternative | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Pinehurst | 7 | 4.8 | 2.2 | 1.7 | 6 | 6.2 |
| Harrison | 3.5 | 2.6 | 1.6 | 1.25 | 3.2 | 3.1 |

**Table ES-2**
**Estimates of Years Required for Post-Remediation Dissolved Zinc loadings at Pinehurst and at Harrison to Meet Ambient Water Quality Criteria as a Function of Remedial Alternative**

| Estimate | Remedial Alternative (years) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| **Pinehurst** | | | | | | |
| Median | 890 | 700 | 400 | 280 | 820 | 845 |
| 10% and 90% bounds | 650-1000+ | 550-1000 | 250-650 | 150-500 | 600-1000+ | 600-1000+ |
| **Harrison** | | | | | | |
| Median | 720 | 570 | 270 | 170 | 650 | 675 |
| 10% and 90% bounds | 650-1000+ | 250-1000+ | 0-750 | 0-650 | 350-1000+ | 350-1000+ |

The second version analyzes "what-if" scenarios that allow input of hypothetical or estimated remediation factors for specific areas of the basin, including major tributaries and reaches of the South Fork Coeur d'Alene River (SFCDR), the upper basin, and Coeur d'Alene River (CDR), the lower basin. These calculations were made for dissolved zinc at the following locations: Canyon Creek, Ninemile Creek, Pine Creek, upper basin (SFCDR at Pinehurst), and lower basin (CDR at Harrison).

## UNCERTAINTY ANALYSIS

The predictive analysis uses a simple probabilistic approach to capture uncertainties and propagate their effect through the analysis. Best estimates, standard deviations, and correlations are assessed for the input parameter values; and best estimates, standard deviations, and correlations are calculated for the output forecasts. Standard probabilistic methods are used to account for the way uncertainties propagate in the analysis. The uncertainties considered are of two types: *aleatory*, due to variability in time or space or measurement error, and *epistemic*, due to lack of knowledge. Variability manifests as changes over time and space, which are characterized by frequency distributions. Lack of knowledge typically manifests as uncertainty about models and parameter values, which are characterized by best estimates and some measure of possible error.

Forecasts made with the predictive analysis are simple mathematical functions of the input parameter values. Thus, if the input parameter values are uncertain, so, too, must be the forecast values. Given expected values, standard deviations, and correlations of the uncertainties of the input parameters, the corresponding expected values, standard deviations, and correlations of the uncertainties on the forecasts are directly calculated. Forecast results of the predictive analysis are expressed as non-exceedance probabilities, as well as expected values and coefficients of variation. A non-exceedance probability is that which describes the chance that the uncertainty in a forecast leads to an actual outcome that is less than or equal to a particular value. The default assumption in the predictive analysis is that uncertainties in both the input parameters and in forecasts can be approximated by lognormal-shaped distributions. There are reasons for this choice, although there is also no reason that the choice cannot be varied to assess the sensitivity of the results to the assumption.

## SENSITIVITY STUDIES

Sensitivity studies were conducted to verify the predictive analysis. The purpose of sensitivity analysis is to determine which factors have the greatest effect on measures of performance and how large these effects are.

Post-remediation load ratios—the main output of the modeling effort—are calculated from three considerations and three corresponding parameter estimates. First, pre-remediation loadings are estimated for each source type based on the relative loading potential. Second, remediated volume and remedial effectiveness are estimated for each combination of remedial alternative and source type. Third, decline of the post-remediation loading with time due to source leaching is calculated by multiplying the initial post-remediation loading by an exponentially decreasing decay term. Thus, three (uncertain) parameters are important in calculating post-remediation loading and were the subject of sensitivity analyses: relative loading potential for each source

type, remedial effectiveness, or remediation factor[1] for each alternative and source type, and the volume of each source type remediated by each respective alternative. Sensitivity studies were also performed for the assumption of lognormality in the uncertainty analysis. As a general observation, the sensitivity of post-remediation loadings to each of the parameters is modest, although the sensitivity is greatest to relative loading potential rather than to remedial effectiveness or remediation volumes.

[1] "Remedial effectiveness" is the complement of the "remediation factor," which is the parameter estimated in the predictive analysis. Remedial effectiveness equals one minus the remediation factor.

# ABBREVIATIONS AND ACRONYMNS

| | |
|---|---|
| ARAR | applicable or relevant and appropriate requirement |
| AWQC | ambient water quality criteria |
| BHSS | Bunker Hill Superfund Site |
| BIF | Bunker Hill Box inclusion factor |
| CDR | Coeur d'Alene River |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CSM | conceptual site model |
| cy | cubic yard |
| EPA | U.S. Environmental Protection Agency |
| FS | feasibility study |
| lbs/day | pounds per day |
| NFCDR | North Fork Coeur d'Alene River |
| PAT1 | Probabilistic Analysis Tool 1 |
| PAT2 | Probabilistic Analysis Tool 2 |
| RI | remedial investigation |
| RLP | relative loading potential |
| ROD | Record of Decision |
| SFCDR | South Fork Coeur d'Alene River |
| TMDL | total maximum daily load |
| USGS | U.S. Geological Survey |

# 1.0 INTRODUCTION

This memorandum documents the *predictive analysis* developed to forecast post-remediation metal loading at two stream monitoring locations (Pinehurst and Harrison) in the Coeur d'Alene River Basin of Idaho. The predictive analysis is a risk management tool intended to be used in the remedy selection process to compare cleanup efforts.

The analysis focuses on the six remedial alternatives identified in the Coeur d'Alene Basin feasibility study for the upper and lower Coeur d'Alene Basin to Harrison (EPA 2000a). This part of the basin includes Conceptual Site Model (CSM) Units 1, 2, and 3, but excludes Lake Coeur d'Alene (Unit 4) and the Spokane River (Unit 5).

The objective of the predictive analysis is to assess the effect of specific upstream remedial alternatives on downstream metal loadings and to use available information to quantify the certainty with which remedial goals can be met. The predictive analysis can also be used to assess the downstream effect of hypothetical metal load reductions in tributary streams and, thus, to identify the remedial effectiveness required to meet target metal loadings.

## 1.1 ORGANIZATION OF THIS DOCUMENT

The sections and appendices that make up this technical memorandum are summarized below. The narrative sections describe what the predictive analysis does, how it works mathematically, and the meanings and limitations of its results. The appendices provide technical and mathematical detail.

- Section 1, Introduction, presents the objective, purpose, scope of the analysis.
- Section 2, Conceptual Background, provides an overview of the approach.
- Section 3, Assumptions and Parameter Value Estimates, discusses principal assumptions, data resources, how parameter values of the analysis were assessed, and how uncertainty in parameter values was estimated.
- Section 4, Results, summarizes the predictions of the analysis and provides interpretation.
- Section 5, Sensitivity Studies, discusses the variability of predictions to changes in assumptions and parameter values.
- Section 6, Conclusions

- Section 7, References
- Appendix A, Characterization of Uncertainty in Estimates, provides a general explanation and documentation of how uncertainty is described.
- Appendix B, Equations Used for the Predictive Analysis of Metal Loadings, documents mathematical and technical details, together with supporting assumptions and hypotheses.
- Appendix C, Input Used for Predictive Analysis, summarizes the analysis input values, assumptions, and hypotheses that are not otherwise documented in the remedial investigation/feasibility study (RI/FS).
- Appendix D, Sensitivity Studies, summarizes studies undertaken to validate the predictive analysis

## 1.2 USE OF THE PREDICTIVE ANALYSIS

The purpose of the predictive analysis is to inform risk management decision making. It does so by helping to quantify both best estimates of cleanup outcomes and the certainty with which a remedial alternative or a proposed remedy can lead to meeting cleanup goals. The analysis results are intended to provide defensible, quantitative estimates of an alternative's potential performance. This performance is measured in future metal loadings at particular locations in the basin, or can be converted to ambient water quality. Predictions can then be evaluated within the context of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) criteria: compliance with applicable or relevant and appropriate requirements (ARARs), long-term effectiveness and permanence, and short-term effectiveness (time to achieve remedial action objectives). The predictive analysis is a working tool. The analysis approach can be updated as needed to support an evolving remedy selection and implementation process.

### 1.2.1 Scope of the Analysis

As with any analytical approach, the predictive analysis has a proscribed scope. First, the predictive analysis provides outcome forecasts for two specific locations in the basin: on the South Fork Coeur d'Alene River (SFCDR) at Pinehurst and on the mainstem of the Coeur d'Alene River (CDR) at Harrison. The former reflects remedial activities in the upper basin to Pinehurst (but without the Bunker Hill Box), while the latter also reflects remedial activities in the lower basin from Cataldo to Harrison.

Second, the current analysis does not explicitly include the Bunker Hill Box. This is consistent with alternatives developed in the FS, which do not include remedial actions in the Bunker Hill Box, because the Bunker Hill Box is undergoing remedial actions based on existing Records of Decision (RODs). However, the results of the predictive analysis can be modified parametrically to incorporate effects from the Bunker Hill Box if desired.

Third, the present results are estimates. That is, they are engineering approximations based on the interpretation and synthesis of currently available information. While there is a great deal of information on the Coeur d'Alene Basin, the basin is large and complex. Therefore, the results are conditional on the hypotheses and assumptions made in the modeling, which are detailed in this memorandum. The results obtained are based on contemporary standards of engineering practice and applied science, and it appears that credible variations in input estimates do not lead to practical differences in major conclusions of the analysis (see Section 5). Standard practices for quantifying and propagating uncertainties through the predictive analysis have been adopted.

### 1.2.2 Expert Judgment

The impetus for a predictive analysis stems from the complexity of the basin and from the resulting need to combine a large number of considerations, calculations, and parameter estimates in making forecasts. An assessment of uncertainty is necessary because so many considerations must come together and historical data are limited.

Among the uncertainties that must be dealt with are the following:

- Factors for relative loading potential and remediation effectiveness
- Source type characterizations, for example, volume and characterization estimates
- Differences in contaminant levels in waste materials
- Blending of waste materials at a given site
- Degree to which loadings/reductions are associated with source type volumes
- Limited synoptic surface water sampling data
- Degree to which target sampling location represents all upgradient loading
- Seasonal variability in loading processes and surface water response

Not all of these are known with precision. Therefore, while best estimate forecasts can be made, these forecasts also contain uncertainty. It is important that uncertainties entering the analysis be quantified and then translated into uncertainty bands on resulting forecasts. The predictive analysis does this using probabilistic methods.

The predictive analysis combines existing information on the basin with scientific understanding of environmental processes, but neither the existing information nor our scientific understanding of environmental processes is perfect. In an ideal setting, a long history of empirical data would

be available from which to estimate model parameters. However, in many applications, as here, this is not the case. Detailed historical monitoring data in the Coeur d'Alene Basin on stream flows, levels of contamination, and other environmental conditions are limited for the purposes of analyzing and predicting conditions in the basin. This situation is no different from most large river basins.

As a result of the absence of detailed historical data, the professional judgment of experts was called upon to interpret those data that do exist and to help estimate parameter values. This is standard practice in policy and regulatory modeling where the use of quantified scientific and engineering judgment is widespread (e.g., see Cooke 1991 and Morgan and Henrion 1992) and has been endorsed in both National Research Council reports (e.g., NRC 1994 and 1996) and in federal agency guidance (e.g., Budnitz et al. 1995 and USNRC 1996). The Office of Management and Budget and the National Academy of Science have repeatedly called for the quantification and propagation of judgmental uncertainty in important regulatory decisions (NRC 2007).

Quantified expert judgment is typically used when data are few, difficult to obtain, or subject to interpretation. It is also used to bring together differing types of information, to determine what is known and how well, and to document information. Probabilistic methods are an integral part of the analysis of expert judgment, providing mathematical methods for aggregating judgments, quantifying the precision with which predictions are made, combining different sources of data, and formulating models. Typically, expert judgment is used both to structure a scientific problem (e.g., which data are relevant, which variables or analytical methods are appropriate, and which assumptions are valid) and to provide parameter estimates (e.g., weighting factors for combining data sources or uncertainties).

This process, however, also introduces uncertainties that the predictive analysis attempts to capture. However, as the monitoring program continues and a more extensive data base is compiled, the present model and parameter estimates will be refined.

### 1.2.3 Types of Uncertainty

The uncertainties entering the calculations are of two types. One has to do with the variation of natural processes in time and space. For example, in some years there is a great deal of rainfall, while in others there is not. Process or outcomes that depend on stream flow, as a result, will also differ from one year to another. The other type of uncertainty has to do with limited knowledge. For example, there may be too few data from which to precisely estimate the total metal mass in a particular source, and judgment must be used. Downstream metal loads depend on the metal mass in the source, and, as a result, errors in the judgmental estimate cause errors in the downstream prediction. The predictive analysis accommodates both types of uncertainty—sometimes called *aleatory* and *epistemic*, respectively.

The predictive analysis uses a simple probabilistic approach to capturing uncertainties and propagating their combined effect through to forecasts. Best estimates, standard deviations, and correlations are assessed for the input entering the analysis, and best estimates, standard deviations, and correlations are calculated for the output. The standard deviations associated with the output allow quantitative conclusions to be drawn about the degree of uncertainty in the forecasts.

## 1.3 ECOLOGICAL ALTERNATIVES IN THE FEASIBILITY STUDY

Six ecological remedial alternatives for the upper (CSM Units 1 and 2) and lower (CSM Unit 3) Coeur d'Alene River Basin were developed in the FS. These are the alternatives, as summarized in this section, considered by the predictive analysis.

### 1.3.1 Overall Remedial Approach

The overall remedial approach inherent in the ecological alternatives for reducing metal loadings to surface water is a combination of site-specific actions based on containment and treatment. These may be used singly or in combination.

Containment is used to isolate source material (i.e., tailings, impacted sediments, and waste rock) from flowing water that can transport metals to surface water, either directly or via groundwater. Containment options include, in general order of increasing effectiveness, in-place stabilization; capping and covering (including regrading); hydraulic isolation; and removal (excavation or dredging) with containment (disposal) in on-site, local, or regional repositories. Stabilization is used to control erosion and includes regrading of source material out of stream channels and into more stable configurations plus various bioengineering measures applied to stream banks.

Chemical treatment is used to reduce metal loadings from surface water (including adit discharges) and groundwater for those alternatives where groundwater would be collected, generally as part of hydraulic isolation. For some alternatives in the lower basin, chemical treatment of sediments is proposed to reduce lead bioavailability (or toxicity) to environmental receptors. Treatment would also reduce loadings from sediments to surface water. Chemical treatment options for water broadly include various "passive" treatments accomplished on-site[2] and various "active" treatments accomplished in a regional water treatment plant. Active treatment is more effective at metal removal than passive treatment, possibly at higher cost.

[2] Passive treatment removes metals from water by passing the water through a reactive medium, such as mineral apatite. Passive treatment is accomplished on site using treatment beds, trenches, or reactive barriers. Although apatite has been assumed for the FS, other treatment media could be used, based on the remedy selected in the ROD.

Hydraulic isolation includes, but does not require, groundwater cutoff walls to control transport to surface water. Cutoff walls may be used to isolate localized areas of impacted sediments from upgradient groundwater flow, or to isolate colocated affected groundwater. Hydraulic isolation may be used in conjunction with treatment of broadly distributed groundwater source areas that are covered by existing development and not accessible to removal or amenable to effective capping. In these situations, treatment could be active or passive.

Active treatment could use a regional water treatment plant with groundwater collection, conveyance, and treatment. Passive treatment could be accomplished in situ using permeable reactive barriers or the like, or in various possible pond configurations.

Active treatment was explicitly assumed in the FS, but could potentially be replaced or complemented by passive treatment in an actual remedy. The use of either active or passive treatment, or combinations of both, would have relatively minimal affect on current analysis results, which already include an appropriate range of potential effectiveness for hydraulic isolation scenarios.

### 1.3.2 Remedial Alternatives

The six ecological alternatives of the FS are organized into alternatives for the upper basin and the lower basin. Alternative 1 is the "no action" alternative. Alternatives 2, 3, and 4 are the U.S. Environmental Protection Agency (EPA) action alternatives, which represent successively increasing levels of cleanup effort. Alternative 5 is the State of Idaho Plan. Alternative 6 is the Mining Companies Plan. Each alternative includes institutional controls, long-term monitoring, and natural recovery.

**Alternative 1 – No Action.** The no action alternative provides a baseline from which to compare the action alternatives. Metal loadings in basin streams are expected to decrease over time as natural processes that release and transport metals deplete the mining-related sources. The reduction of metal loadings in basin streams due to source depletion is quantitatively analyzed.

**Alternative 2 – Contain and Stabilize With Limited Removal and Treatment.** Of EPA's three action alternatives, Alternative 2 is the lowest level of cleanup action. Actions are aimed at controlling sources having the highest metal loadings and the highest levels of ecological exposure. Limited removals and in-place and on-site waste containment and isolation would be used to control ecological and human exposures and to minimize metal transport via erosion and leachate loading. Bioengineering would be used to provide bank and stream stabilization, control erosion of contaminated sediments, and support natural recovery of riverine and riparian habitat. Chemical treatment would be limited to passive treatment of adits. Metal loadings would be associated with contaminated media left in place or only partially contained.

**Alternative 3 – More Extensive Removal, Disposal and Treatment.** Alternative 3 extends the cleanup level of Alternative 2 to include more extensive and effective removal, containment, and treatment. This includes regional repositories and a regional water treatment plant for active treatment of surface water (adit discharges) and groundwater collected as part of hydraulic isolation. A passive treatment pond near the mouth of Canyon Creek is included. Contaminated media left in place or only partially contained would be less than under Alternative 2.

**Alternative 4 – Maximum Removal, Disposal and Treatment.** Alternative 4 calls for the removal of sources to the maximum practicable extent with containment in regional repositories. Sources beneath developed or urbanized areas, including I-90 and other public and private infrastructure, would be treated using hydraulic isolation with groundwater collection and treatment at a regional water treatment plant. Contaminated media left in place or only partially contained would be minimized.

**Alternative 5 – State of Idaho Plan.** Alternative 5 was independently developed by the Idaho Department of Environmental Quality and focuses on containing or stabilizing the largest sources of metals loading to surface water. Alternative 5 includes measures generally similar to Alternatives 2 and 3. It includes regional repositories, but not hydraulic isolation or water treatment plants.

**Alternative 6 – Mining Companies Plan.** Alternative 6 was independently developed by the mining companies and consists of rank ordered actions primarily focused on regrading or removing source materials from water courses to reduce erosion and the potential for contact with surface and groundwater that could result in leaching and surface water loading. Localized areas of bioengineered and vegetative stream bank stabilization are included. Regional repositories, hydraulic isolation, and water treatment plants are not included.

### 1.3.3 Source Types and Volumes of Materials

EPA has developed an inventory of the location, type (e.g., tailings and waste rock), and volume of mining wastes in the basin. This inventory is used to provide inputs to the predictive analysis for each candidate remedial alternative. The mining wastes are divided into categories. Remedial actions for the alternatives in CSM Units 1 and 2 in the upper basin are organized by the four source types: tailings-impacted floodplain sediment, tailings piles, waste rock piles, and adits. Remedial actions for the alternatives in CSM Unit 3 in the lower basin are organized by the six source types: riverbed sediments, river banks and levees, wetland sediments, lateral lake sediments, floodplain area sediments, and Cataldo/Mission Flats dredge spoils.

The upper basin source types include the mining-related wastes that are primary sources and impacted floodplains sediments that have become secondary sources. The lower basin source types represent mining-waste impacted areas that have become secondary sources because of transport and deposition of contaminated materials from the upper basin.

A summary of the volumes of materials treated under the five alternatives is provided in Table 1-1. *(Note: For the convenience of the reader, figures and tables appear at the end of the sections in which they are cited.)*

## Table 1-1
## Summary of Estimated Dissolved Zinc Loading Immediately After Remedy Completion, Time *t* = 0

| Source Type | Remedial Alternative | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| **CSM Units 1 and 2 (Upper Basin) to Pinehurst SF271, Excluding the Bunker Hill Superfund Site** | | | | | | |
| Estimated Remediation Factor | 1.00 | 0.71 | 0.37 | 0.28 | 0.86 | 0.90 |
| **Estimated Loading Contribution (percent)** | | | | | | |
| Floodplain sediments | 71 | 79 | 84 | 84 | 79 | 77 |
| Tailings—Impounded, inactive facilities | 5 | 1 | 1 | 0 | 2 | 3 |
| Tailings—Impounded, active facilities | 7 | 9 | 6 | 5 | 8 | 7 |
| Tailings—Unimpounded | 5 | 4 | 5 | 7 | 5 | 4 |
| Floodplain waste rock | 4 | 3 | 1 | 1 | 4% | 3 |
| Upland waste rock | 0.1 | 0.2 | 0.3 | 0.2 | 0.1 | 0.1 |
| Waste rock at active facilities | 1 | 1 | 2 | 2 | 1 | 1 |
| Adit drainage | 7 | 2 | 0 | 1 | 1 | 4 |
| Total Percent | 100 | 100 | 100 | 100 | 100 | 100 |
| **Estimated Post-Remediation Zinc Load (pound/day)** | | | | | | |
| Estimated Zinc Load by Source Type | | | | | | |
| Floodplain Sediments | 974 | 733 | 371 | 267 | 919 | 932 |
| Tailings—Impounded, inactive facilities | 73 | 13 | 3 | 1 | 24 | 41 |
| Tailings—Impounded, active facilities | 93 | 87 | 27 | 17 | 90 | 90 |
| Tailings—Unimpounded | 72 | 35 | 22 | 21 | 60 | 51 |
| Floodplain waste rock | 52 | 27 | 6 | 3 | 43 | 40 |
| Upland waste rock | 1 | 1 | 1 | 1 | 1 | 1 |
| Waste rock at active facilities | 8 | 8 | 7 | 7 | 8 | 8 |
| Adit drainage | 101 | 20 | 2 | 2 | 17 | 50 |
| Total dissolved zinc load | 1,374 | 924 | 439 | 319 | 1,163 | 1,214 |
| **CSM Unit 3 (Lower Basin) Cataldo LC50 to Harrison LC60** | | | | | | |
| Estimated Remediation Factor | 1.00 | 0.90 | 0.30 | 0.19 | 0.86 | 0.94 |
| **Estimated Loading Contribution (percent)** | | | | | | |
| Riverbed sediment | 66 | 73 | 42 | 60 | 75 | 70 |
| Banks and levees (bank wedges) | 10 | 8 | 6 | 9 | 10 | 10 |
| Wetland (palustrine) sediments | 6 | 1 | 4 | 5 | 1 | 1 |
| Lake (lacustrine) sediments | 9 | 10 | 29 | 11 | 5 | 10 |
| Other floodplain areas | 5 | 6 | 16 | 9 | 6 | 6 |
| Cataldo/Mission Flats dredge spoils | 4 | 2 | 4 | 6 | 2 | 4 |
| Total Percent | 100 | 100 | 100 | 100 | 100 | 100 |
| **Estimated Post-Remediation Dissolved Zinc Load (pound/day)** | | | | | | |
| Riverbed sediment | 163 | 163 | 31 | 28 | 160 | 163 |
| Banks and levees (bank wedges) | 24 | 17 | 4 | 4 | 22 | 23 |
| Wetland (palustrine) sediments | 16 | 3 | 3 | 3 | 3 | 3 |
| Lake (lacustrine) sediments | 23 | 23 | 22 | 5 | 11 | 23 |
| Other floodplain areas | 13 | 13 | 12 | 4 | 12 | 13 |
| Cataldo/Mission Flats dredge spoils | 9 | 4 | 3 | 3 | 5 | 9 |
| Total dissolved zinc load | 248 | 223 | 74 | 48 | 213 | 234 |

# 2.0 CONCEPTUAL BACKGROUND

The predictive analysis developed for the FS intended to estimate post-remediation loadings in the basin expected to result from each of the six remedial alternatives. This became the predictive analysis discussed here.

The basic concept and functioning of the predictive analysis is introduced in this section. First, attention is given to how the analysis works, that is, how it accounts for sources upstream and calculates metal loads downstream. Next, estimates of pre-remediation conditions are discussed in the context of information from the RI program. Then, the mechanics of calculating post-remediation metal loads are summarized. Greater detail on the latter two topics is presented in Appendices B and C.

## 2.1 HOW THE PREDICTIVE ANALYSIS WORKS

The analysis uses a straightforward accounting scheme to sum up the contributions of sources upstream to metal loads in the river downstream. Metal load is taken to be the *daily mass of dissolved zinc* in the river passing a particular monitoring location. This is used as an index for total metal load. Individual sources contribute dissolved metal to the river system in proportion to their type and size. Ultimately, the analysis converts metal loads to concentrations for comparison with water quality standards.

Two monitoring locations are considered in the analysis: Pinehurst and Harrison. After subtraction of measured adit loads, the analysis ascribes the remaining load at the Pinehurst or Harrison locations to each source type (e.g., waste rock) based on estimates of the proportional "loading strength" of that source type and the volume of material of that source type in the basin upstream of the monitoring location.

The effect of remedial actions at the sources is taken into account by modifying the contributions of each source to metal entering the river. The combined effect of each of the six remedial alternatives of Section 1.3 is forecast by aggregating the contributions over all the sources.

Uncertainty in the analysis predictions is estimated by assessing the uncertainty in the analysis input parameters and then propagating those input uncertainties to corresponding uncertainties in the output. This calculated uncertainty in the output is expressed by best estimates (means), standard deviations, and probability distributions.

The effect of source depletion over time is addressed by allowing the loadings generated by the various sources to decay with time in proportion to the amount of remaining leachable metal at any given time in the future. As the source generates loading, its remaining metal mass

decreases correspondingly. Thus, even if no remedial actions are taken, the loadings from the various sources decreases slowly.

## 2.2 SOURCES

Dissolved metal is assumed to enter the river system from a large number of discrete sites or *source types* (Figure 2-1). These are of several types, divided among groups thought to have similar loading effects on the river system.

For the upper basin (CSM Units 1 and 2), the source types include mining-related wastes that are primary sources and impacted floodplains sediments that have become secondary sources. These are as follows:

- Tailings-impacted floodplain sediments
- Impounded tailings piles at inactive facilities
- Impounded tailings piles at active facilities
- Unimpounded tailings piles
- Waste rock piles in floodplains
- Waste rock piles in upland areas
- Adits

For the lower basin (CSM Unit 3), the source types represent mining-waste impacted areas that have become secondary sources because of transport and deposition of contaminated materials from the upper basin. These are as follows:

- Riverbed sediments
- River banks and levees
- Wetland sediments
- Lake sediments
- Other floodplain sediments
- Cataldo/mission flats dredge spoils

For each source type, all of the individual sites upstream of a monitoring location are aggregated into a single source type contribution, which is modeled as contributing an aggregate metal loading to the river system. For example, the model provides estimates of the combined loading contribution at Pinehurst from all upstream, unimpounded tailings piles.

## 2.3 PRE-REMEDIATION METAL LOADS

The *relative loading potential* (RLP) of a given source type is an index of the average contribution of metal (zinc) load from that source type to the river per cubic yard (cy) of source material per year. That is, the RLP is a "grand average" for a particular source type. The RLP is introduced to facilitate the estimation of loads contributed by various source materials.

The RLP expresses the relative propensity of a source type to contribute metal load to the river. That source judged to have the highest propensity is assigned an RLP of 1.0, and other source types are scaled proportionately.

The *absolute pre-remediation load* attributed to a source type is found by apportioning the observed total load at a monitoring location in proportion to the RLPs and corresponding volumes of all the source types.

$$L_j = \frac{(RLP_j)(V_j)}{\sum_j (RLP_j)(V_j)} L_{TOTAL} \tag{1}$$

in which $L_j$ is the pre-remediation load attributed to source type $j$, $RLP_j$ is the relative load potential of source type $j$, $V_j$ is the upstream volume of source type $j$, and $L_{TOTAL}$ is the total pre-remediation load at the monitoring location.

RLPs were estimated by professional judgment from an interpretation of available data, consideration of metal concentrations in different source types, mobility, and exposure to leaching and erosion (Section 1.2.2). While RLPs may differ somewhat from one specific site to another for the same source type, the process of adding the contributions of all the sites into a single term leads to an averaging out of these variations.

## 2.4 POST-REMEDIATION METAL LOADS

The post-remediation metal loading at a monitoring location is calculated by reducing the pre-remediation loads contributed by each source type by a corresponding *remediation factor*. The remediation factor reflects the reduction of load contributed by a source type due to the remediation alternative applied and to the volume of source remediated. The remediation factor immediately after remediation, $R_0$, is the ratio of post-remediation loading to pre-remediation loading for a treated volume of source material,

$$R_0 = \frac{\text{Post} - \text{remediation loading}}{\text{Pre} - \text{remediation loading}} \tag{2}$$

The remediation factor is a number between zero and one: $R_0 = 0$ implies that the remedial alternative is perfectly effective (e.g., complete source removal) in reducing metal load and $R_0 = 1$ implies no effect. The effectiveness of the remedial alternative is the complement of the remediation factor.

Thus, the post-remediation load from source type $j$ immediately after remediation is modeled as

$$F_j = R_0 L_j \tag{3}$$

in which $F_i$ is the post-remediation loading from source type $j$, and $L_i$ is the pre-remediation loading.

As time passes and leaching proceeds, the sources become depleted of metals and loading to the water decreases. This source depletion is modeled as an exponential decay of the form

$$F_j(t) = R_0 e^{-\beta t} L_j = R(t) L_j \tag{4}$$

in which post-remediation load at a monitoring location is now a function of time, $F_i(t)$, and $\beta$ is a depletion rate. The exponential decay reflects an assumption that loading from a source type is proportional to the mass of leachable metal in the source.

The remediation factor for a source type and remedial alternative is estimated from three considerations:

- Relative loading potentials of upstream source types
- Remediated volumes by source type and remedial action
- Remedial action effectiveness

For each alternative, the remediation factor was estimated for each remedial action constituting the alternative. Using impacted sediments as an example, a remedial action of limited in-place erosion control would result in a relatively low effectiveness and thus a remediation factor near 1.0, since there would still be erosion potential and metal transport by leaching would not be significantly reduced. A remedial action based on removing the impacted sediments to a well-engineered repository would minimize all environmental exposure pathways of concern and, thus, have a higher effectiveness and lower remediation factor.

Estimates were based on engineering interpretation of the range of potential effectiveness for the typical conceptual designs, as documented in the FS. These interpretations used qualitative engineering analysis, limited quantitative performance modeling, experience with similar remedial actions, and professional judgment. Experience with similar remedial actions generally

considered how well actions have performed in the past and included considerations inherent in the technology screening documented in FS.

## 2.5 AMBIENT WATER QUALITY CRITERIA GOALS

The quantitative performance goal for surface water in the Coeur d'Alene Basin is to reduce concentrations of dissolved metals to meet ambient water quality criteria (AWQC). The AWQC are the principal legal requirements for surface water. Attainment of AWQC also protects the aquatic environment, based on results of the ecological risk assessment (EPA 2001a).[3]

AWQC are functions of water hardness, which correlates with stream discharge at a given location. Lower hardness is associated with higher discharge and conversely. A test for compliance with AWQC is quantified using a *loading capacity*,

$$loading\ capacity = AWQC \times discharge \tag{5}$$

The loading capacity translates concentration values as specified in the AWQC into loads as used in the predictive analysis. In practical terms, AWQC are met if loadings are below total maximum daily load (TMDL) capacities.[4] Stream discharges were correlated with AWQC using an interpolation of TMDL flow tiers. The TMDL flow tiers are estimated by hydrologic analysis of stream discharges in the basin as reported by EPA (EPA 2000b).

The predictive analysis is limited to dissolved metals because AWQC apply only to dissolved metals. The current analysis uses dissolved zinc as an indicator for total dissolved metals. Other metals, such as cadmium or lead, can be incorporated in the predictive analysis as necessary.[5]

Dissolved zinc is used as an indicator for the following reasons: zinc is the most ubiquitous of the metals in the study, zinc occurs at the highest measured concentrations and has the highest ratios of average measured concentration to AWQC (or average measured load to TMDL loading capacities), zinc is relatively mobile compared to other metals, and other dissolved metals

[3]The remedial alternatives in the draft FS have pursued the surface water goal in combination with related goals to protect human health and the environment by reducing metal concentrations in groundwater and other media and by controlling potential exposures to contaminated media, including soils and sediments.

[4]Although not of scientific importance to the analysis, there is a CERCLA consideration that should be understood: AWQC is the ARAR, not the TMDL. TMDLs are CERCLA "to be considered" criteria.

[5]Newly announced AWQC for dissolved cadmium (*Federal Register*, April 12, 2001, at 18935,6) could make cadmium more critical than zinc for many waters of the basin.

typically correlate with dissolved zinc.[6] The one exception to the use of dissolved zinc as an indicator is total lead in the lower basin, and remedial alternatives in the lower basin have been specifically developed to deal with total lead.

## 2.6 UNCERTAINTY ANALYSIS

The predictive analysis uses a simple probabilistic approach to capture uncertainties and propagate their effect through the analysis. Best estimates, standard deviations, and correlations are assessed for the input parameter values; and best estimates, standard deviations, and correlations are calculated for the output forecasts. Standard probabilistic methods are used to account for the way uncertainties propagate in the analysis.

### 2.6.1 Nature of Uncertainty in the Predictive Analysis

From a philosophical view, the uncertainties entering environmental engineering models are of two types, *aleatory*, due to variability in time or space or measurement error, and *epistemic*, due to lack of knowledge. Variability manifests as changes over time and space, which are characterized by frequency distributions. Lack of knowledge typically manifests as uncertainty about models and parameter values, which are characterized by best estimates and some measure of possible error.

Both uncertainties arise in the predictive analysis. Aleatory uncertainties lead to frequency distributions in model forecasts, for example, the probability of exceeding some metal load in any given year. Epistemic uncertainties lead to confidence bounds around those forecast frequencies, for example, how confidently such a probability of exceedance can be predicted. There are also other uncertainties related to decision making, for example, what discount rate to use for costs and benefits that accrue over time, but these are not related to the forecasts.

### 2.6.2 Quantifying Uncertainties

Probability measures are used to capture the uncertainties entering the analysis, and the mathematics of probability theory is used to propagate the effects of the input uncertainties to forecasts.

Estimates of input parameters are expressed in expected values and coefficients of variation. The *expected value* of a parameter, $x$, is denoted $E[X]$ and can be considered the "best estimate" of the parameter. Mathematically, the expected value is the average or mean.

[6]Dissolved cadmium appears well correlated with dissolved zinc throughout the Coeur d'Alene Basin. Dissolved lead appears reasonably well correlated with dissolved zinc in the upper basin, but not in the lower basin. Other metals have varying degrees of correlation with dissolved zinc.

The *coefficient of variation*, denoted *CV[X]*, is used as a measure of the variability or uncertainty around the expected value, *E[X]*. The greater the coefficient of variation, the greater the uncertainty about *X*. Mathematically, the coefficient of variation is the ratio of the standard deviation of *X* to the mean,

$$CV[X] = SD[X]/E[X] \tag{6}$$

in which *SD[X]* is the standard deviation of *X*. The standard deviation is the root-mean-square error in *X* and provides a measure of the width of the range of uncertainty over *X*. The square of the standard deviation is called the *variance*.

In relative terms, *CV[X]* less than 0.20 could be considered "low" uncertainty and *CV[X]* of 0.50 or greater could be considered "high" uncertainty, with values in between considered "moderate" uncertainty. A *CV[X]* greater than 1.0 would be considered "very high" uncertainty.

The expected value and coefficient of variation establish the minimum necessary information to provide a probabilistic description of a variable in the predictive analysis.

### 2.6.3 Correlations

When a forecast depends on more than one uncertain variable, it is necessary to consider the possibility of covariation among the uncertainties in the estimates of the variables. Correlation is a measure of how uncertainties may vary together. For example, if errors in the same direction for two variables tend to occur together—if one estimate is too high, the other one is typically also too high—then there is positive correlation between the uncertainties. If errors typically occur in opposite directions, then there is negative correlation.

The *correlation coefficient*, ranging from −1 to +1, measures the degree of linear dependence between the two variables. Independent variables are uncorrelated and have a correlation coefficient of zero. Dependent variables that always and perfectly vary together have a correlation coefficient of +1 if they vary in the same direction, or −1 if they vary in opposite directions. Values between 0 and +/−1 indicate partial correlation.

Correlation need not be causal. A shared dependence on other parameters may cause two uncertainties to be correlated even if there is no direct relationship between the variables in question.

### 2.6.4 Propagating Uncertainties Through the Predictive Analysis

Forecasts made with the predictive analysis are simple mathematical functions of the input parameter values. Thus, if the input parameter values are uncertain, so, too, must be the forecast values. Given expected values, standard deviations, and correlations of the uncertainties of the

input parameters, the corresponding expected values, standard deviations, and correlations of the uncertainties on the forecasts are directly calculated.

A second-moment approximation is used to propagate uncertainties in the analysis. The uncertainties in the input parameters could also be propagated through the predictive analysis using Monte Carlo simulation, in which a random-number generator is used to create a variety of input values having the required expected values, standard deviations, and correlations, and then the corresponding variations in forecasts are sampled numerically. However, the mathematics of the predictive analysis are sufficiently simple that the first-order, second-moment approach works well, and this is what is used.

### 2.6.5 Non-Exceedance Probabilities

Forecast results of the predictive analysis are expressed as *non-exceedance probabilities*, in addition to expected values and coefficients of variation. These probabilities are easier to mesh with remedial goals and target metrics. A non-exceedance probability is that which describes the chance that the uncertainty in a forecast leads to an actual outcome that is less than or equal to a particular value. Thus, to say that the non-exceedance probability for $Y = y_0$ is 0.9 is to mean that $Pr(Y \leq y_0) = 0.9$, in which Pr(.) is probability.

However, knowing the expected value and coefficient of variation of the forecast is insufficient information from which to calculate a non-exceedance probability. The non-exceedance probabilities depend not only on these, so-called, first two moments of the probability distribution, but on the full shape of the distribution. Thus, to calculate a non-exceedance probability, some assumption must be made about the shape of the probability distribution.

The default assumption in the predictive analysis is that uncertainties in both the input parameters and in forecasts can be approximated by lognormal-shaped distributions. A lognormal distribution is that for which the logarithms of the uncertain quantities are themselves normally (i.e., bell-shaped) distributed. There are reasons for this choice, although there is no reason that the choice cannot be varied to assess the sensitivity of the results to the assumption.

Why is the lognormal distribution a reasonable assumption for the predictive analysis? First, historical data on the variability of metal load are well approximated by lognormal distributions (Figure 2-2). Second, many of the calculations in the predictive analysis are multiplicative, and by the Central Limit Theorem, their outcomes will tend to lognormality as the number of terms in the products increases (Ang and Tang 1975). There are no empirical data to substantiate a lognormal assumption for RLP and remediation factor (R), but by analogy with many geological data types, the assumption appears reasonable (Davis 1986).

**Figure 2-1 Metal Loading Before and After Remedial Action**

**Figure 2-2 Historical Dissolved Zinc Loadings: South Fork Coeur d'Alene River at Pinehurst (1991-1999)**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 2-2 (Continued)

# 3.0 ASSUMPTIONS AND PARAMETER VALUE ESTIMATES

This section describes the principal assumptions of the predictive analysis and how input parameter values and their uncertainties are estimated.

## 3.1 PRINCIPAL ASSUMPTIONS

The predictive analysis involves engineering approximations based on interpretations of information available at this time. Thus, forecasts of the analysis are necessarily based on hypotheses and assumptions, of which the following are considered the most important:

1. *Historical stream data are statistically representative of pre-remediation conditions*. This historical data includes stream discharges and dissolved zinc concentrations, and thus zinc loadings, at monitoring stations in the basin. These data have been collected by various entities, including Idaho Division of Environmental Quality, U.S. Geological Survey (USGS), McCulley, Frick, & Gilman, CH2M Hill, and URS Greiner, Inc. There is no known reason to expect significant inaccuracy in this historical record.

2. *Loading is proportional to volume, and load reductions are proportional to remediated volume*. This assumption is used to estimate how much loading is generated by the various sources and how loadings from the various sources decrease as a result of remediation. The assumption is that the whole volume of the respective sources contributes to loadings, or that that the shapes of the sources are sufficiently similar (e.g., all are tabular) that other geometric measures, such as area or extent or depth, are themselves approximately proportional to volume.

3. *Loading decays over time, based on total remaining metal mass.* This model hypothesis is used to estimate the time evolution of loading following remedial action ($t > 0$). It is related to the hypothesis that load reductions are proportional to remediated volume for a given source type and remedial action. The potential inaccuracy in this hypothesis was explicitly included in the analysis by adding a model uncertainty coefficient of variation on source depletion.

4. *Source-type RLPs represent spatial averages*. This means the true (but uncertain) RLP for a given source type reflects the aggregate effect of loadings and the mix of source types upstream from a monitoring location.

5. *Effectiveness of (remediation factor for) a given remedial action represent spatial averages for a given source type*. This means the true (but uncertain) future effectiveness of a given remedial action will generally vary with the specific sources remediated.

6. *Deeper aquifer material is a zinc source*. There are credible but unverified technical arguments that suggest, as a zinc source, deeper aquifer material in the upper basin could be more voluminous and have a greater load effect than estimated in the analysis. If the true zinc loading from deeper aquifer material greatly exceeds the estimate, then for each action alternative, the expected values of the remediation factor, loadings, and load ratios would be systematically underestimated.

7. *Groundwater loadings are accounted for in the source type RLP estimates*. For example, floodplain tailings have a high loading potential in part because of effects on and interactions with groundwater. As a practical approximation, this means that impacted groundwater does not affect surface water quality until it discharges to surface water. The load carried by such groundwater could, however, cause errors in the estimates of source contributions within affected stream reaches between monitoring locations. Importantly, both the Pinehurst and Harrison monitoring locations have low groundwater flow and, therefore, the measured surface water loadings are good estimates of the total upstream loading.

8. *AWQC will not change*. Because AWQC are functions of hardness, it is assumed that the relationships between stream discharge and water hardness will continue into the future and not be significantly affected by remedial action. The relationship between stream discharge and water hardness is formally accounted for in the analysis. Inclusion of engineering measures to maintain, or even increase, water hardness may be considered as part of remedial action. Potentials for future regulatory changes in AWQC or relationships between AWQC and aquatic risks, neither of which are formally accounted for in the analysis, can be considered in interpreting the results.

## 3.2 PRE-REMEDIATION LOADINGS

Estimates of the relative loading potentials began by segregating and aggregating identified and potential sources into source types having loading effects that are expected to be generally similar.

For a given remedial alternative, each source type would be remediated by various site/source-specific remedial actions, as documented in the FS. As an example, for tailings-impacted floodplain sediments, remedial actions for a given alternative could include the following:

- Removal and disposal in a regional repository
- Erosion control using bioengineering techniques
- Hydraulic isolation (i.e., groundwater collection and treatment), and so on

Generally, there is also a quantity of source material that would receive no action. Depending on the alternative, each remedial action, including no action, would be applied to a different aggregate volume of source (the volume could be zero for some remedial actions, depending on the alternative). These volumes are termed "remediated volumes."

Remediated volumes were estimated for each remedial alternative based on the volume of each source type that would be remediated by the individual remedial actions comprising the alternative, as documented in the FS. Using tailings-impacted floodplain sediments as an example, the volume remediated by removal and disposal, by in-place capping, and so on for each remedial action, was estimated for each alternative, including the volume receiving no action. These estimates were based on an assessment of the source-specific remedial actions that were identified for each alternative. Estimates were done for the upper and lower basin.

As with RLP estimates, the uncertainty in the volume estimates was handled probabilistically. The remediated volume estimates used an expected value and coefficient of variation and assumed that the uncertainty in the estimates followed a lognormal distribution.

Dissolved zinc is used as the indicator for dissolved metals. Statistical methods were used to fit frequency distributions to the available historical measurements at selected stream sampling locations, including TMDL monitoring locations. The results of these analyses are presented in the RI and summarized in the FS (EPA 2000b and 2000c). The frequency distributions represent estimates of current conditions, based on available data. These distributions reflect the variability associated with loading and the net effect from all upstream metal sources and fate and transport processes that result in the loadings.

The historical loadings are estimates of current loadings, recognizing that conditions can change over time. Potential changes occurring from past cleanup activities in the basin not otherwise represented in the historical data were not included in the pre-remediation estimates. The historical pre-remediation estimates are documented in the RI and summarized in the FS.

In estimating RLPs for source types, as well as remediation factors for specific remedial actions, a concerted effort was made to avoid "over-confidence" bias in quantifying probability distributions (Anderson 1998). High and low values were first estimated, as bounding 90 percent of the probable variation of the parameter. Then equations for the lognormal probability distribution were used to calculate expected values and coefficients of variation.

### 3.2.1 Tailings-Impacted Floodplain Sediments

Tailings-impacted floodplain sediments that are upstream of Pinehurst were considered the source type making the greatest load contribution at Pinehurst. The most severely impacted sediments were given an RLP of 1.0. The estimate considered the following factors related to zinc in tailings-impacted sediments: high concentrations and mobility, high exposure to leaching from groundwater and surface water effects, and high exposure to erosion.

Although any source type could be used as the reference source type, the most severely impacted floodplain sediment was selected because it is expected to be the source type contributing the maximum zinc load per unit volume. This expectation follows from these materials having relatively high zinc concentrations and mobility, high exposure to leaching from groundwater and surface water effects, and high exposure to erosion. The metals in tailings-impacted floodplain sediments can include metals in tailings that are dispersed within natural sediments, metals in lenses or strata of tailings buried or mixed within the sediments, and metals that have been transported to sediments from tailings, waste rock, adit discharges, or other mining-related sources. Tailings-impacted sediments also include those tailings in sediments that underlie tailings piles or impoundments.

That the most severely impacted floodplain sediments would have the highest average RLPs recognized that virtually all tailings piles have relatively high zinc concentrations and that zinc transport can occur from groundwater flowing into unimpounded piles from abutting hill slopes, or where runoff or run-on can infiltrate into the pile or flow to surface water. However, tailings piles do not have the same constantly high exposure to both surface water and groundwater effects that floodplain sediments have and were therefore estimated to have a generally lower relative loading potential. Note that impacted floodplain sediments that are located below tailings piles are included in the sediment source type.

For impacted sediments, refined estimates of the RLPs were made where potentially significant differences could be distinguished between specific locations or kinds of impacted sediments. The RLP of 1.0 was applied to those sediments having the highest RLP (i.e., the highest combination of zinc concentrations and leaching and erosion exposure). Those sediments identified as having less RLP received RLP estimates of less than 1.0, consistent with their expected relative contribution (on a per-cubic-yard basis). Tailings-impacted floodplain sediments were thus subdivided into several subclasses having successively decreasing relative loading potentials. The subclasses were correlated with the FS action alternatives, Alternatives 2 through 6, to help facilitate the analysis and comparison of the alternatives, discussed as follows:

- **Alternatives 5 and 6.** The most severely impacted floodplain sediments, those having an RLP of 1.0, were assigned to the total sediments identified for removal by the state as part of their Alternative 5 (approximately 195,000 cy). The total

sediment identified for removal by the mining companies as part of their Alternative 6 (approximately 170,000 cy) was also assigned an RLP of 1.0.

- **Alternative 2.** The impacted sediment identified for removal under Alternative 2 and not included as part of Alternatives 5 or 6 was assigned an RLP of 0.80. Floodplain sediments identified for removal under Alternative 2 consisted of relatively near-surface, tailings-impacted sediments identified by the USGS that are within the 100-year floodplain, principally along Ninemile Creek, Canyon Creek, and the SFCDR. The volume of these RLP = 0.80 sediments was approximated as the total sediment removal volume for Alternative 2 minus the combined sediment volumes for Alternatives 5 and 6. The RLP for impacted floodplain sediments below tailings impoundments ("discrete facilities") was assigned an RLP of 1.0, reflecting the expectation that floodplain material directly below these facilities are likely to be "severely" impacted.

- **Alternative 3.** The impacted sediment identified for removal under Alternative 3 and not included as part of Alternative 2 was assigned an RLP of 0.70. These impacted near-surface sediments were relatively close to basin streams (principally the SFCDR), but outside the 100-year floodplain. The volume of these RLP = 0.70 sediments was approximated as the total sediment removal volume for Alternative 3 minus the total sediment removal volume included in Alternative 2. The RLP for impacted floodplain sediments below tailings piles was assigned an RLP of 1.0. The RLP for impacted floodplain sediments associated with hydraulic isolation applied to river reaches was assigned an RLP of 0.80.

- **Alternative 4.** The impacted sediment identified for removal under Alternative 4 and not included as part of Alternative 3 was assigned an RLP of 0.60. These materials represented the remaining near-surface sediments identified by the USGS as tailings impacted and located principally along the SFCDR, but outside the 100-year floodplain. The volume of these RLP = 0.60 sediments was approximated as the total sediment removal volume for Alternative 4 minus the total sediment removal volume included in Alternative 3. The RLP for impacted floodplain sediments associated with hydraulic isolation applied to river reaches was assigned an RLP of 0.80.

The expected value of the volumetric average RLP for impacted floodplain sediments was computed from the subclass RLPs discussed above. This resulted in an expected value, *E[RLP]*, of 0.79. A coefficient of variation of the volumetric average RLP, *CV[RLP]*, of 0.30 was estimated. This coefficient of variation relates to a 90 percent probable range from

approximately 59 percent of the expected value (95 percent lower bound) to 155 percent of the expected value (95 percent upper bound).

### 3.2.2 Impounded Tailings

Impounded tailings were estimated to have an average RLP of between 0.01 and 0.50, with 90 percent probability. There was a 5 percent probability that the true RLP was less than 0.01 and a 5 percent probability that the true RLP was greater than 0.50, which resulted in $E[RLP] = 0.14$ and $CV[RLP] = 1.76$. Although there are differences between active and inactive tailings impoundments, as a practical approximation, the same values of relative loading potential were used for both active and inactive facilities. Impounded tailings do not include underlying floodplain material.

These estimates were based on impounded tailings on and above the floodplain, such that there were virtually no loading effects from groundwater flow or fluctuating groundwater table elevations in the underlying floodplain material. Loadings to surface water were therefore restricted to the influence of erosion and leaching by infiltration of surface water, with subsequent percolation to laterally flowing groundwater that discharges to surface water. Infiltration and subsequent leaching is limited, particularly where tailings are capped or graded to control surface water infiltration and where composed of flotation tailings, which have relatively low permeability (hydraulic conductivity). Erosion is also limited where impounded tailings are effectively capped. Thus, discharges from impounded tailings are expected to be very much less than flows through floodplain materials.

However, compared to impacted floodplain sediments, impounded tailings have higher average zinc concentrations. This is expected to result in higher concentration in both leachate and sediment transported by erosion. In particular, concentrations of dissolved zinc in leachate were expected to greatly exceed leachate concentrations in the most severely impacted floodplain sediments (reference material having an RLP of 1.0) because of high concentrations in the tailings, susceptibility to oxidation, and relatively long "residence times." Concentrations in eroded sediments were also expected to be higher for tailings than for impacted floodplain sediments. Based on the reasoning given above, the relative loading per unit volume of impounded tailings compared to severely impacted floodplain material was estimated to average 0.01 to 0.50, with 90 percent probability. This also allows a small probability that the RLP for impounded tailings could actually exceed that for floodplain material, on a per-unit-volume basis.

### 3.2.3 Unimpounded Tailings

Unimpounded tailings were estimated to have an average true RLP of between 0.10 and 1.0 with 90 percent probability. There was a 5 percent probability that the true RLP was less than 0.10

and a 5 percent probability that the true RLP was greater than 1.0, which resulted in *E[RLP]* = 0.40 and *CV[RLP]* = 0.80. Unimpounded tailings do not include underlying floodplain material.

Unlike impounded tailings, transport of metals from unimpounded tailings piles to groundwater and surface water can occur from groundwater flowing into the piles from abutting hill slopes, or where runoff or run-on can infiltrate into the pile or flow to surface water. In addition, unimpounded tailings are generally not as well graded as impounded tailings and could have generally higher hydraulic conductivity. Relative loadings from unimpounded tailings were therefore estimated to be roughly 2 to 10 times greater than loadings from impounded tailings. These tailings generally do not, however, have the same constantly high exposure to both surface water and groundwater effects that floodplain sediments have and were therefore estimated to have a generally lower RLP. The relative loading of unimpounded tailings compared to severely impacted floodplain material was thus estimated to average 0.10 to 1.0, with 90 percent probability. This allows a 5 percent probability that the RLP for unimpounded tailings (which do not include underlying floodplain material) exceeds that for severely impacted floodplain material, on a per-unit-volume basis.

### 3.2.4 Floodplain Waste Rock

Waste rock was given the lowest RLPs. A distinction was made between waste rock in floodplains and waste rock in upland areas, because the relative remoteness of the upland piles from streams was considered to decrease their exposure to leaching and erosion that could transport metals to streams.

Waste rock in floodplains of the upper basin was estimated to have an average true RLP of between 0.005 and 0.20, with 90 percent probability. There was a 5 percent probability that the true RLP was less than 0.005 and a 5 percent probability that the true RLP was greater than 0.20, which resulted in *E[RLP]* = 0.06 and *CV[RLP]* = 1.59. Waste rock does not include underlying floodplain material.

Floodplain waste rock piles were assumed to load surface water similar to tailings piles, with important differences. Waste rock is expected to have generally higher discharges because of generally higher hydraulic conductivities (with particle gradations ranging from silt size to small boulders) and generally lower zinc concentrations in leachate, at least partly because of lower zinc concentrations in waste rock compared to tailings. Further, because of the generally larger particle sizes of waste rock, the zinc in waste rock was considered less susceptible to leaching or erosion than zinc in tailings. Waste rock was considered generally heterogeneous in hydraulic and chemical properties, varying from country rock, where mineable ore was not discovered, to rock having more elevated levels of zinc associated with ore bodies. However, a large portion of the total floodplain waste rock also occurs within or immediately adjacent to surface water streams, which likely increases relative loading. The relative loading from floodplain waste rock

compared to severely impacted floodplain material was estimated to average 0.005 to 0.20, with 90 percent probability.

### 3.2.5 Upland Waste Rock

Upland waste rock was estimated to have an average true RLP of between 0.001 and 0.005, with 90 percent probability. There was a 5 percent probability that the true RLP was less than 0.001 and a 5 percent probability that the true RLP was greater than 0.005, which resulted in *E[RLP]* = 0.003 and *CV[RLP]* = 0.52. The relative remoteness of the upland piles from streams was considered to decrease their exposure to leaching and erosion that could transport metals to streams, which resulted in very low estimates of their true RLP.

### 3.2.6 Adits

Adits were a special case, since loadings have been directly measured for most individual significant sources. The sum of all adit loadings (measured as dissolved zinc per day) was assigned an RLP of 1.0 and an "equivalent" volume of tailings-impacted sediments. The equivalent volume was based on the proportion of upstream adit loading to the loading measured in the SFCDR at Pinehurst. The net effect was that estimated average adit loading (using relative loading potentials) was identical to the measured average adit loading.

### 3.2.7 Unremediated Source Types

In addition to the source types identified in the preceding paragraphs, source types were included in the analysis for which remediation was not included under any alternative. These source types collectively represent potential zinc sources not subject to reduction by any potential remedial action documented in the FS, except natural attenuation by source depletion. Different approaches for characterizing these unremediated source types were used in the upper and lower basins consistent with how the remedial alternatives were developed. These are discussed as follows.

***Upper Basin***

In the upper basin, the unremediated source type was represented by "deeper impacted floodplain sediments," which, for the purpose of the analysis, collectively represents potential zinc sources not subject to remedial actions documented in the FS. These deeper impacted sediments principally include aquifer materials below the depth of floodplain sediments identified in Table 1-1 as subject to potential remedial action. This source type also represents potential zinc sources associated with impacted material within floodplains that is not otherwise included in the FS volume estimates (e.g., road and former railroad embankments). In this regard, possible groundwater loading to streams through deep bedrock or from deeper parts of the alluvial system is also included.

The principal component of this collective source is believed to be historical mining-related zinc that has become sorbed, precipitated, or otherwise contained within deeper aquifer materials. This expectation is based on analysis and interpretation of information in the RI and the technical memorandum on background concentrations (EPA 2001b), reports by others (Paulson et al. 1996), and discussions with USGS personnel. Because of the general similarity in the source material and metal transport conditions, the deeper aquifer material was also used to characterize potential loading from the other floodplain sources, including the possible deep-groundwater sources. The total volume of material potentially associated with this source type was approximated to range from between 4,000,000 and 20,000,000 cy, with 90 percent probability.

***Lower Basin***

In the lower basin, a composite of all the source types was used as a surrogate unremediated source type. It consisted of an estimated 20 percent of each source type otherwise subject to remediation under at least one of the alternatives. The 20 percent was a nominal estimate based on the fact that source volumes in the lower basin were associated with total lead, not zinc (lower basin source volume estimates were based on a lead concentration threshold of 1,000 parts per million). Although lead and zinc are colocated in the affected lower basin sediments, it was considered appropriate to include extra source volumes to account for potential additional zinc sources. More refined estimates of the zinc source volumes were not conducted, because the zinc load associated with the lower basin lead-based volumes is a small percentage of the total zinc load at Harrison (i.e., less than 7 percent).

Estimates of relative loading potential are independent of remedial action, except as correlated with the alternatives for impacted floodplain sediments. However, to estimate loadings after remediation, it is necessary to estimate both the volumes of each source type that would be remediated by the individual remedial actions comprising a given remedial alternative and the effectiveness associated with those remedial actions. These concepts are discussed next.

## 3.3 POST-REMEDIATION LOADINGS

Metal transport associated with mining activity in the basin starts with the primary metal sources created by historical mining activities. Scattered throughout the upper basin, primary metal sources include tailings and waste rock piles, tailings mixed or buried in floodplains, and discharges from mine adits. Secondary sources include impacted floodplain sediments in the upper basin and contaminated sediments in the floodplains, wetlands, and lateral lakes of the lower basin. These primary and secondary sources vary dramatically in the degree to which they release metals to the river system.

As water contacts these sources, metals become dissolved or suspended. Streams flow over exposed sources in stream channels, groundwater flows through sources buried in river floodplains, and surface water runoff from rainfall and snowmelt flow over or into source material.

The rate of dissolution or suspension of metals into the water depends on geochemical, hydrologic, and geologic conditions. Under certain conditions, metals that are already dissolved or suspended in water can be removed by natural physical, chemical, and biological processes. The quantity of metal that is available for transport depends on the net difference between the quantity of metals entering the water and the quantity of metals leaving the water. This net difference varies from location to location and over time.

As water flows downgradient from higher areas of the basin, it mixes with other waters. Mixing occurs both as different groundwater flows merge or seep into surface water and as surface water streams combine into large streams. Sooner or later, metals carried in these waters will enter the major streams of the basin and be further transported by stream flow down the basin. The merging and mixing of basin waters depend on geologic and hydrologic conditions that vary over time and location.

The stream flows and the transported metal concentrations and loadings in the basin generally show great variability. This variability results from temporal and spatial variability in metal sources, in the degrees to which metals enter and remain in water, in the quantities of flowing water, and in the mixing processes that occur as waters flow downgradient. Variability is dynamic. It occurs both by location along the stream and over time at any given stream location.

From the standpoint of predicting metal transport, uncertainty is a consequence of imperfect knowledge about the natural system. It is the result of not having complete information on all the processes, conditions, factors, and parameters that determine actual stream flows and metal concentrations throughout the basin. Complete knowledge would also include knowing how these determinates will change over time. Such complete knowledge is unattainable.

### 3.3.1 Assigning Remediation Factors

Uncertainty in the effectiveness of remedial action follows from uncertainty in the variables used to estimate the effectiveness (in terms of remediation factors) of each remedial alternative. These uncertain variables include source volumes, relative loading potentials, remediated volumes, and remediation factors.

As used in the post-remediation estimates, lognormal distributions were used to generally represent the probability of any uncertain variable over its full range of potential values. The probabilities formally represent the uncertainty in the estimates.

The post-remediation loadings are predicted from the pre-remediation loadings using a "remediation factor." The remediation factor is an estimate of the ability of a remedial alternative to reduce future metal loadings.

As a measure of the net effectiveness of a given remedial alternative, the remediation factor is different for each monitoring location. The remediation factor measures the aggregate ability of the various site-specific remedial actions that constitute a remedial alternative to reduce metal loadings from the sources upstream of the monitoring location.

Metal loadings to basin surface water depend on factors that vary with source type and location and include the following:

- Metal concentrations and mass available for transport
- Metal mobility (including geochemical reactions and interactions with surrounding media)
- Environmental exposure to metal transport by leaching or erosion, where leaching may be from groundwater flow, water table fluctuations, percolation of infiltrated surface water, or combinations of these effects

However, with the exception of certain adits that discharge directly to surface water, available data for the basin are generally inadequate to directly estimate current loadings from individual or discrete sources.

Loadings were therefore estimated indirectly using the concept of RLPs, as explained in Section 2.

### 3.3.2 Effects of Natural Recovery Due to Source Depletion

Natural recovery due to source depletion is assumed to occur for any remedy, including no action. When remediation is completed, there is an immediate drop in loading. Following this initial drop, there is a decay over time of the remaining unremediated loading as metal leaches out of the source. Even if there were no remediation (i.e., no action), the source would still deplete with time and the loading decrease.

Potential effects of long-term natural recovery due to source depletion are included in the remediation factor estimates. Because of the effect of natural recovery, remediation factors are functions of time. Estimates of natural recovery were based on a model of source depletion that describes the reduction in metal loading and concentration over time as a function of a decay rate (Appendix B).

### 3.3.3 Load Ratios and Ambient Water Quality Criteria

For each remedial alternative, the post-remediation lognormal distributions for loadings were used to estimate the probability that the true future dissolved zinc loading would not exceed loading capacities (numerically equivalent to TMDL loading capacities) and thus would meet zinc AWQC. These estimates were based on the ratio of future loading over time to the loading capacities—termed the "load ratio," and denoted *Lr*. The load ratio is the post-remediation loading divided by the loading capacity. A load ratio of one or less means that the estimated loading is equal to or less than the loading capacity and that AWQC are expected to be met. A load ratio of, say, 10 would indicate that loadings are 10 times the loading capacity and that AWQC would be exceeded by a factor of 10. As future loads would decrease with time after implementation of a remedy, so would the load ratios.

A target *Lr* of one ($Lr = 1$) signifies compliance with AWQC. *Lr* greater than one ($Lr > 1$) are used for development of interim benchmarks. Interim benchmarks represent "interim" remediation goals of practical significance that are less protective than AWQC, but still supportive of limited fisheries.

# 4.0 RESULTS

This section presents the principal results of the predictive analysis.

## 4.1 IMPLEMENTATION OF THE PREDICTIVE ANALYSIS

Based on the analysis details documented in Appendixes B and C, the analysis was implemented in two complementary MS Excel spreadsheets: Probabilistic Analysis Tool 1 (PAT1) and Probabilistic Analysis Tool 2 (PAT2).

### 4.1.1 Probabilistic Analysis Tool 1

PAT1 analyzes the six FS alternatives based on source-by-source remedial actions documented in the FS (EPA 2000a). Appendix C includes the principal input estimates used in the analysis of the remedial alternatives.

PAT1 results are limited to post-remediation estimates for the SFCDR at Pinehurst (USGS station SF271) and the CDR at Harrison (USGS station LC60). Results for Pinehurst, representing the upper basin, are presented in Section 4.3. Results for Harrison, representing the combined upper and lower basins, are presented in Section 4.4.

The PAT1 analysis and results do not include loading contribution from the Bunker Hill Box, which is undergoing remedial action under existing RODs. However, separate graphs have been included in Section 4.4 that can be used with the results without the Bunker Hill Box loading to make loading and load ratio estimates that include Bunker Hill Box loading.

### 4.1.2 Probabilistic Analysis Tool 2

PAT2 implements a "what-if" scenario analysis that allows input of hypothetical or estimated remediation factors for specific areas of the basin, including major tributaries and reaches of the SFCDR (upper basin) and CDR (lower basin).

As output, PAT2 makes post-remediation estimates for the following selected TMDL monitoring locations:

- Canyon Creek at its mouth (USGS station CC288)
- Ninemile Creek at its mouth (USGS station NM305)
- Pine Creek near its mouth (USGS station PC305)[7]

[7]Uses TMDL loading capacity for PC315.

- SFCDR at Pinehurst (USGS station SF271)
- CDR at Harrison (USGS station LC60)

PAT2 was also used to estimate remediation factors required to meet TMDL load capacities, and thus AWQC, at these locations. These results are presented in Section 4.5, and are independent of any particular remedial alternative. Results are included for the upper and lower basins, both with and without historical loading from the Bunker Hill Box.

## 4.2 MEETING AMBIENT WATER QUALITY CRITERIA

The analysis implemented in PAT1 and PAT 2 uses loading capacities, which are numerically equivalent to TMDL loading capacities, as a metric for compliance with AWQC. Load capacities are the maximum metal loadings consistent with attaining AWQC. AWQC and loading capacities vary with changes in stream discharge and associated water hardness. The relationship between AWQC and load capacities is detailed in Appendix B.

At any given time, *t*, the ratio of loading to loading capacity, termed the "load ratio,"

$$L_r(t) = \frac{load}{load\ capacity} \tag{7}$$

is equivalent to the ratio of concentration to AWQC, because *load* is equivalent to *concentration-times-discharge*, *load capacity* is equivalent to *AWQC-times-discharge*, and *discharge* cancels in taking the ratio. Thus, $L_r(t) = 1.0$ is the target load ratio for compliance with AWQC.

Load ratios greater than one, $L_r > 1$, may represent "interim benchmarks," which are remediation goals of practical significance that are less protective than AWQC, but still supportive of limited fisheries. The results include a range of load ratios consistent with potential interim benchmarks that may be included in the Proposed Plan and ROD.

Analysis results for load ratios are assumed to include background effects. Although variable, estimated background loadings are approximately 10 percent of TMDL loading capacities. Consistent with EPA's finding (EPA 2000c), loading capacities use a conservative interpretation of hardness-discharge relationships and thus underestimate AWQC. The degree of underestimation is roughly equal to the background concentrations, and so balance out.

The target $L_r(t) = 1.0$ is based on meeting load capacities and AWQC without consideration of TMDL allocations, margins of safety, or background loadings (EPA 2000c). EPA defines "gross allocation" as TMDL loading capacity minus various upstream loading allocations, estimated background loadings, and a margin of safety. From this, the ratio of gross allocation to loading

capacity could be defined as a "gross allocation factor" equal to the gross allocation (loading) as a decimal fraction of the loading capacity.

Loads, load ratios, and probabilities that are functions of time after remediation are graphed from time $t = 0$ immediately after implementation to 1,000 years. This time scale attempts to capture the effect of source depletion.

## 4.3 UPPER BASIN RESULTS FOR SFCDR AT PINEHURST

Analysis results for the upper basin forecast dissolved zinc in the SFCDR at Pinehurst (USGS monitoring station SF271). The results do not include load contributions from the Bunker Hill Box.

### 4.3.1 Pre-remediation Dissolved Zinc Load Estimates for Pinehurst SF271

Pre-remediation loading for the upper basin at Pinehurst was estimated from historical data as the sum of measured loading at Elizabeth Park SF268 and Pine Creek PC305. This resulted in an expected value of dissolved zinc loading at SF271 of 1,374 pounds per day (lbs/day) without loading from the Bunker Hill Box. The measured historical dissolved zinc loading at SF271 from all loads, including the Bunker Hill Box, has an expected value of 2,921 lbs/day. This indicates a historic loading (based on 1991 to 1999 data) of approximately 1,547 lbs/day from the Bunker Hill Box, which has, therefore, historically contributed more than half the upper basin total dissolved zinc load. Effects of recent remedial action at the Bunker Hill Box would not be reflected in these estimates, which are based on historical data.

### 4.3.2 Post-Remediation Forecasts

Dissolved zinc results for Pinehurst SF271 are presented in Figures 4-1 through 4-11. Figures 4-1 through 4-3 show results for $t = 0$, which is the time immediately following completion of remedy implementation, but allowing for dissipation of any short-term effects from construction disturbances. Figures 4-4 through 4-11 show selected results over time, starting at $t = 0$ and projecting to 1,000 years after remedy completion ($t = 1{,}000$). The time projections assume no change in the remedies after $t = 0$ and only represent the effect of source depletion. Results for Alternative 1 represent the effect of no action, except for "natural recovery" by source depletion.

Figure 4-1 presents estimated remediation factors at $t = 0$, immediately after implementation of remedial action for each of the five remedial alternatives, 2 through 6. Alternative 1, no action, has $R_o = 1.0$ and is not included. The graphs are cumulative probability distributions based on lognormal probability distributions of the $R_o$ estimates. The graphs show the probability (vertical axis) that the actual value of $R_o$ is less than or equal to a particular value (horizontal axis). The expected value, $E[R_o]$, is indicated by "+" and the 0.9 non-exceedance value is circled. The

results indicate that the level of remediation measured in the SFCDR at Pinehurst would be greatest for Alternative 4, followed in decreasing order by Alternatives 3, 2, 5 and 6.

Figure 4-2 is similar to Figure 4-1, but shows daily average dissolved zinc loading at $t = 0$, $F_o$, measured in units of pounds of zinc per day. The $F_o$ estimates for each alternative represent the product of the pre-remediation loading and $R_0$. Figure 4-2 includes $F_o$ estimates for all six of the alternatives, including Alternative 1. $F_o$ for Alternative 1 (no action) represents the current loading. The estimated TMDL loading capacity for Pinehurst is also shown. Figure 4-2 indicates that none of the alternatives result in loading below the TMDL loading capacity, and thus below AWQC, at Pinehurst.

Figure 4-3 shows the probability of meeting zinc load ratios at Pinehurst. The load ratio, *Lr*, is the ratio of loading to TMDL loading capacity and the ratio of concentrations to AWQC. These probabilities incorporate both time variation due to stream flow and uncertainties due to parameter inaccuracy. Therefore, the probabilities should not be interpreted to mean that AWQC will be achieved a corresponding fraction of the time (e.g., an 0.5 probability does not mean that TMDL loading capacities and AWQC are met 50 percent of the time).

Figure 4-4 shows expected values of remediation factors over time, $E[R(t)]$, for each of the six alternatives for the first 100 years after remediation. The expected values at $t = 0$ are the same as those presented in Figure 4-3. The remediation factor expresses post-remediation loading as a fraction of the current loading. Remediation factors for all alternatives slowly decrease over time due to source depletion. The level of remediation is greatest for Alternative 4, followed in decreasing order by Alternatives 3, 2, 5, 6, and 1.

Figure 4-5 is similar to Figure 4-4, but shows the expected value of zinc loading over time, $E[F(t)]$, in lbs/day for the first 100 years.

Figure 4-6 shows 0.9 non-exceedance probability values for the daily average zinc loadings in lbs/day. These are estimates of loadings with only a 10 percent probability of being exceeded. In contrast to Figures 4-4 and 4-5, this shows the continuing decay of loading for times greater than 100 years, showing the very gradual natural decay out to as long as 1,000 years, suggesting the length of time necessary for natural geobiohydrological processes to effect loads.

Figure 4-7 presents the expected value of load ratio, *Lr*, over time, $E[Lr(t)]$, out as far as 1,000 years. Load ratio is the ratio of loading to TMDL loading capacity and the ratio of concentrations to AWQC. The expected load ratio at $t = 0$ ranges from nearly 10 for Alternative 1 to slightly over 2 for Alternative 4. The load ratios decrease with time for all alternatives, including no action, due to source depletion.

Figure 4-8 presents, for each alternative, 0.9 non-exceedance probability values for load ratio.

Figure 4-9 presents the probability of meeting the TMDL loading capacity, and thus AWQC, in the SFCDR at Pinehurst. The probabilities are estimated over time for each alternative.

The results imply the following approximate time periods after remedy completion would be required to meet TMDL loading capacities, and thus AWQC, with probability between 0.1 and 0.9 at Pinehurst SF271 (not accounting for loading from the Bunker Hill Box):

- Alternative 4 would take 150 to 500 years
- Alternative 3 would take 250 to 650 years
- Alternative 2 would take 550 to 1,000 years
- Alternative 5 would take 600 to more than 1,000 years
- Alternative 6 would take 600 to more than 1,000 years
- Alternative 1 would take 650 to more than 1,000 years

As discussed in the Section 3, compared to meeting TMDL load capacities, longer times would be required to meet a gross allocation.

The results imply the approximate levels shown on Table 4-1 of zinc load ratio (*Lr*) at Pinehurst and Harrison (i.e., the daily load relative to AWQC) at 100 years. Results suggest that only Alternatives 3 and 4 provide an approximate match to AWQC with a 100-year window. All the other alternatives require a longer period of leaching.

The effectiveness of the various remedial alternatives can also be seen in the amount of zinc reduction they cause over time. Figure 4-10 shows the cumulative mass of zinc passing Pinehurst over the first 100 years after remediation for the six remedial alternatives. The cumulative mass is least for Alternative 4 and most for Alternative 1. Figure 4-11 shows the same results, but expressed as AWQC ratio.

## 4.4 LOWER BASIN RESULTS FOR CDR AT HARRISON

The analysis results for the lower basin include the loading from both the upper basin and the lower basin, as well as loading from the North Fork Coeur d'Alene River (NFCDR). As with the upper basin, it is assumed that there is no contribution from the Bunker Hill Box. Compared to the upper basin pre-remediation load, which can be directly related to USGS monitoring station SF271 at Pinehurst, the lower basin loading is more complex.

### 4.4.1 Pre-remediation Load Estimates

Loading in the CDR at Harrison, USGS station LC60, consists of the loading in the SFCDR at Pinehurst SF271 plus the sum of all loadings to the CDR downgradient of SF271 to LC60. The sum of loads from SF271 to LC60 was characterized by the following source areas, which

include the NFCDR and the lower basin (CSM Unit 3) from the confluence of the SFCDR and NFCDR to Harrison:

- SFCDR from Pinehurst SF271 to the confluence with the NFCDR
- NFCDR NF50 (Enaville)
- Lower basin–CDR from the confluence to Cataldo LC50
- Lower basin–CDR from Cataldo LC50 to Harrison LC60

Pre-remediation dissolved zinc loadings from these four source areas were estimated from statistical analysis of historical data reported in the RI and information from the FS. The average total load from Pinehurst to Cataldo, 567 lbs/day zinc, was based on the average difference in loads between LC50 and SF271 for reasonably synoptic samplings (n = 73). Similarly, the average total load from Cataldo to Harrison, 248 lbs/day zinc, was based on the average difference in loads between LC60 and LC50 for reasonably synoptic samplings (n = 86). Estimated loads at LC60 assumed that the discharge measured at LC50 was the same as that at LC60 (to eliminate potential discharge-measurement error at LC60). The estimated average load from the NFCDR, 243 lbs/day zinc, was estimated from lognormal analysis of USGS data, as reported in the final RI.

The coefficient of variation for each of these areas is high (see Appendix C, Table C-3), indicating a wide range of loadings over time. In fact, the synoptic analyses indicate that during low-flow conditions, the lower basin is generally a net *sink* for dissolved zinc (i.e., zinc loads can decrease from Pinehurst SF271 to LC60). During high-flow conditions, the lower basin is generally a net *source* of dissolved zinc.

Stream discharge and concentration data are not available to estimate the loads from SF271 to the confluence or from the confluence to LC50, since there is no monitoring station at the confluence. Therefore, the zinc loading from SF271 to the confluence was based on the estimated loading from approximately 280,000 cy of impacted floodplain sediments that has been identified along the SFCDR from SF271 to the confluence. The zinc load indirectly estimated for these sediments assumed an RLP of 1 and resulted in an estimated 2.5 percent of the upper basin load at SF271 (not including the Bunker Hill Box), or approximately 34 lbs/day of zinc. The coefficient of variation of this loading is expected to be between approximately 0.5 and 1.0.

The average dissolved zinc load from the confluence to Cataldo was estimated as 290 lbs/day by taking the 567 lbs/day load between SF271 and LC50 and subtracting the 34 lbs/day load from the sediments along the SFCDR and the 243 lbs/day load from the NFCDR. This gave the total average zinc load along the CDR from the confluence to Harrison as 538 lbs/day (confluence to LC50 + LC50 to LC60: 290 + 248 lbs/day). The 538 lbs/day estimate indicates that the average lower basin zinc load is less than half the average upper basin zinc load at SF271 (approximately

1,374 lbs/day, not including the Bunker Hill Box, and, historically, approximately 2,921 lbs/day, including the Bunker Hill Box).

The total average dissolved zinc load added between Pinehurst SF271 and Harrison LC60, including the NFCDR, was estimated at 815 lbs/day (SF271 to confluence + NFCDR + confluence to LC60: 34 + 243 + 538 lbs/day). The 815-lbs/day average total load was consistent with the 860-lbs/day average difference in loads between LC60 (using the LC50 discharge) and SF271 for reasonably synoptic samplings (n = 60), which had a coefficient of variation of 1.86. The expected value of the dissolved zinc load at Harrison, including the Bunker Hill Box, is approximately 3,736 lbs/day, (SF271 + SF271 to LC60: 2,921 + 815 lbs/day).

The source of the estimated 290 lbs/day of zinc (more than half the average lower basin zinc load of approximately 538 lbs/day) that occurs from the confluence to Cataldo LC50 is currently unidentified. No remedial action was, therefore, assigned to this reach in the FS. Because it is not remediated, the unidentified source is not a significant data gap for the analysis—although the 280,000 cy of impacted SFCDR sediments could contribute more than the estimated 34 lbs/day of zinc, but certainly very much less than 290 lbs/day. The unidentified source could be impacted groundwater from the lower basin that expresses itself downgradient of Pinehurst SF271.

### 4.4.2 Post-remediation Forecast

In contrast to zinc, the major source of total lead occurs downgradient of Cataldo, where the majority of the remedial action is concentrated. This is consistent with the lower basin remedial alternatives being generally aimed at reducing total lead loads and concentrations, not zinc. Zinc reductions from remedial actions in the lower basin were, therefore, only applied to the zinc load from Cataldo to Harrison.

For each alternative, a composite point estimate of the remediation factor at time $t = 0$, $R_o$, was calculated as the pre-remediation load-weighted average of the $R_o$ point estimate for the four source areas downgradient of SF271. The composite point estimates used the equations of Appendix B, Section B.3.5.1. $R_o$ point estimates for the SFCDR from SF271 to the confluence (34 lbs/day zinc) were 0.01 for Alternatives 2, 3, and 4 (which identified removal to a regional repository) and 1.0 for Alternatives 5 and 6 (which identified no action). Consistent with no action, $R_o = 1$ was assigned to the NFCDR (243 lbs/day zinc) and the confluence to Cataldo reach (290 lbs/day zinc). $R_o$ estimates for the Cataldo to Harrison reach (248 lbs/day zinc) used the estimates documented in Appendix C. The $R_o$ point estimates were weighted based on the expected values of the pre-remediation loadings from the sum of the four source areas (815 lbs/day zinc).

The composite $R_o$ point estimate for SF271 to LC60 was used to make probabilistic $R$ estimates for each alternative. The probabilistic $R$ estimates were used with the estimated pre-remediation total zinc loading to make post-remediation estimates of loading from Pinehurst SF271 to Harrison LC60. These loads were combined with loading at Pinehurst SF271 to estimate post-remediation loads, $F(t)$, and load ratios, $L_r(t)$, at Harrison LC60.

Results for the lower basin are presented in Figures 4-12 through 4-19. All results are for dissolved zinc in the mainstem CDR at Harrison.

Figures 4-12 through 4-14 show results for $t = 0$, the time immediately following completion of remedy implementation, allowing for dissipation of any short-term effects from construction disturbances. Figures 4-15 through 4-19 show selected results over time, starting at $t = 0$ and projecting to 1,000 years after remedy completion ($t = 1{,}000$). As for the upper basin, the time projections assume no change in the (hypothetical) remedies after $t = 0$, and only represent the effect of source depletion. Results for Alternative 1 represent the effect of no action, except for natural recovery by source depletion.

The estimates in Figure 4-12 represent composite remediation factors at $t = 0$, $Ro$, for the basin from the SFCDR at Pinehurst SF271 to the CDR at Harrison LC60, including the SFCDR to the confluence and the NFCDR. The graphs are cumulative probabilities, based on lognormal probability distributions of the $R_o$ estimates. The $R_o$ results indicate the relative level of remediation from Pinehurst to Harrison, which includes two areas where remediation is identified: on the SFCDR to the confluence (Alternatives 2, 3, and 4 only) and from Cataldo to Harrison.

The alternatives group into two sets. The first set, having the greater remedial effectiveness, and in order of effectiveness, consists of Alternatives 4 and 3. The second set, having less remedial effectiveness than the first set and in order of effectiveness, consists of Alternatives 2, 5, and 6.

The results in Figure 4-12 are unique in that they *only* include the basin from Pinehurst to Harrison. *All subsequent figures combine loads and remedial action over the entire basin, as measured at Harrison LC60.* That is, all subsequent figures represent cumulative loading at Harrison from the entire basin, including the NFCDR, but not including the Bunker Hill Box. Results assume the same remedial alternative in both the upper and lower basins; that is, Alternative 1 is assumed in the upper and lower basins, Alternative 2 is assumed in the upper and lower basins, and so on for all six alternatives.

Figure 4-13, which is similar to Pinehurst Figure 4-2, shows daily average dissolved zinc loading at $t = 0$, $F_o$, in terms of the cumulative probability distribution for each action alternative.

Figure 4-14 presents, for each of the six alternatives, estimates of the probability (vertical axis) that the load ratio, $Lr$, (horizontal axis) would be met at $t = 0$, immediately after completion of

remedial action. The load ratio ranges from 1 to 10, equating with loadings ranging from 1 to 10 times the TMDL loading capacity with concentrations at 1 to 10 times the AWQC. The load ratios assume no load contribution from the Bunker Hill Box. Figure 4-14 indicates that only Alternatives 3 and 4 would result in a non-zero probability that loading would be below the TMDL loading capacity ($Lr$ =1), and thus below AWQC, at Harrison immediately following remedy implementation at $t = 0$.

Figure 4-15 presents the expected value of the remediation factors for the entire basin (not including the Bunker Hill Box) to the CDR at Harrison LC60 over time, $E[R(t)]$, for each of the six alternatives for the first 100 years after remediation. The remediation factors for all alternatives slowly decrease over time. Alternatives 4 and 3 remain clearly grouped distinctly below Alternatives 2, 5, 6, and 1.

Figure 4-16 is similar to Figure 4-15, but shows the expected value of zinc loading over time, $E[F(t)]$, in lbs/day of zinc for the first 100 years.

Figure 4-17 presents the expected value of load ratio over time, $E[Lr(t)]$ for the first 100 years after remedy completion. The expected value, or average, load ratio at $t = 0$, $Lr(t = 0)$, would range from somewhat greater than 4.5, for Alternative 1, to about 1.6 for Alternative 4. The load ratios decrease with time for all alternatives, including no action.

Figure 4-18 presents, for each of the alternatives, the load ratios having a 90 percent probability of not exceeding the true load ratio.

Figure 4-19 presents the probability of meeting the TMDL loading capacity, and thus AWQC, in the CDR at Harrison. The probabilities are estimated over time for each alternative.

The results estimate that the following approximate time periods after remedy completion ($t = 0$) would be required to meet TMDL loading capacities, and thus AWQC, with probability between 0.1 and 0.9 at Harrison LC60 (not accounting for loading from the Bunker Hill Box):

- Alternative 4 would take 0 to 650 years
- Alternative 3 would take 0 to 750 years
- Alternative 2 would take 250 to more than 1,000 years
- Alternative 5 would take 350 to more than 1,000 years
- Alternative 6 would take 350 to more than 1,000 years
- Alternative 1 would take 350+ to more than 1,000 years

Longer times would be required to meet gross allocations, and the probability of meeting a gross allocation would be less than the probability of meeting the loading capacity.

## 4.5 REMEDIATION FACTORS REQUIRED TO MEET TMDLS AND AWQC

Based on the analysis implemented in PAT2, this section presents estimates of the remediation factors required to meet TMDL load capacities, and thus AWQC, for dissolved zinc at the following locations:

- Canyon Creek
- Ninemile Creek
- Pine Creek
- Upper basin (SFCDR at Pinehurst)
- Lower basin (CDR at Harrison)

The results are based on historical loadings and are independent of any particular remedial alternative.

Figure 4-20 presents the remediation factor required to meet the zinc TMDL loading capacity, and thus AWQC, for watersheds upstream of the following locations:

- Canyon Creek at its mouth (USGS station CC288)
- Ninemile Creek at its mouth (USGS station NM305)
- Pine Creek near its mouth (USGS station PC305)[8]
- SFCDR at Pinehurst (USGS station SF271)
- CDR at Harrison (USGS station LC60)

The required remediation factors would represent the aggregate remedial action for the entire watershed upstream of these locations, including the Bunker Hill Box, as applicable. Specifically, the SFCDR at Pinehurst would include all upstream tributaries and reaches, and the CDR at Harrison would include the entire upper basin, the entire lower basin, and the NFCDR.

The remediation factors are presented in terms of the probability of meeting TMDLs and AWQC at the TMDL stations. The probabilities range from 1 to 90 percent (0.01 to 0.90).

Figure 4-21 shows loadings from the upper basin only, without the Bunker Hill Box. This is equivalent to assuming that cleanup of the Bunker Hill Box has been 100 percent effective and that neither the NFCDR nor the lower basin contribute any loading. These assumptions only affect the SFCDR at Pinehurst and the CDR at Harrison. For these two stations, the required remediation factors are increased, which includes all upstream loading. Required remediation factors for Canyon Creek, Ninemile Creek, and Pine Creek are not affected.

[8] Uses TMDL loading capacity for PC315.

Figure 4-22 shows loadings only from the Bunker Hill Box, based on available historical data through 1999. Figure 4-23 shows loading only from the lower basin.

Based on cleanup in the upper basin, Figure 4-24 presents the estimated probability of meeting multiples of the TMDL loading capacity, and thus AWQC, for the SFCDR at Pinehurst. Multiples of the TMDL loading capacity and AWQC are measured by the load ratio, *Lr*, the ratio of loading to TMDL loading capacity and concentrations to AWQC, from *Lr* = 1 to *Lr* = 10.

In Figure 4-24 upper basin cleanup is separated into absolute cleanup conditions (i.e., 100 percent cleanup or 0 percent cleanup) with and without the Bunker Hill Box. Specifically, the following three conditions are presented: (1) upper basin only—100 percent cleanup of the upper basin (R = 0) and 0 percent cleanup of the Bunker Hill Box (R = 1), (2) Bunker Hill Box only—0 percent cleanup of the upper basin (R = 1) and 100 percent cleanup of the Bunker Hill Box (R = 0), and (3) no cleanup—0 percent cleanup of the upper basin (R = 1) and 0 percent cleanup of the Bunker Hill Box (R = 1).

Figure 4-25 presents the estimated probability of meeting multiples of the TMDL loading capacity, and thus AWQC, for the CDR at Harrison. Multiples of the TMDL loading capacity and AWQC are measured by the load ratio. Figure 4-25 presents results for the following seven absolute cleanup conditions: (1) upper basin only R = 0 (100 percent cleanup of the upper basin without Bunker Hill Box), (2) Bunker Hill Box only R = 0 (100 percent cleanup of the Bunker Hill Box only), (3) lower basin only R = 0 (100 percent cleanup of the lower basin only), (4) upper and lower basins R = 0 (100 percent cleanup of the upper and lower basins without the Bunker Hill Box), (5) upper basin with Bunker Hill Box R = 0 (100 percent cleanup of the upper basin and the Bunker Hill Box), (6) upper basin with Bunker Hill Box and NFCDR R = 0 (100 percent cleanup of the upper basin, the Bunker Hill Box, and the NFCDR—i.e., 100 percent cleanup of everything except the lower basin), and (7) no cleanup all R = 1 (no action).

### 4.5.1 Loading and Load Ratio Estimates That Include the Bunker Hill Box

The curves included in Figures 4-26 and 4-27 can be used with results presented above to include loading effects from the Bunker Hill Box. Figure 4-26 applies to loads and load ratio estimates at Pinehurst SF271, and Figure 4-27 applies to loads and load ratio estimates at Harrison LC60. These are based on the relationships developed in Appendix B.

For Pinehurst SF271, remediation factor estimates *E[R(t)]* from Figure 4-4 are used with Figure 4-26 and independent estimates of *E[R]* for the Bunker Hill Box to determine a Bunker Hill Box inclusion factor (BIF). The BIFs are time dependent, *BIF(t)*, and correspond to the time associated with *E[R(t)]*. Corresponding loading *F(t)* and load ratios *Lr(t)* estimates from Section 4.3 figures are multiplied by *BIF(t)* to approximate the effect at SF271 of including loadings from the Bunker Hill Box.

For Harrison LC60, remediation factor estimates *E[R(t)]* from Figure 4-15 are used with Figure 4-27 and the estimates of *E[R]* for the Bunker Hill Box to determine a the corresponding *BIF(t)* for LC60. Corresponding loading *F(t)* and load ratios *Lr(t)* estimates from Section 4.4 are multiplied by *BIF(t)* to approximate the effect at LC60 of including loadings from the Bunker Hill Box.

**Figure 4-1 Remediation Factors for Upper Basin to SF271 w/o BHSS at Time t=0, $R_o$**

Color. Takes 2 pages. Start on an odd numbered page.

**Figure 4-1 (Continued)**

**Figure 4-2 Zinc Loading at Pinehurst w/o BHSS at Time t=0): $F_o$ (#/d)**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-2 (Continued)

**Figure 4-3 Probability of Meeting Zinc Load Ratios (Lr) at Pinehurst w/o BHSS at Time t=0: Load Ratio Lr = Multiple of Loading Capacity or AWQC**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-3 (Continued)

**Figure 4-4 Remediation Factors for Zinc at Pinehurst w/o BHSS, Expected Values Over Time t: E[R(t)], for the First 100 Years After Remediation**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-4 (Continued)

**Figure 4-5 Zinc Load at Pinehurst w/o BHSS, Expected Values Over Time t: E[F(t)] in Pounds of Zinc Per Day (#/d)**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-5 (Continued)

**Figure 4-6 Zinc Loading at Pinehurst w/o BHSS, Loadings Having 90% Probability of Non-exceedance, $F(t)_{90\%}$**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-6 (Continued)

**Figure 4-7 Zinc Load Ratio (Lr) at Pinehurst w/o BHSS, Lr = Multiple of Zinc Loading Capacity and AWQC: Expected Value E[Lr(t)]**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-7 (Continued)

**Figure 4-8 Zinc Load Ratio Lr at Pinehurst w/o BHSS, 90% Probability Loading Meets Multiple of Zinc Loading Capacity and AWQC**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-8 (Continued)

**Figure 4-9 Probability of Meeting Loading Capacity and AWQC (Load Ratio LR<=1), Zinc Loading from Upper Basin w/o BHSS at Pinehurst**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-9 (Continued)

**Figure 4-10 Accumulate Total Zinc Mass (in 1000's of lbs.) Passing Pinehurst, Expected Value of Time Integral F(t)*dt w/o BHSS**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-10 (Continued)

**Figure 4-11 Accumulated Zinc AWQC Ratio at Pinehurst, Expected Value of Time Integral Lr(t)*dt w/o BHSS**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-11 (Continued)

**Figure 4-12 Remediation Factors for Lower Basin (SF271 to LC60 w/NFCDR) w/o BHSS at time t=0, $R_o$**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-12 (Continued)

**Figure 4-13 Zinc Loading at Harrison w/o BHSS at time t=0: $F_o$ (#/d)**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-13 (Continued)

**Figure 4-14 Probability of Meeting Zinc Loading Ratios (Lr) at Harrison w/o BHSS at time t=0: Load Ratio LR = Multiple of Loading Capacity or AWQC**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-14 (Continued)

**Figure 4-15 Remediation Factors for Zinc at Harrison w/o BHSS Expected Values Over Time, E[R(t)]**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-15 (Continued)

**Figure 4-16 Zinc Load at Harrison w/o BHSS Expected Values Over Time t, E[F(t)] in Pounds of Zinc per day (#/d)**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-16 (Continued)

**Figure 4-17 Zinc Load Ratio (Lr) at Harrison w/o BHSS, Lr = Multiple of Zinc TMDLs and AWQC: Expected Value E[Lr(t)]**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-17 (Continued)

**Figure 4-18 Zinc Load Ratio Lr at Harrison w/o BHSS, 90% Probability Loading Meets Multiple of Zinc Loading Capacity and AWQC**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-18 (Continued)

**Figure 4-19 Probability of Meeting TMDLs and AWQC (Load Ratio LR<=), Zinc Loading From Upper and Lower Basin w/o BHSS at Harrison**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-19 (Continued)

**Figure 4-20 Remediation Factor R Required to Meet Zinc Loading Capacities and AWQC With Specified Probability**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-20 (Continued)

**Figure 4-21 Remediation Factor R Required to Meet Zinc Loading Capacities and AWQC With Specified Probability – Upper Basin (without BHSS) the Only Source**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-21 (Continued)

**Figure 4-22 Remediation Factor R Required to Meet Zinc Loading Capacities and AWQC With Specified Probability – BHSS the Only Source**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-22 (Continued)

**Figure 4-23 Remediation Factor R Required to Meet Zinc Loading Capacities and AWQC With Specified Probability – Lower Basin Only Source**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-23 (Continued)

**Figure 4-24 Probability of meeting Multiples of Zinc Loading Capacity and AWQC for the SFCDR at Pinehurst – Based on Extent of Upper Basin Cleanup**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-24 (Continued)

**Figure 4-25 Probability of Meeting Multiples of Zinc Loading Capacity and AWQC for the CDR at Harrison – Based on Extent of Cleanup**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-25 (Continued)

**Figure 4-26 BHSS Inclusion Factor (BIF) – Pinehurst SF271**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-26 (Continued)

**Figure 4-27 BHSS Inclusion Factor (BIF) – Harrison LC60**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 4-27 (Continued)

**Table 4-1**
**Levels of Zinc Load Ratio (*Lr*) at Pinehurst and Harrison, Daily Load Relative to AWQC, at 100 Years After Remediation**

| Remedial Alternative | Pinehurst | Harrison |
|---|---|---|
| 1 | 7.0 | 3.5 |
| 2 | 4.8 | 2.6 |
| 3 | 2.2 | 1.6 |
| 4 | 1.7 | 1.25 |
| 5 | 6.0 | 3.2 |
| 6 | 6.2 | 3.1 |

AWQC - ambient water quality criteria

# 5.0 SENSITIVITY STUDIES

The three parameters relative loading potential ($RLP_i$), remedial-action-specific remediation factors (complements of remedial effectiveness) ($R_{ij}$), and source volume remediated ($V_i$) were the principal subjects of sensitivity studies. As a general observation, the sensitivity of post-remediation loadings to each of the parameters is modest, although the sensitivity is greatest to relative loading potential rather than to remediation factor (1 – remedial effectiveness) or remediation volumes. Other sensitivity studies were performed on the depletion rate ($\beta$).

Post-remediation load ratios—the main output of the analysis effort—are calculated from three considerations and three corresponding parameter estimates. First, pre-remediation loadings are estimated for each source type, based on the relative loading potential. Second, remediated volume and remedial effectiveness, via remedial-action-specific remediation factors, are estimated for each combination of remedial alternative and source type. Third, decline of the post-remediation loading with time due to source leaching is calculated by multiplying the initial post-remediation loading by an exponentially decreasing decay term. Thus, three (uncertain) parameters are important in calculating post-remediation loading: relative loading potential for each source type, remedial-action-specific remediation factor (1 – remedial effectiveness) for each alternative and source type, and the volume of each source type remediated by each respective alternative.

## 5.1 RELATIVE LOAD POTENTIAL

The sensitivities of downstream loadings to relative load potential for the various source types, measured by the derivative, are summarized in Table 5-1. These range from +0.14 to −0.22, with the exception of the unremoved deeper floodplain sediments, which have sensitivities as high as 0.65.

The way to interpret these sensitivities is the following: The sensitivities are slopes of the curves found by plotting the value of *E[Ro]* vs. the parameter of which the sensitivity is being measured, in this case, *RLP*. The slope is measured by taking the value of downstream *E[Ro]* at the 0.95 bound on *RLP*, subtracting the value of *E[Ro]* at the 0.05 bound on *RLP*, and dividing by the difference in the value of *RLP* between those two bounds (mathematically, the values in Table 5-1 are the slopes of the secant to each of the curves). This is explained in more detail in Appendix D.

The range of uncertainty in the input values of relative loading potential are high, although the relatively high sensitivity for deeper floodplain sediments is somewhat balanced by a low coefficient of variation. Post-remediation loadings are more sensitive to RLPs than to remedial effectiveness or remediation volumes.

## 5.2 REMEDIAL-ACTION-SPECIFIC REMEDIATION FACTORS

Table 5-2 summarizes the sensitivities of downstream loadings to remedial-action-specific remediation factors (1 – remedial effectiveness) for the various remedial alternatives and source types, measured by the derivative. These range from 0.0 to −0.28. The range of uncertainty in the input values of remediation factors measured as coefficients of variation is 0.04 to 0.7 (Appendix D, Section D.4). Thus the uncertainty in remedial effectiveness has a relatively small contribution to the uncertainty in downstream, post-remedial loadings. The one exception to this range of uncertainty is the remedial alternative of excavation and disposal in a repository, which has a coefficient of variation of 1.76, and is part of remedial alternatives 3 and 4. However, the expected value of the remedial effectiveness for this remedial approach is about 0.01, meaning that the approach is highly effective, and the high coefficient of variation is principally due to a small standard deviation being divided by an equally small expected value. The impact on predictive uncertainty is negligible.

## 5.3 REMEDIATED VOLUME

Table 5-3 summarizes the sensitivities of downstream loadings to the volume remediated for the various source types, measured by the derivative. These range from 0.0 to −0.30. The range of uncertainty in the input values of the volume remediated is 0.2 to 0.3. Thus the uncertainty in remediated volumes have relatively small contribution to the uncertainty in downstream, post-remediation loadings.

## 5.4 DISTRIBUTIONAL ASSUMPTION

Sensitivity studies were performed for the assumption of lognormality in the uncertainty analysis. Neither the results for non-exceedance probabilities related to remedial effectiveness (Figure 5-1) nor exceedance probabilities related to time (Figure 5-2) are sensitive to the distribution assumption, within reasonable bounds. These figures show exceedance probabilities under the competing assumptions of normal, lognormal, and beta distributed uncertainty. The results differ little from one distribution to another.

## 5.5 CORRELATIONS AMONG PARAMETERS

Correlation among the principal parameters is discussed in Appendix B, Section B.3.3.1, which details the approach used in the predictive analysis to deal with this correlation. Sensitivity analyses were performed to assess the importance of such possible correlation. Detailed results are presented in Appendix D.

The combined effect of correlations among the $RLP_j$, $V_{ij}$, and $R_{ij}$ manifests in the remedial effectiveness, $R_o$. Remedial effectiveness, $R_o$, is calculated as the ratio of post-remediation loading to pre-remediation loading, which in turn is proportional to the ratio of the relative remediated volume of sources after remediation to the relative remediated volume of sources before. However, each of these relative remediated volumes in turn depends on common $RLP_j$, $R_{ij}$, and $V_{ij}$ values. Thus, the numerator and denominator of the ratio used to forecast remedial effectiveness immediately post-remediation are positively correlated. This correlation tends to reduce the uncertainty in $R_o$, but at the same time also changes its mean, partly because the variables are assumed to be lognormally distributed. Details are discussed in Appendix B, Section B.3.3.1.

Higher metal loads at Pinehurst and Harrison are correlated with higher stream discharges. While the concentration of metals at higher discharge decreases, the larger volume of water more than makes up for this decrease in concentration, with the result that the load increases. However, the remediation factors at higher discharges are expected to decrease. Thus, there is expected to be a negative correlation between load and remediation factor.

In the analysis effort, the best estimate of this correlation was taken to be −0.5. In the early years after remediation, up to 100 years, the effect on post-remediation loading is modest, about 10 percent over the range between no correlation and $\rho = -0.5$. However, the effect increases with time and becomes moderate to large for long time periods, say, 500 years.

**Figure 5-1 95% Non-Exceedance Estimates v. Expected Values of Remediation Factor R, Assuming Uncertainty in R Follows Lognormal, Normal, and Beta Distributions**

Color. Takes 2 pages. Start on an odd numbered page.

Figure 5-1 (Continued)

**Figure 5-2 Sensitivity Analysis: Remediation Factors for Zinc at Pinehurst w/o BHSS, Estimates of 95% Non-Exceedance Over Time by Lognormal, Normal and Beta Distributions**

**Table 5-1**
**Sensitivities of the Expected Remediation Factor in the PAT1 Analysis to Relative Loading Potential ($RLP_j$) for Source Types and Remedial Alternatives, Expressed as the Derivative $dE[R_o]/dRLP_j$**

| Source Type | Sensitivity: $dE[R_o]/dRLP_j$ | | | | |
|---|---|---|---|---|---|
| | **Alt 2** | **Alt 3** | **Alt 4** | **Alt 5** | **Alt 6** |
| Floodplain sediments | -0.04 | -0.11 | -0.12 | 0.00 | 0.00 |
| Deeper floodplain sediments: not removed | 0.25 | 0.55 | 0.65 | 0.18 | 0.06 |
| Tailings: impounded in inactive facilities | -0.20 | -0.13 | -0.11 | -0.22 | -0.20 |
| Tailings: impounded in active facilities | 0.14 | -0.03 | -0.03 | 0.04 | 0.04 |
| Tailings: unimpounded | -0.025 | 0 | -0.005 | 0 | -0.025 |
| Waste rock with loading potential | -0.08 | 0.10 | -0.07 | -0.04 | -0.08 |
| Waste rock without loading potential | 0.07 | 0.11 | 0.08 | 0.01 | 0.03 |

Notes:
Alt - Alternative
PAT1 - Probabilistic Analysis Tool 1

**Table 5-2**
**Sensitivities of the Expected Remediation Factor in the PAT1 Analysis to the Remedial-Action-Specific Remediation Factors ($R_{ij}$) for Source Types and Remedial Alternatives, Expressed as the Derivative $dE[R_o]/dR_{ij}$**

| Source Type | Sensitivity: $dE[R_o]/dR_{ij}$ | | | | |
|---|---|---|---|---|---|
| | Alt 2 | Alt 3 | Alt 4 | Alt 5 | Alt 6 |
| Floodplain sediments: excavation and disposal in repository | 0.12 | 0.23 | 0.28 | 0.00 | 0.00 |
| Floodplain sediments: hydraulic isolation at discrete facilities | 0.14 | 0.20 | 0.28 | - | - |
| Floodplain sediments: hydraulic isolation of stream reaches | 0.12 | 0.14 | - | - | - |
| Impounded tailings at inactive facilities: capping and hydraulic isolation | 0.02 | 0.02 | - | - | - |
| Impounded tailings at active facilities: hydraulic isolation | - | 0.12 | 0.12 | - | - |
| Impounded tailings at inactive facilities: excavation and disposal in repository | - | 0.00 | 0.04 | 0.00 | - |
| Unimpounded tailings: excavation and disposal in repository | 0.00 | 0.04 | 0.04 | 0.00 | 0.00 |
| Unimpounded tailings: cap, cover and revegetate | 0.02 | 0.00 | - | 0.01 | 0.00 |
| Waste rock with loading potential: cap | 0.00 | 0.02 | 0.00 | 0.00 | - |
| Waste rock with loading potential: excavation and disposal in repository | - | 0.01 | 0.03 | 0.00 | - |
| Waste rock with loading potential: regrade and cover | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| Upland waste rock: regrade and cover | - | 0.00 | 0.00 | 0.00 | 0.00 |
| Waste rock with loading potential: regrade, revegetate, and stabilize toe | 0.01 | - | - | 0.00 | 0.02 |
| Adit discharge: active treatment | - | 0.05 | 0.05 | 0.00 | - |
| Adit discharge: passive treatment | - | 0.07 | 0.07 | - | - |

Notes:
Alt - Alternative
PAT1 - Probabilistic Analysis Tool 1

**Table 5-3**
**Sensitivities of the Expected Remediation Factor in the PAT1 Analysis to the Volume of Remediated Source Material ($V_{ij}$) for Source Types and Remedial Alternatives, Expressed as the Derivative $dE[R_o]/dV_{ij}$**

| Source Type | Sensitivity: $dE[R_o]/dV_{ij}$ | | | | |
|---|---|---|---|---|---|
| | Alt 2 | Alt 3 | Alt 4 | Alt 5 | Alt 6 |
| Floodplain sediments: excavation and disposal in repository | -0.14 | -0.02 | -0.30 | -0.02 | -0.27 |
| Deeper floodplain sediments: no remediation | 0.05 | 0.10 | 0.15 | 0.01 | 0.01 |
| Floodplain sediments: hydraulic isolation of stream reaches | -0.02 | -0.08 | -0.10 | - | - |
| Impounded at inactive facilities: capping and hydraulic isolation | -0.02 | -0.03 | - | - | - |
| Unimpounded tailings: excavation and disposal in repository | 0.00 | 0.00 | 0.00 | -0.03 | -0.03 |
| Unimpounded tailings: cap, cover and revegetate | - | 0.00 | -0.03 | 0.00 | -0.03 |
| Waste rock | 0.00 | - | - | 0.00 | 0.00 |
| Waste rock with loading potential: cap | 0.00 | -0.01 | 0.00 | 0.00 | - |
| Waste rock with loading potential: regrade and cover | -0.01 | 0.00 | -0.02 | 0.00 | 0.00 |
| Adit discharge: passive and active treatment | -0.04 | -0.02 | -0.02 | -0.04 | -0.02 |

Notes:
Alt - Alternative
PAT1 - Probabilistic Analysis Tool 1

# 6.0 CONCLUSIONS

The principal objective of the predictive analysis is to assess the effect of specific upstream remedial alternatives on downstream metal loadings and to quantify the certainty with which remedial goals can be met. The analysis focuses on the six remedial alternatives identified in the FS for the upper and lower Coeur d'Alene Basin to Harrison and provides outcome forecasts (without the Bunker Hill Box included) for two specific locations in the basin: on the SFCDR at Pinehurst and on the mainstem CDR at Harrison. The former reflects remedial activities in the upper basin to Pinehurst, while the latter also includes remedial activities in the lower basin from Cataldo to Harrison.

The results are scientific and engineering approximations based on the interpretation of available information. While there is a great deal of information on the Coeur d'Alene Basin, the basin is large and complex. Therefore, results are conditional on the assumptions made in synthesizing information and in the analysis.

## 6.1 ASSUMPTIONS

The principal assumptions of the predictive analysis are the following:

1. Historical stream data are representative of pre-remediation conditions.

2. The mass of source material is proportional to source volume, and the effectiveness of remediation in reducing source loads is proportional to the mass remediated.

3. Loading decays over time at a rate proportional to the total remaining metal mass, that is, the ratio of loading to remaining leachable metal mass is constant over time.

4. Loading potential for a given source type reflects the aggregate effect of loadings and the mix of source types upstream of a monitoring location.

5. The effectiveness of a given remedial action varies with the aggregate of the specific sources remediated.

6. Zinc loading from the deep aquifer material has been accurately estimated in a probabilistic sense. To the extent, if any, that the zinc loading from deep aquifer material exceeds that estimated, then for each action alternative, the expected values of the effectiveness of a remedial action may be systematically underestimated.

7. Impacted groundwater does not affect surface water quality until it discharges to surface water.

8. The relationships between stream discharge and water hardness continues into the future and will not be significantly affected by remedial action.

The predictive analysis combines existing information on the basin with scientific understanding of environmental processes, but neither the existing information nor our scientific understanding of environmental processes in the Coeur d'Alene Basin is perfect. Detailed historical monitoring data are limited. As a result, the scientific and professional judgment of experts is called upon to interpret data and to help estimate parameter values, which is standard practice in scientific and regulatory modeling. This process introduces uncertainties which the predictive analysis attempts to capture and quantify. It is important to note that, as the monitoring program continues and a more extensive data base is compiled, the present model and parameter estimates will be refined, if and as appropriate.

## 6.2 SUMMARY RESULTS

The predictive analysis was implemented in two versions. The first version analyzes six alternatives identified in the FS based on source-by-source remedial actions. The analysis and results do not include loading contribution from the Bunker Hill Box, which is undergoing remedial action under existing RODs. A summary of the post-remediation forecasts of dissolved zinc results for Pinehurst SF27 and Harrison LC60 are shown in Table 6-1.

The predictive analysis uses a simple probabilistic approach to capturing uncertainties and propagating their combined effect through to forecasts. Best estimates, standard deviations, and correlations are assessed for the input entering the analysis; and best estimates, standard deviations, and correlations are calculated for the output. The standard deviations associated with the output allow quantitative conclusions to be drawn about the degree of uncertainty in the forecasts.

The 10 and 90 percent probability bounds on the respective estimates shown in Table 6-1 are based on the assumption of a lognormal distribution of uncertainty. The lognormality assumption was considered appropriate because historic concentration and load data in the basin have been shown to follow lognormal distributions, as well as precedent in the geologic/hydrologic literature (e.g., Davis 1986, Gilbert 1987, and Journel and Huijbregts 1978), and consistency with theoretical models based on the central limit theorem and the theory of successive random dilutions (Ott 1995). While other distributional assumptions would lead to somewhat different bounds, the sensitivity study found that the differences were relatively minor, as indicated in Figure 5-1 and 5-2.

The second version of the predictive analysis treats "what-if" scenarios that allow input of hypothetical or estimated remediation factors for specific areas of the basin, including major tributaries and reaches of the SFCDR (upper basin) and CDR (lower basin). These calculations

were made for dissolved zinc at the following locations: Canyon Creek, Ninemile Creek, Pine Creek, upper basin (SFCDR at Pinehurst), and lower basin (CDR at Harrison).

As can be seen in Table 6-1, even if no remedial actions are taken (Alternative 1), natural depletion of source materials in the basin will eventually lead to lowering of dissolved zinc concentrations to meet AWQC. However, this could take 1,000 years. Table 6-2 shows the expected (mean) percent reduction in zinc concentration at Pinehurst and Harrrison for the five remedial alternatives that were analyzed. Alternative 1 is the no action case. Only Alternatives 3 and 4 yield high proportional reductions in zinc concentration within a typical human span of life.

## 6.3 RESULTS NOT SENSITIVE TO VARIATION OF INPUT PARAMETERS

Sensitivity studies were conducted to verify the predictive analysis. The purpose of sensitivity analysis was to determine which factors have the greatest effect on measures of performance and how large these effects are. Three (uncertain) parameters are important in calculating post-remediation loading and were the principal subject of sensitivity analyses: relative loading potential for each source type, remedial-action-specific remediation factors for each alternative and source type, and the volume of each source type remediated and not remediated (i.e., no action) by each respective alternative. Sensitivity studies were also performed for the assumption of lognormality in the uncertainty analysis and for the source depletion factor. As a general observation, the sensitivity of post-remediation loadings to each of the parameters is modest, although the sensitivity is greatest to relative loading potential rather than to remedial effectiveness or remediation volumes.

## 6.4 DATA AVAILABILITY AND EXPERT JUDGMENT

The need for a predictive analysis derives from the complexity of the basin and the need to combine a large number of considerations, calculations, and parameter estimates in making forecasts. Not all of these are known with precision. Therefore, so while best estimate forecasts can be made, these forecasts also contain uncertainty. It is important that uncertainties entering the analysis be quantified and then translated into uncertainty bands on resulting forecasts. The predictive analysis does this using probabilistic methods.

As a result of the absence of detailed historical data and the need to assess and quantify hypothetical future conditions related to remedial performance, the professional judgment of experts was called upon to interpret those data that do exist and to help estimate parameter values. This is standard practice in current policy and regulatory modeling where the use of quantified scientific and engineering judgment is widespread.

Quantified expert judgment is typically used when data are few, difficult to obtain, or subject to interpretation. It is also used to bring together differing types of information, to determine what is known and how well, and to document information. Probabilistic methods are an integral part of the analysis of expert judgment, providing mathematical methods for aggregating judgments, quantifying the precision with which predictions are made, combining different sources of data, and formulating models. As better data become available for the basin, the predictive analysis can be updated and its forecasts improved and made more precise.

**Table 6-1**
**Estimates of Years Required for Post-Remediation Dissolved Zinc Loadings at Pinehurst and at Harrison to Meet Ambient Water Quality Criteria as a Function of Remedial Alternative**

| Estimate | Remedial Alternative (years) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| **Pinehurst** | | | | | | |
| Median | 890 | 700 | 400 | 280 | 820 | 845 |
| 10% and 90% bounds | 650-1000+ | 550-1000 | 250-650 | 150-500 | 600-1000+ | 600-1000+ |
| **Harrison** | | | | | | |
| Median | 720 | 570 | 270 | 170 | 650 | 675 |
| 10% and 90% bounds | 650-1000+ | 250-1000+ | 0-750 | 0-650 | 350-1000+ | 350-1000+ |

**Table 6-2**
**Expected Reduction of Zinc Concentrations at Pinehurst and Harrison (Without the Bunker Hill Box Included) at 100 Years for the Five Remedial Alternatives Analyzed**

| Location | ALT 1 | ALT 2 | ALT 3 | ALT 4 | ALT 5 | ALT 6 |
|---|---|---|---|---|---|---|
| Pinehurst | 25% | 47% | 77.5% | 81% | 35% | 32.5% |
| Harrison | 24% | 42.5% | 65% | 70% | 38% | 30% |

Note: Alt - Alternative

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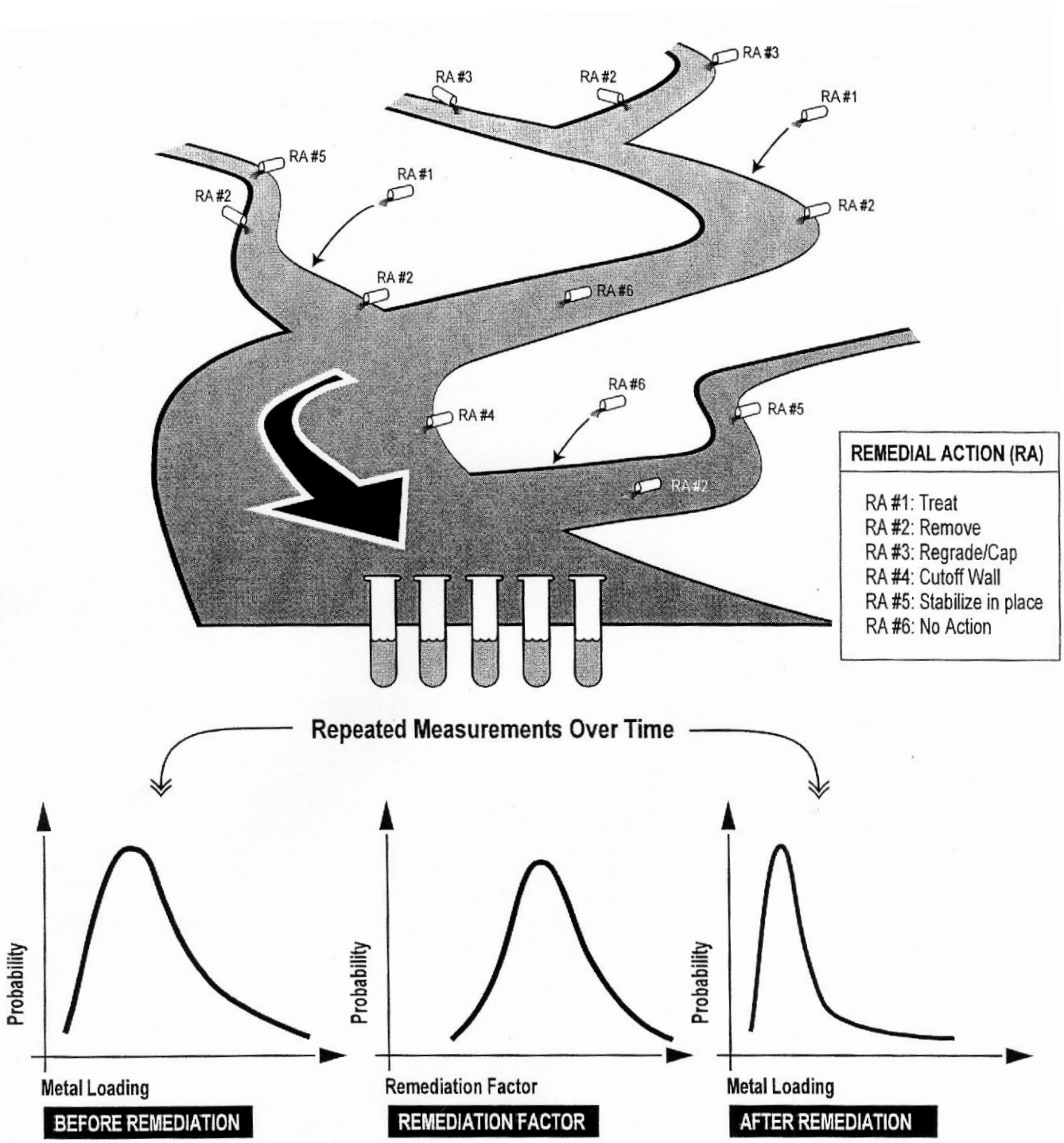
## Metal Loading Before and After Remedial Action




*Remedial actions (RAs) at metal sources reduce metal loading in the stream. The net effectiveness of the RAs are predicted using a "remediation factor." The predicted metal loading after remedial action is equal to the metal loadings before remediation multiplied by the remediation factor. The metal loading before and after remedial action and the remedial factor are each described using lognormal distributions.*

| | | | |
|---|---|---|---|
| EPA REGION 10 | Coeur D'Alene Basin RI/FS<br>A PREDICATIVE ANALYSIS FOR<br>POST-REMEDIATION METAL LOADING<br>Doc Control: 33753909-7326 | Ref: 027-RI-CO-102<br>Coeur D'Alene Basin RI/FS<br>Doc Control: 4162500.6538.05a<br>Probabilistic Series<br>09/13/01 | **Figure 2-1** |

## Historical Dissolved Zinc Loadings:
## South Fork Coeur d'Alene River at Pinehurst (1991-1999)

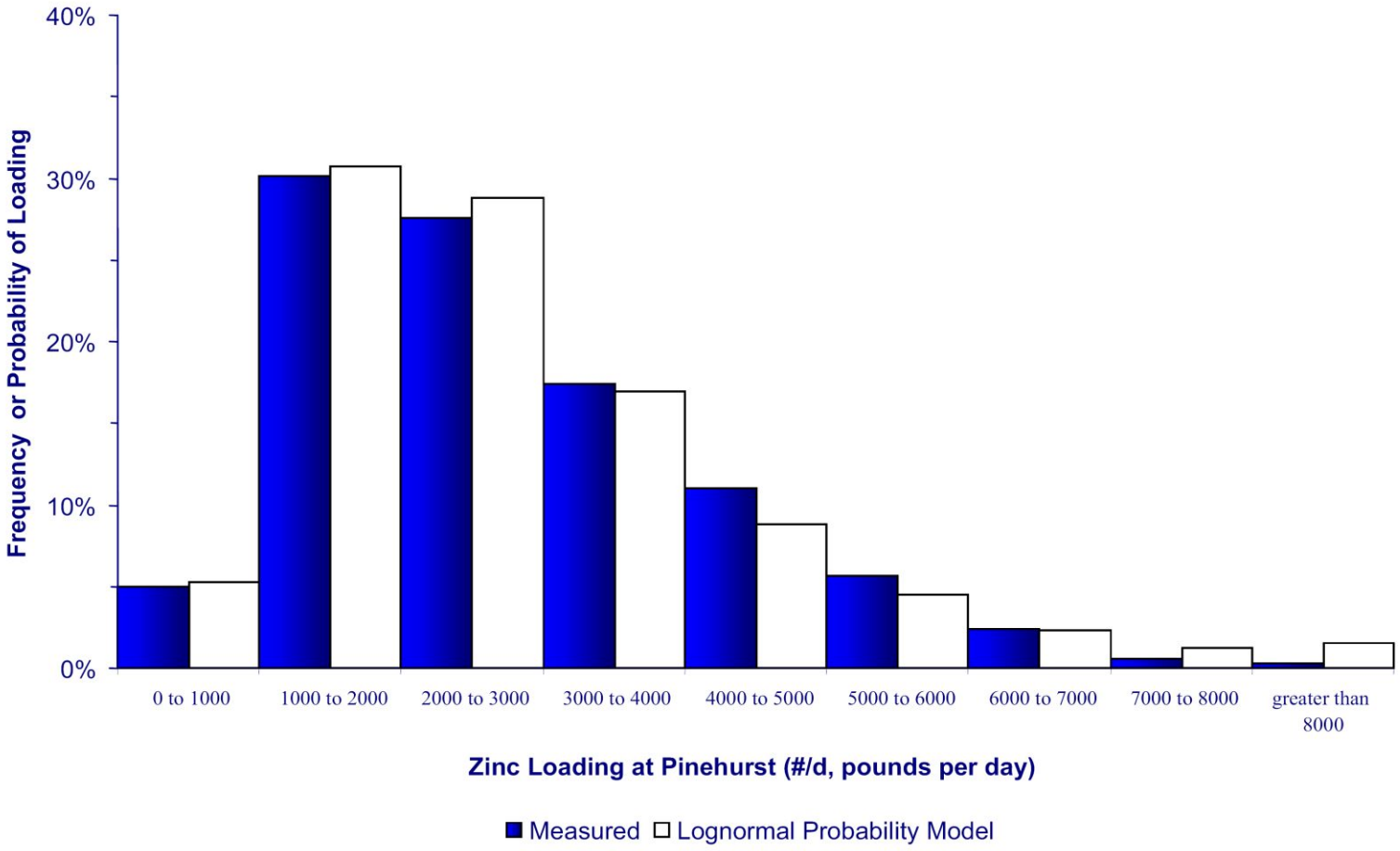



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**Figure 2-2**

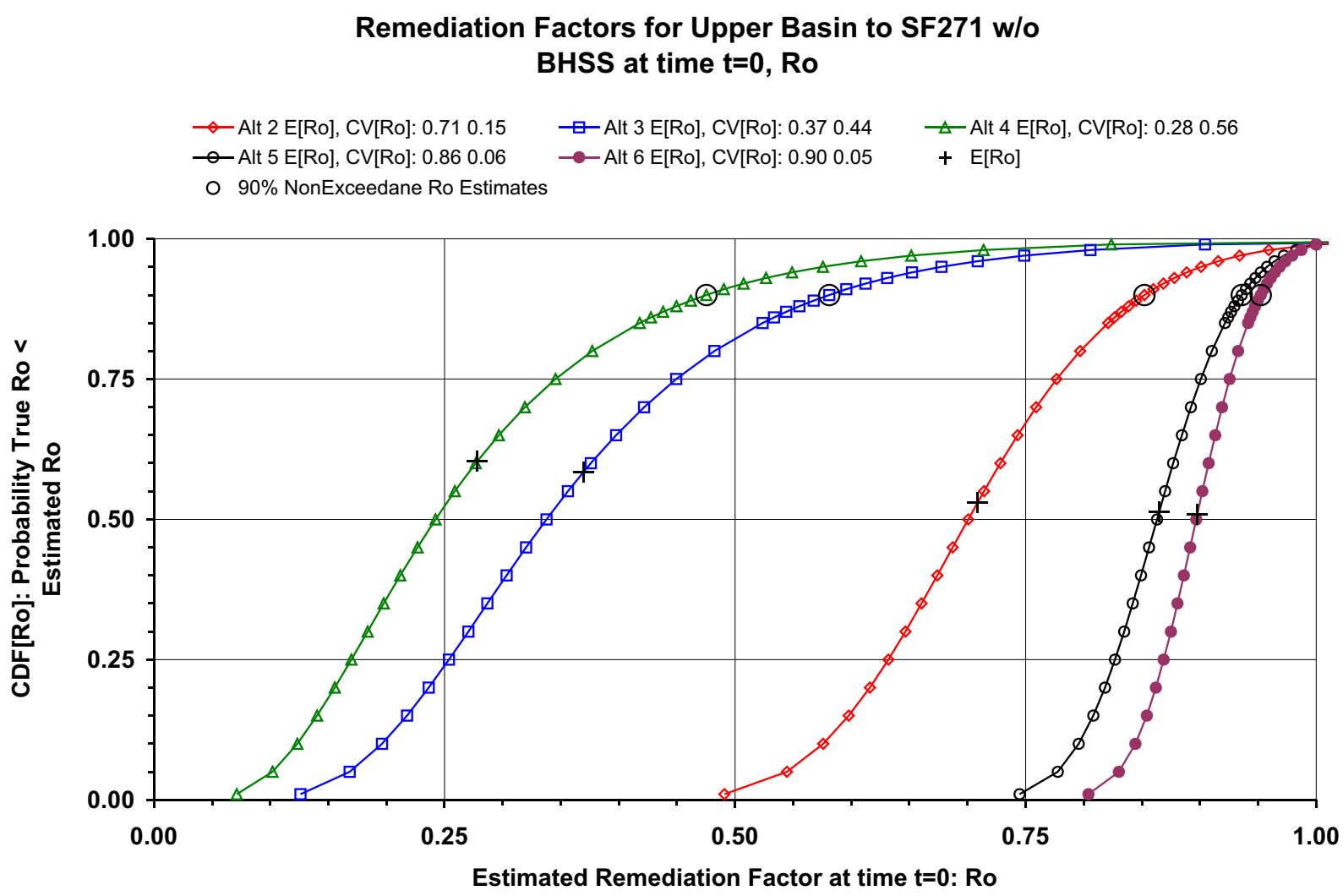


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**Figure 4-1**

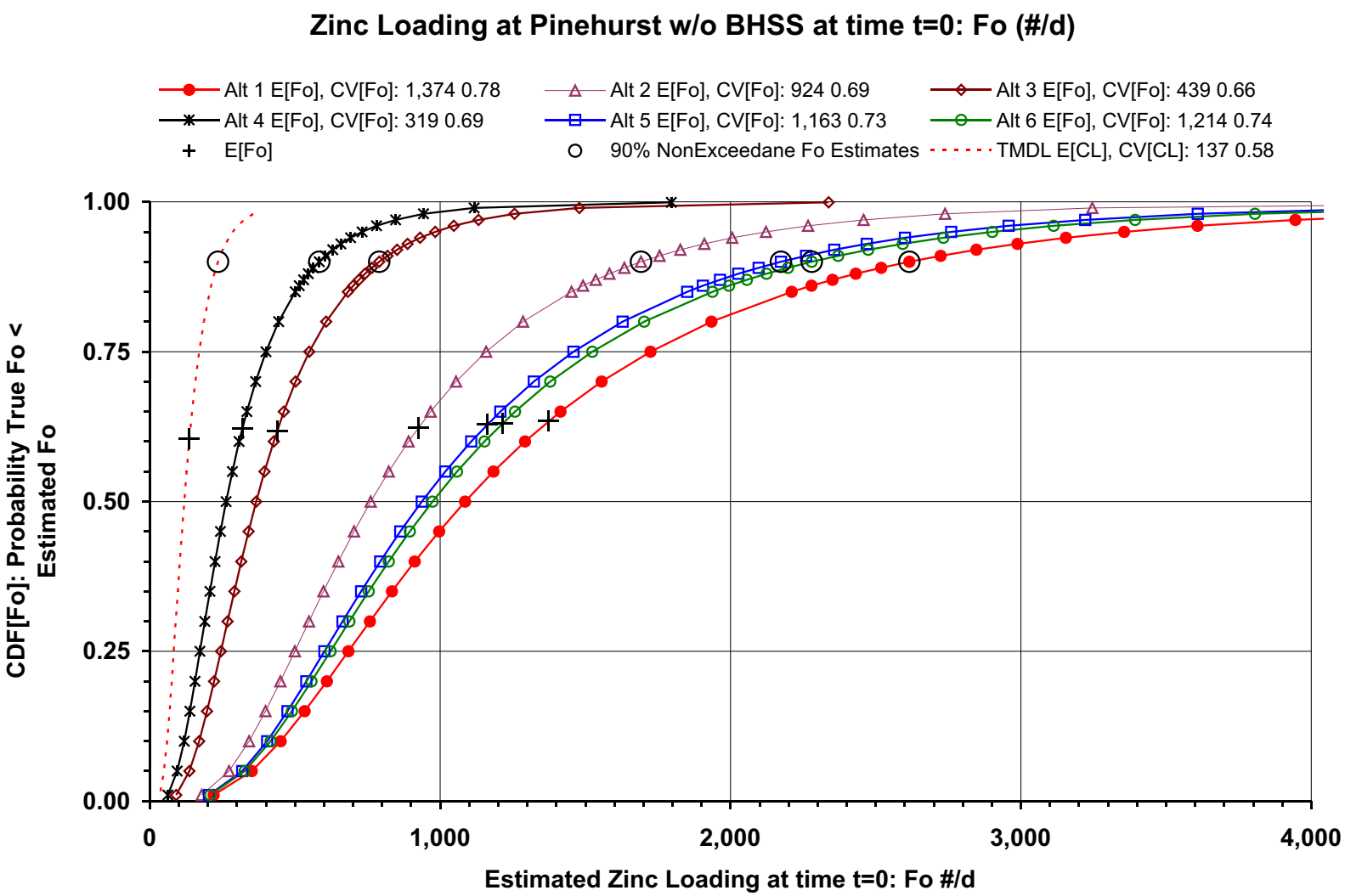


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**Figure 4-2**

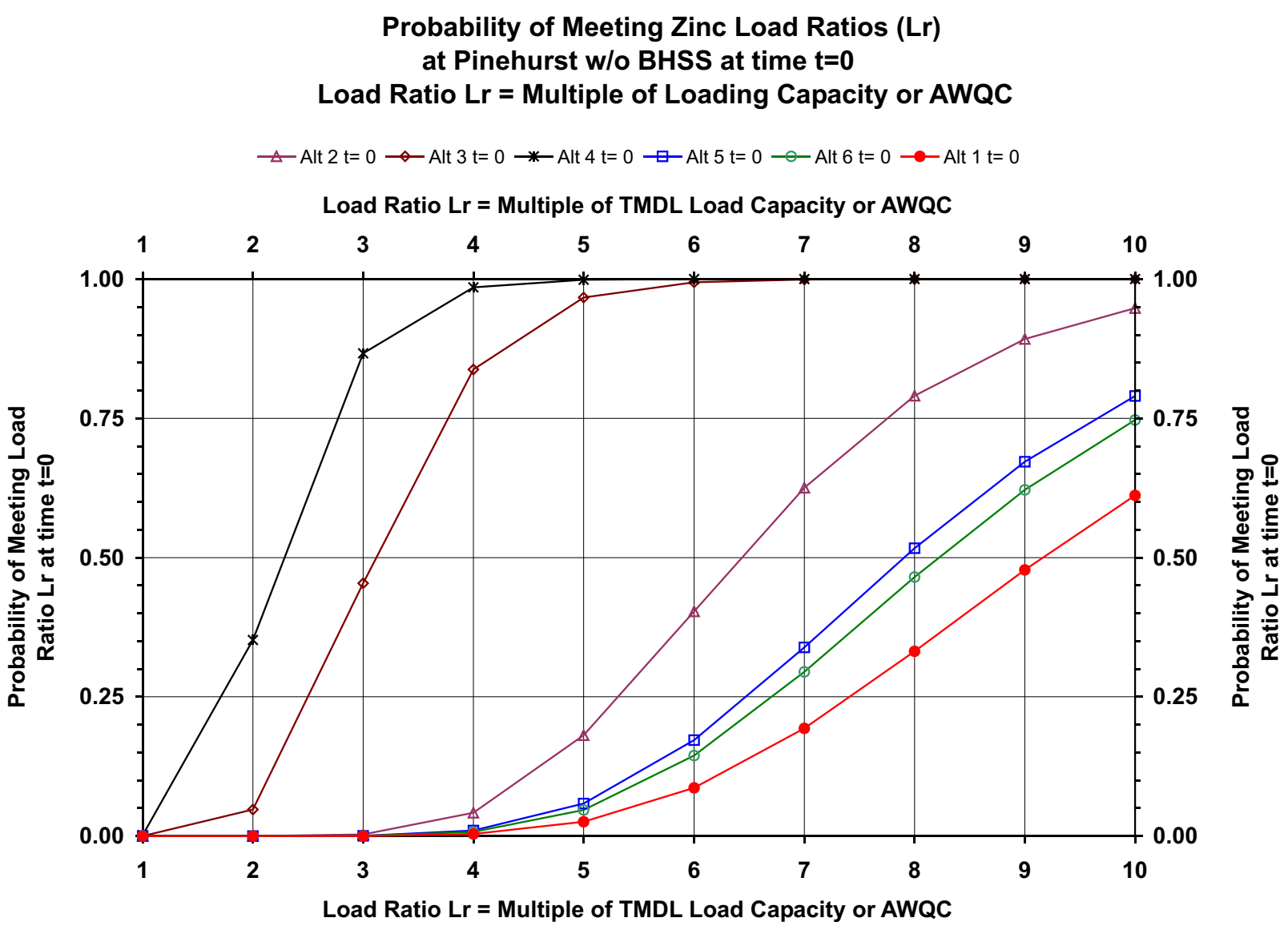


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**Figure 4-3**

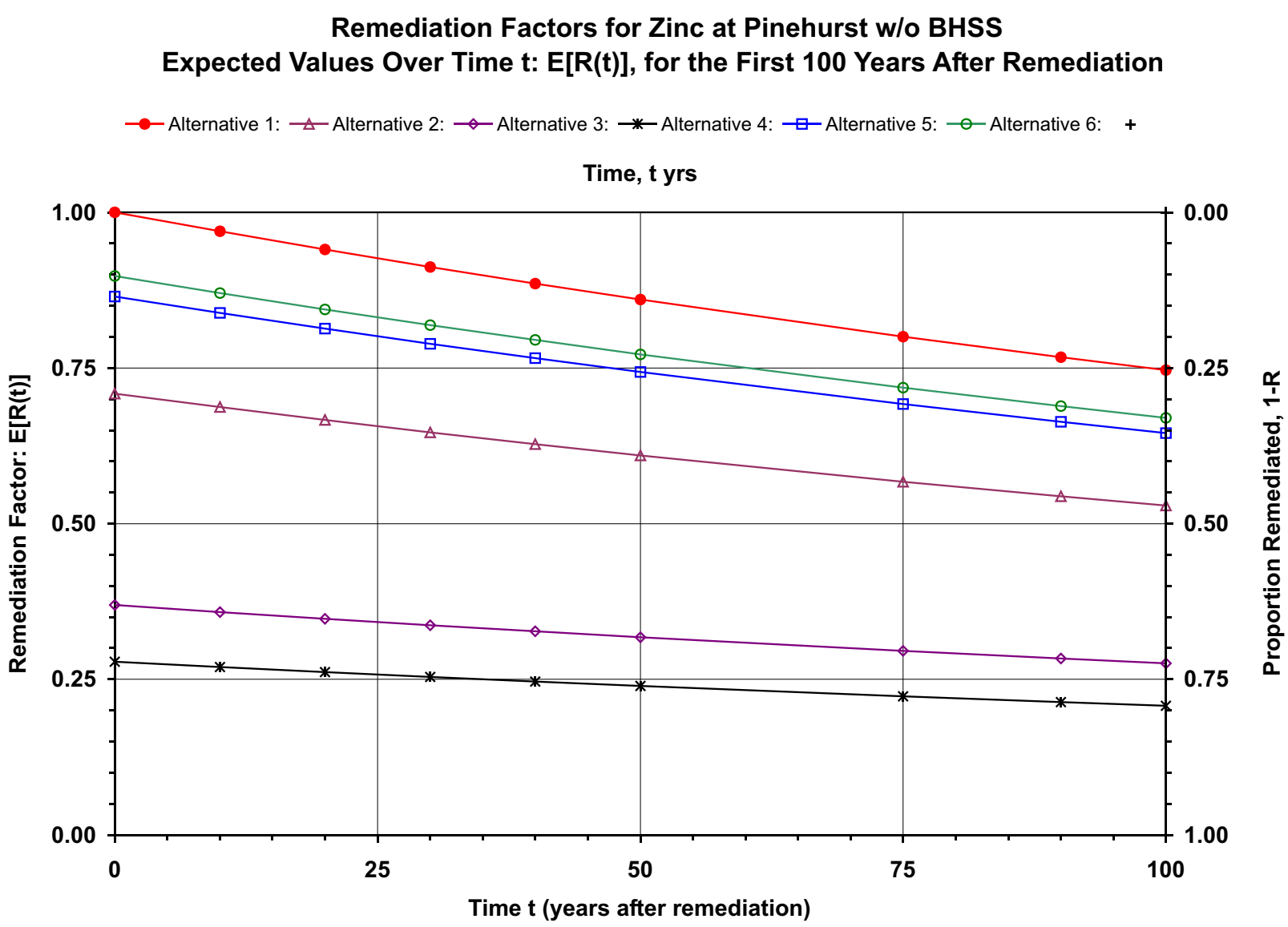


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**Figure 4-4**

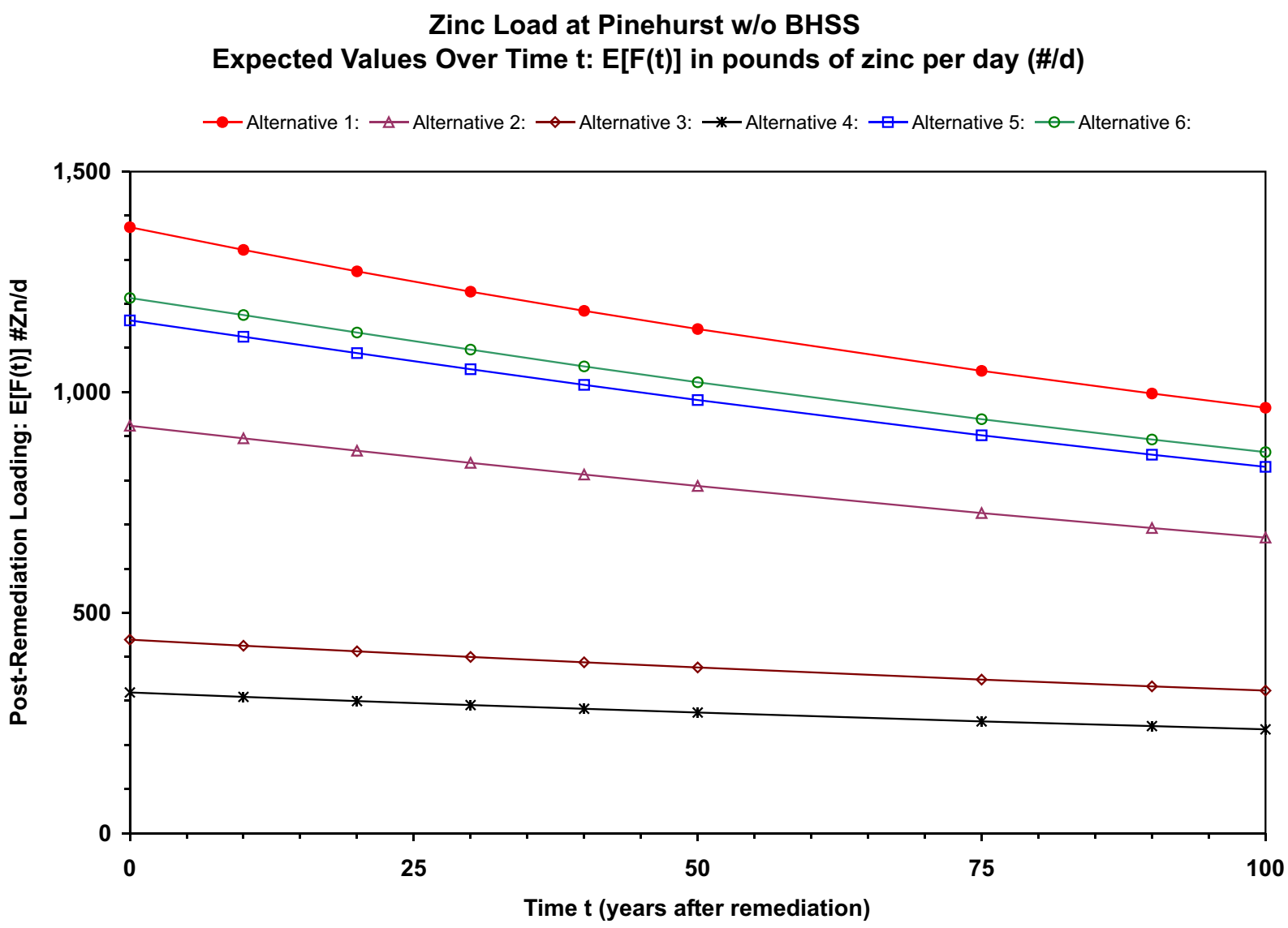


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**Figure 4-5**

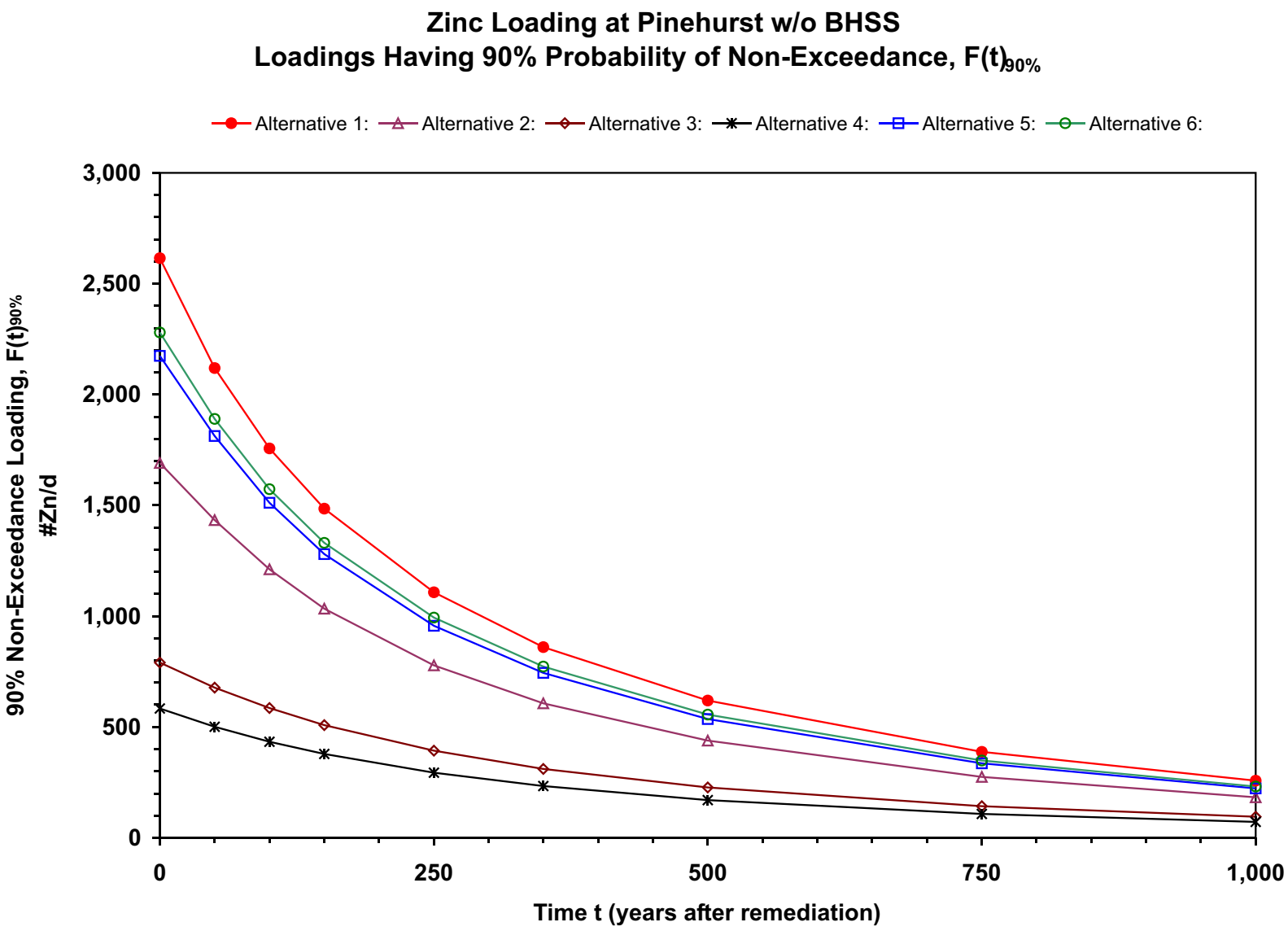


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**Figure 4-6**

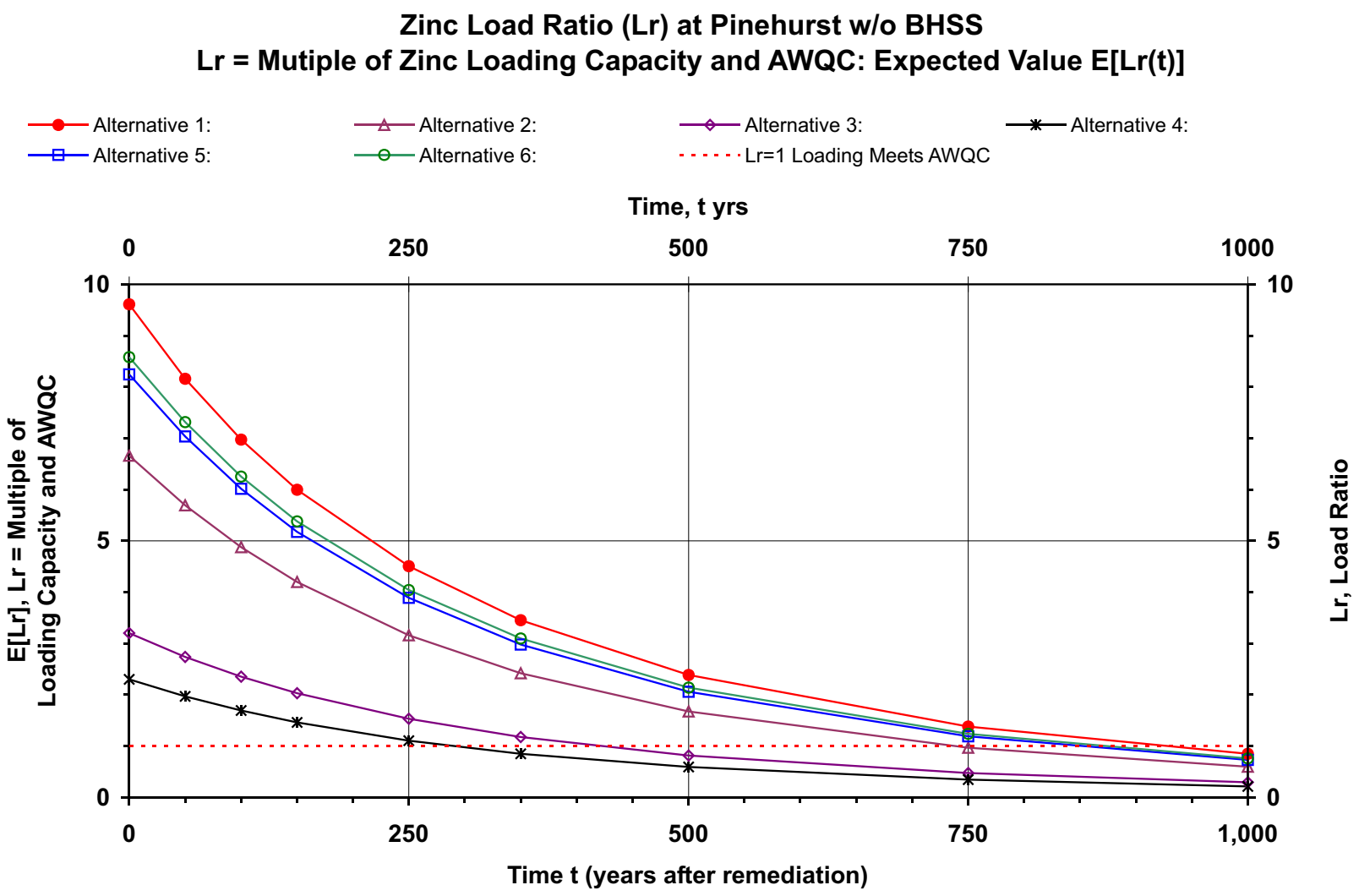


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**Figure 4-7**

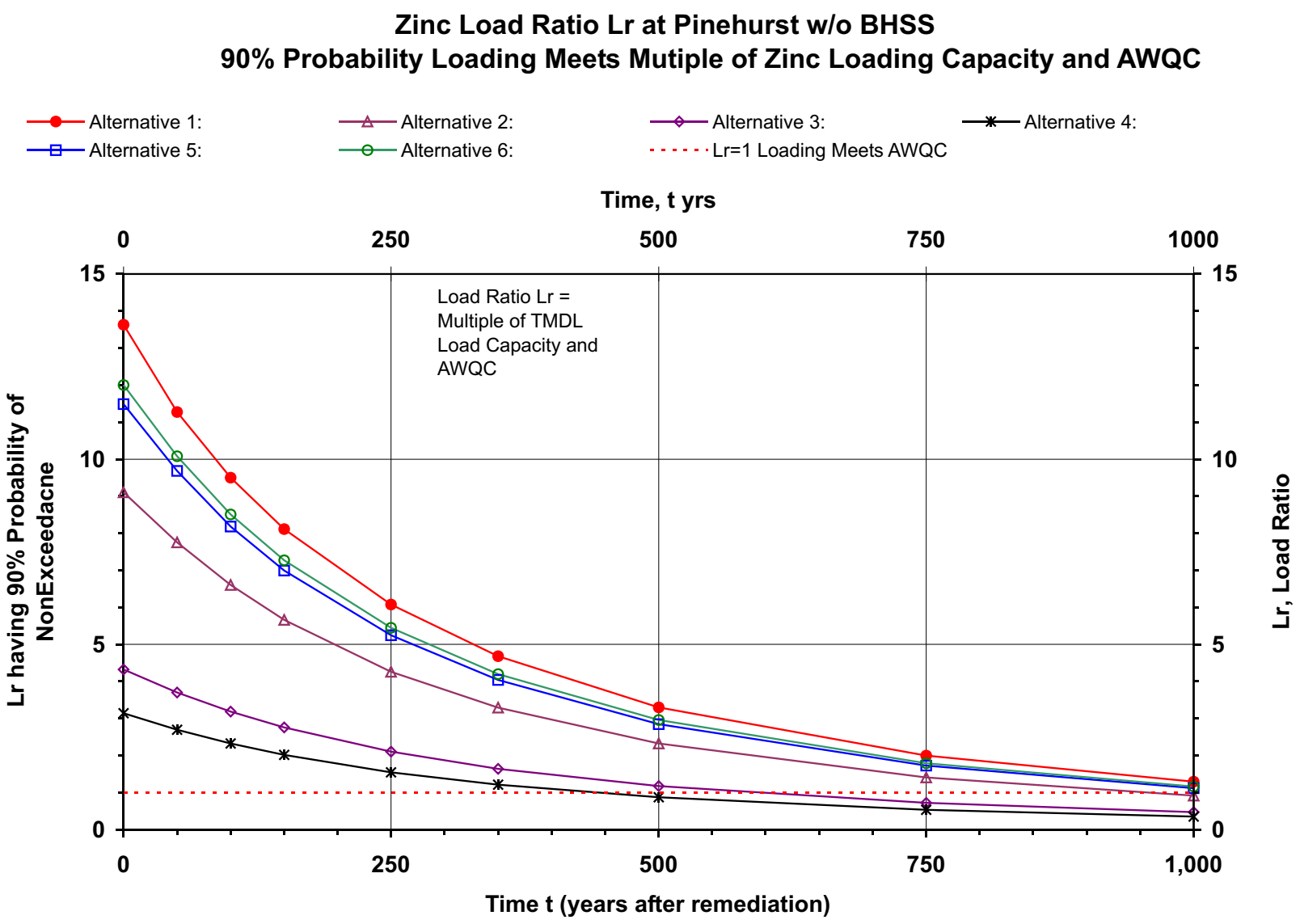


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**Figure 4-8**

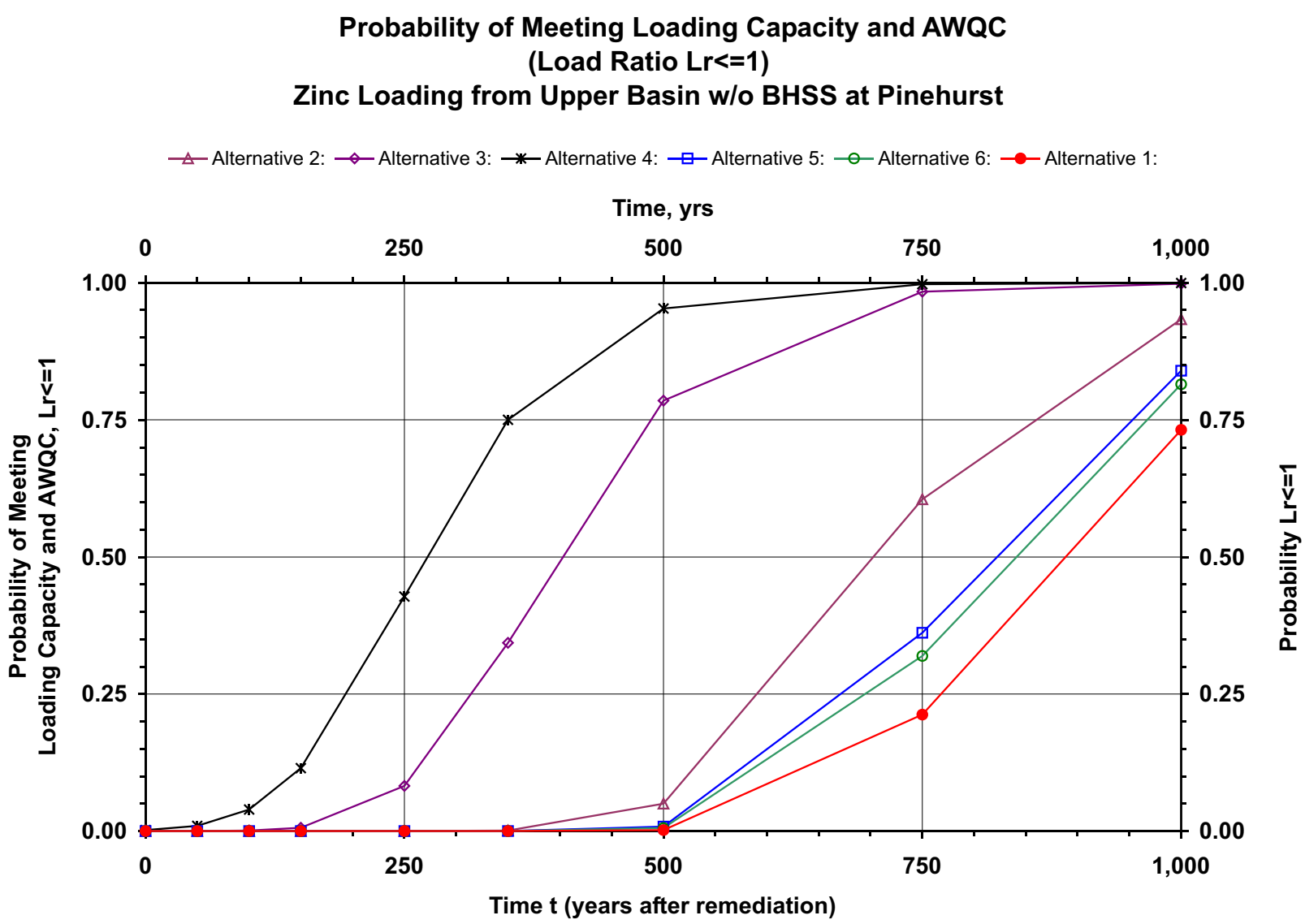


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**Figure 4-9**

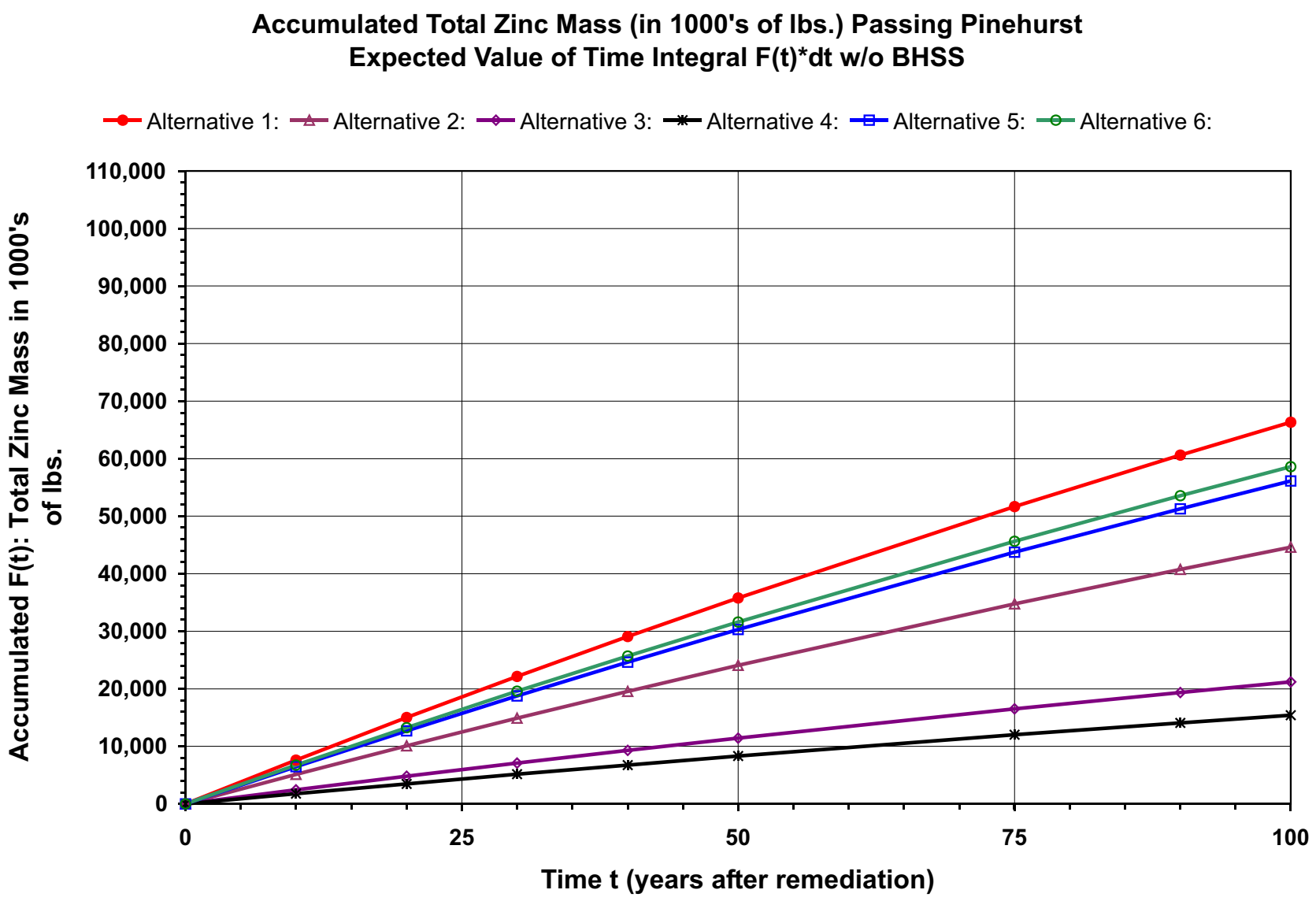


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**Figure 4-10**

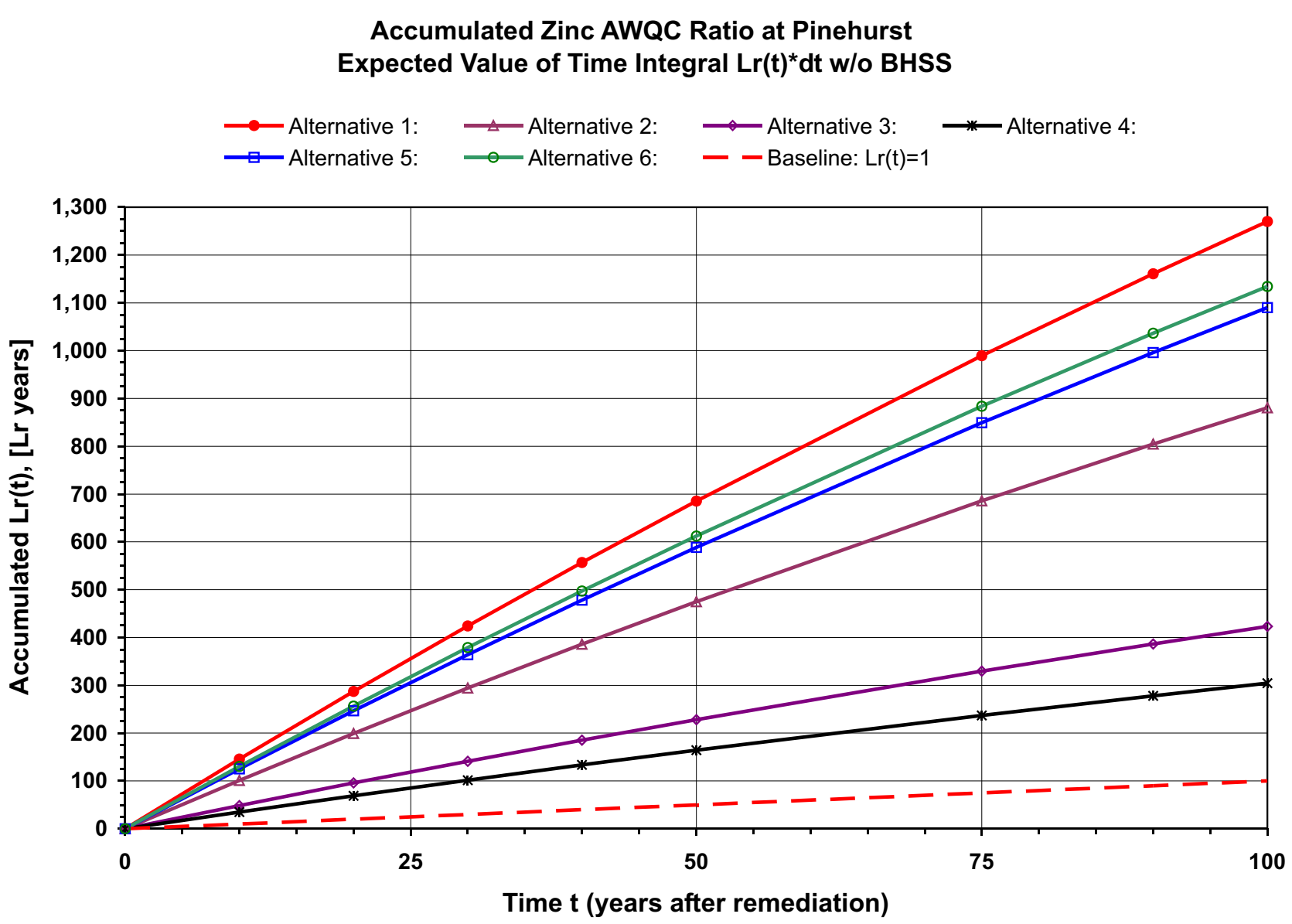


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**Figure 4-11**

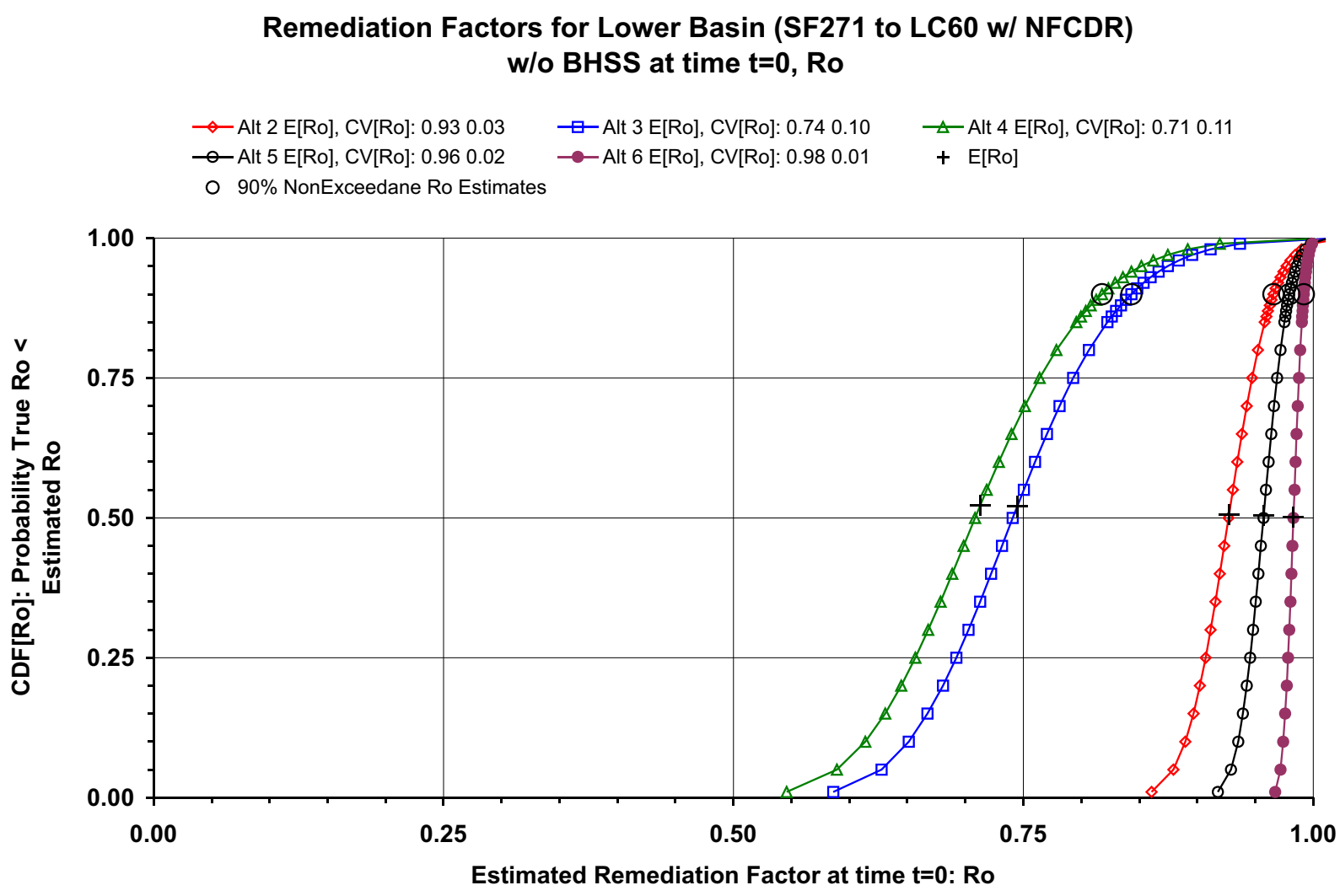


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**Figure 4-12**

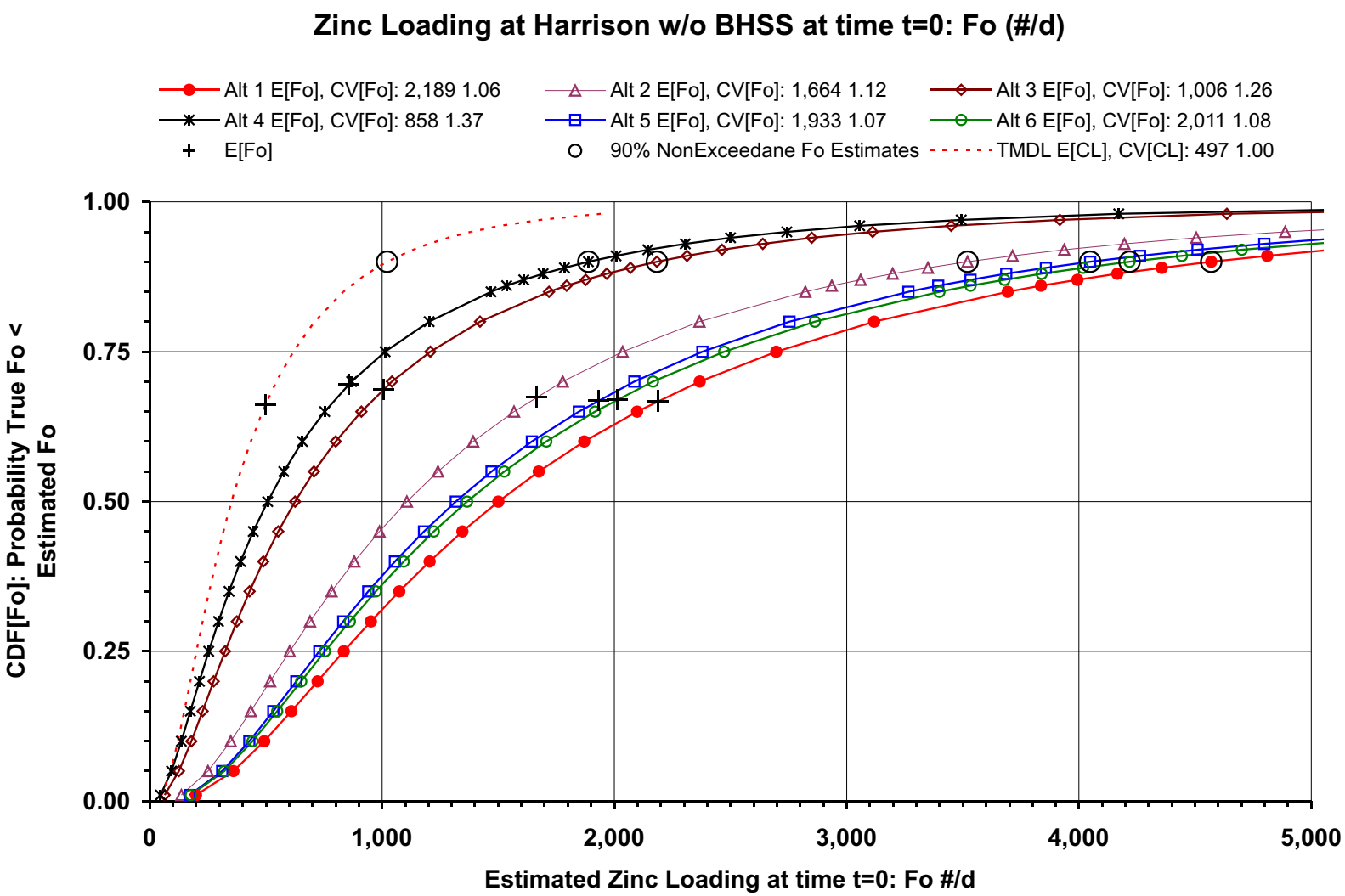


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**Figure 4-13**

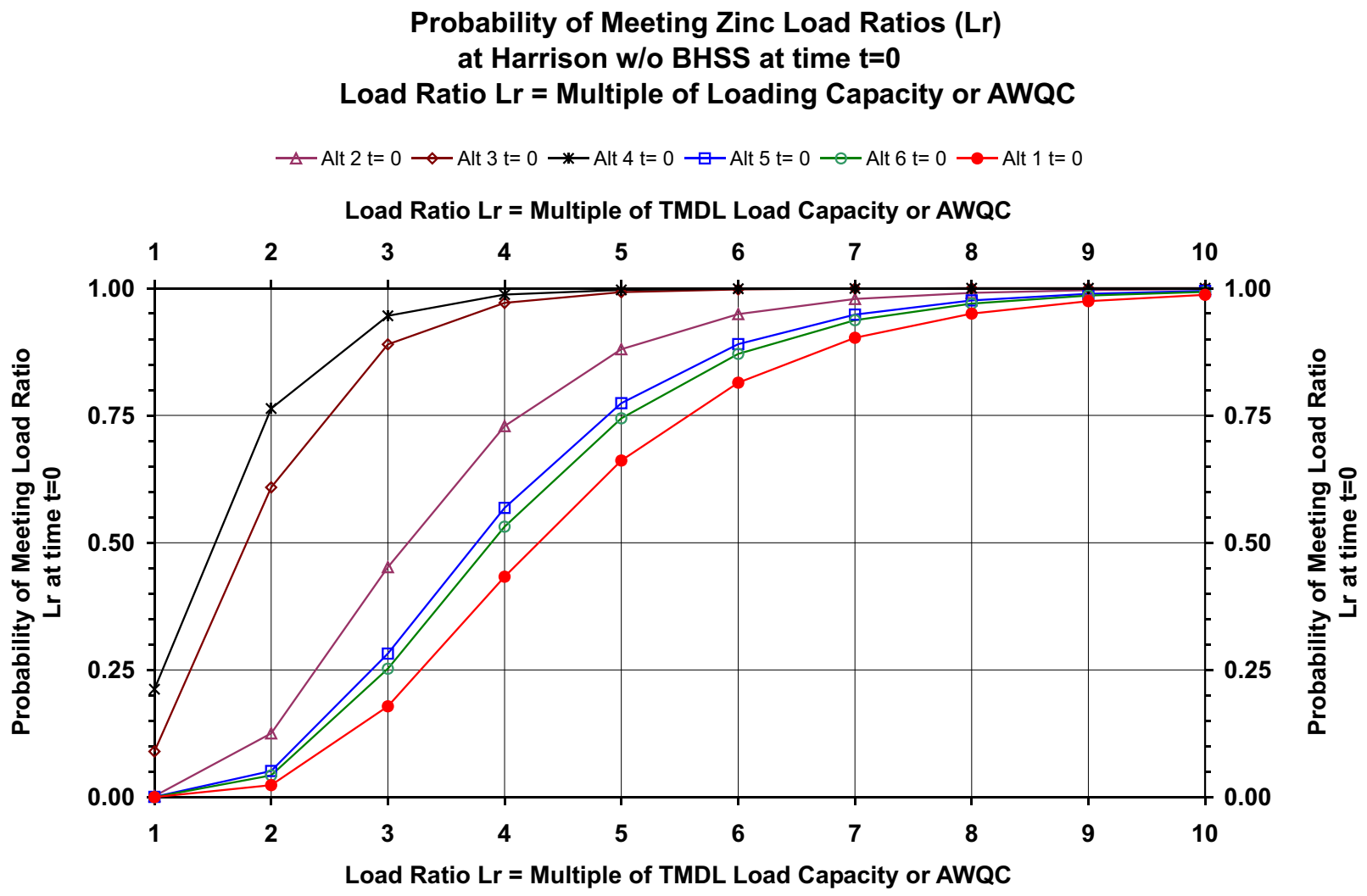


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**Figure 4-14**

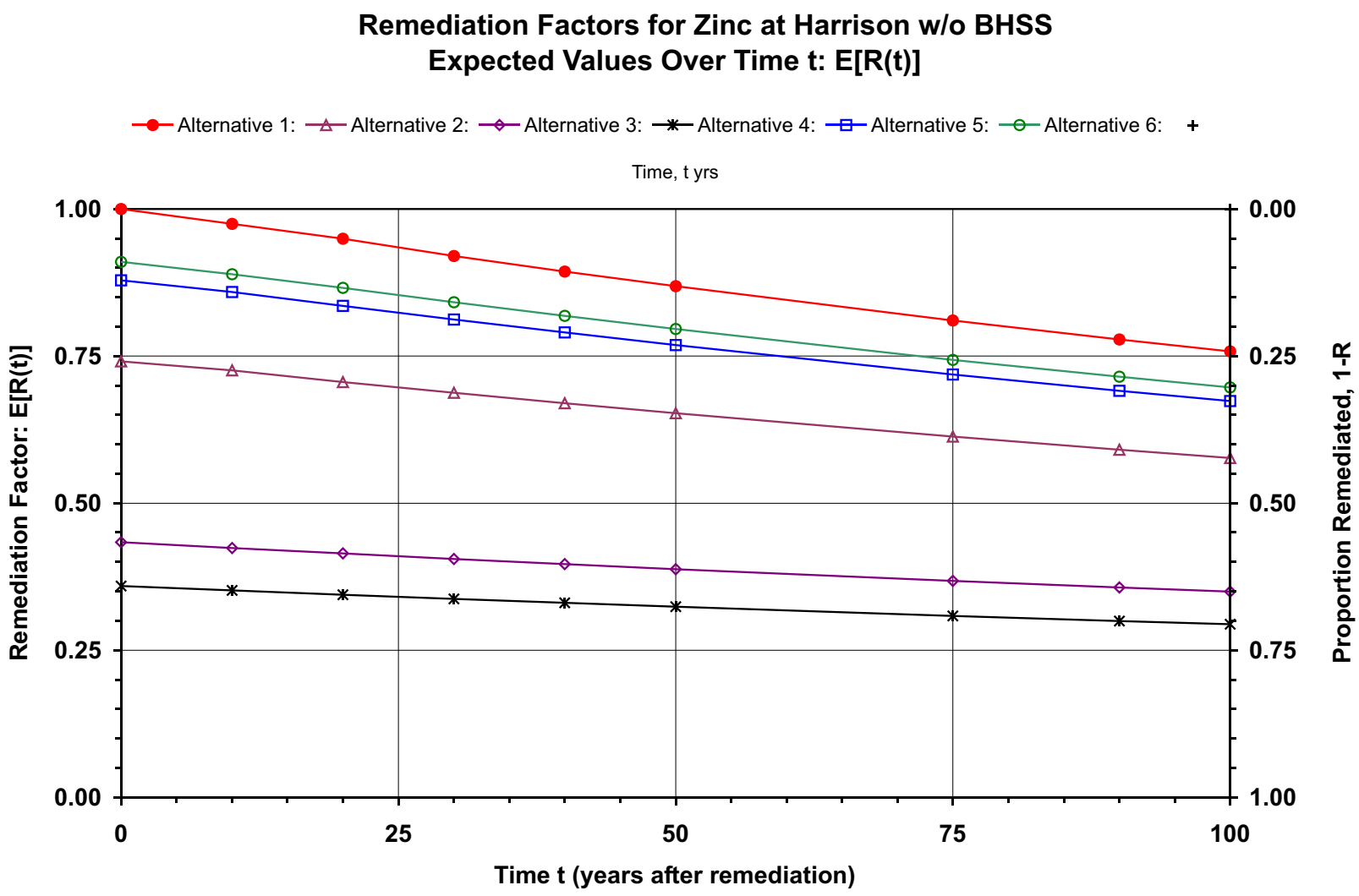


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**Figure 4-15**

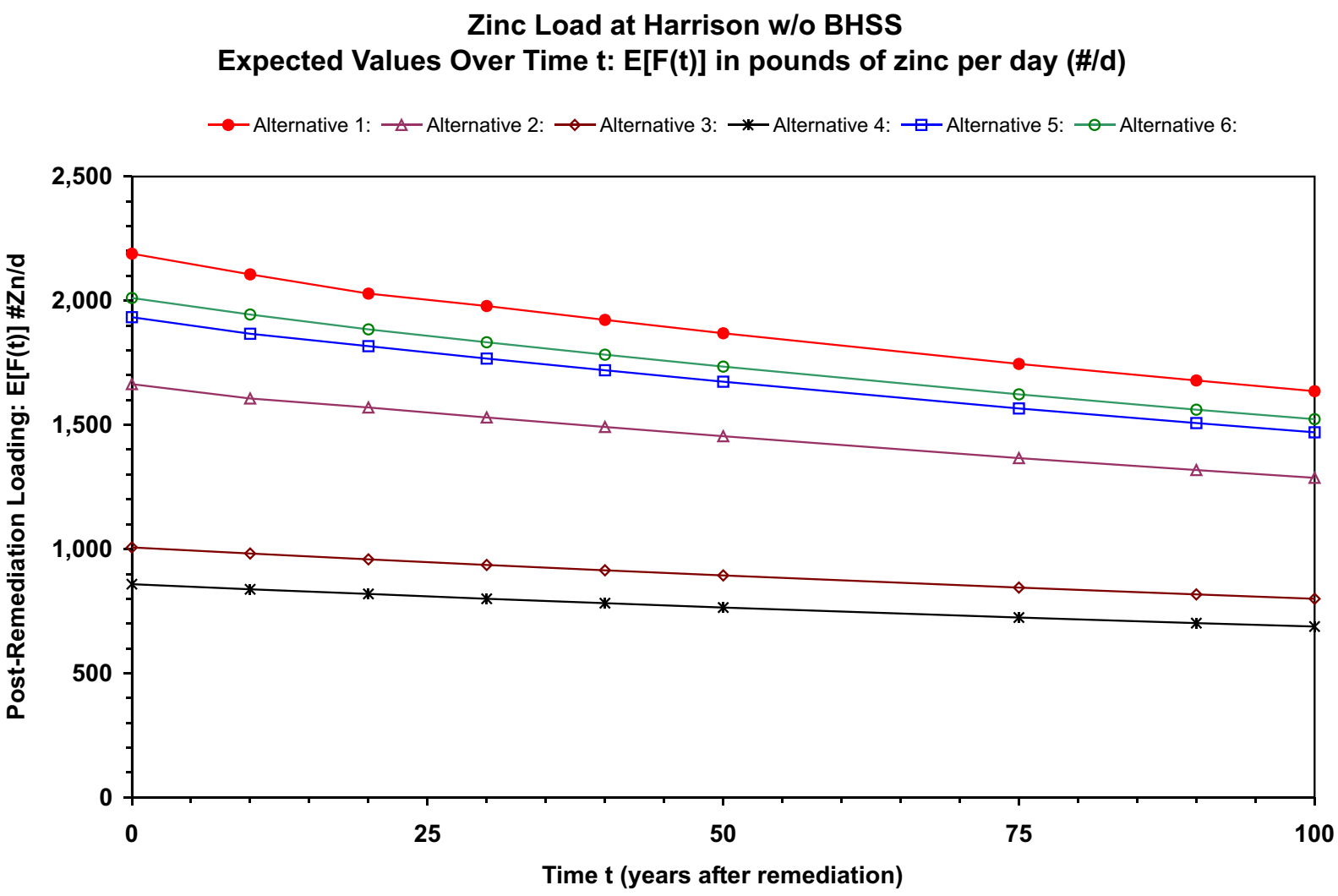


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**Figure 4-16**

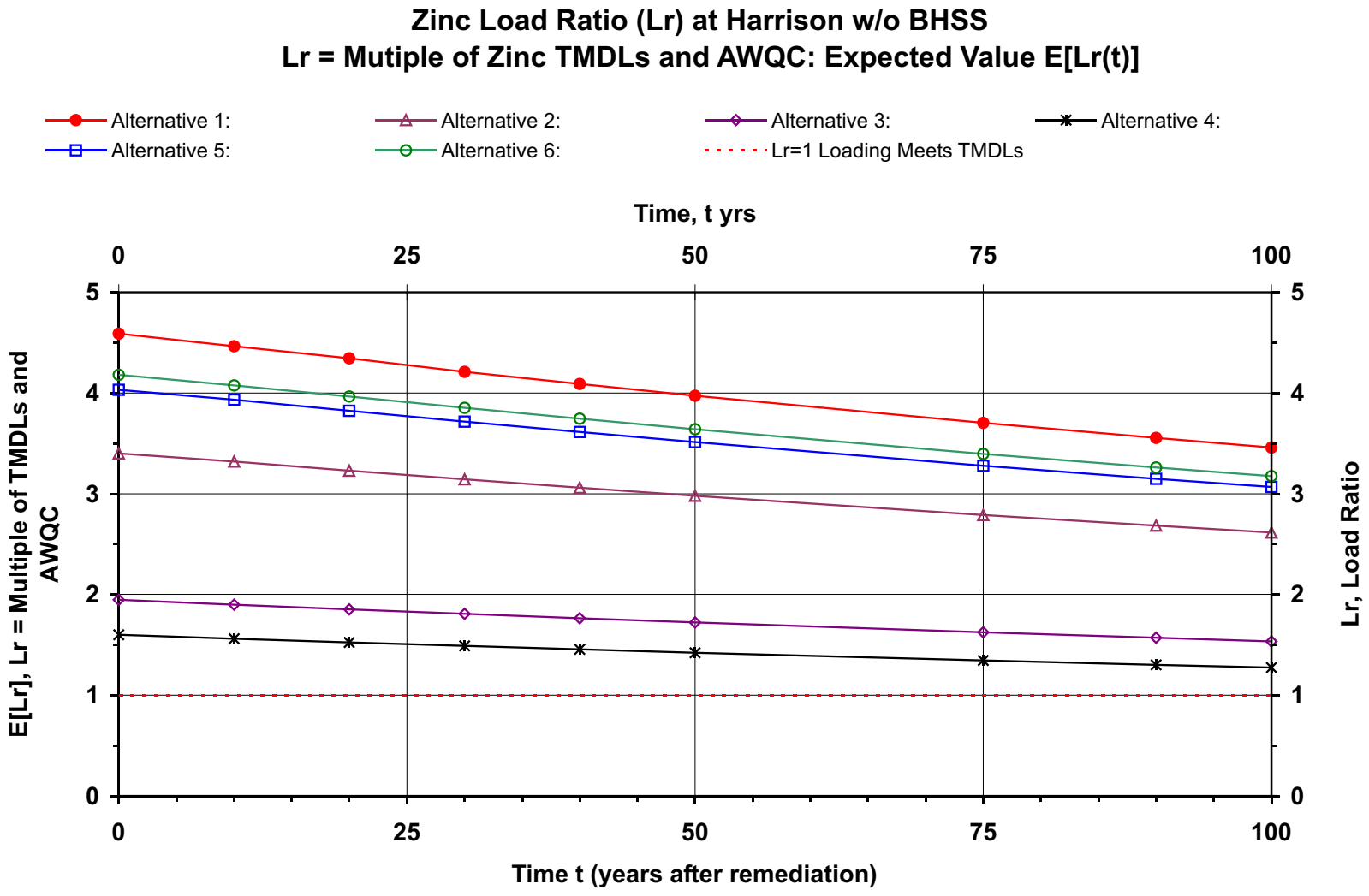


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**Figure 4-17**

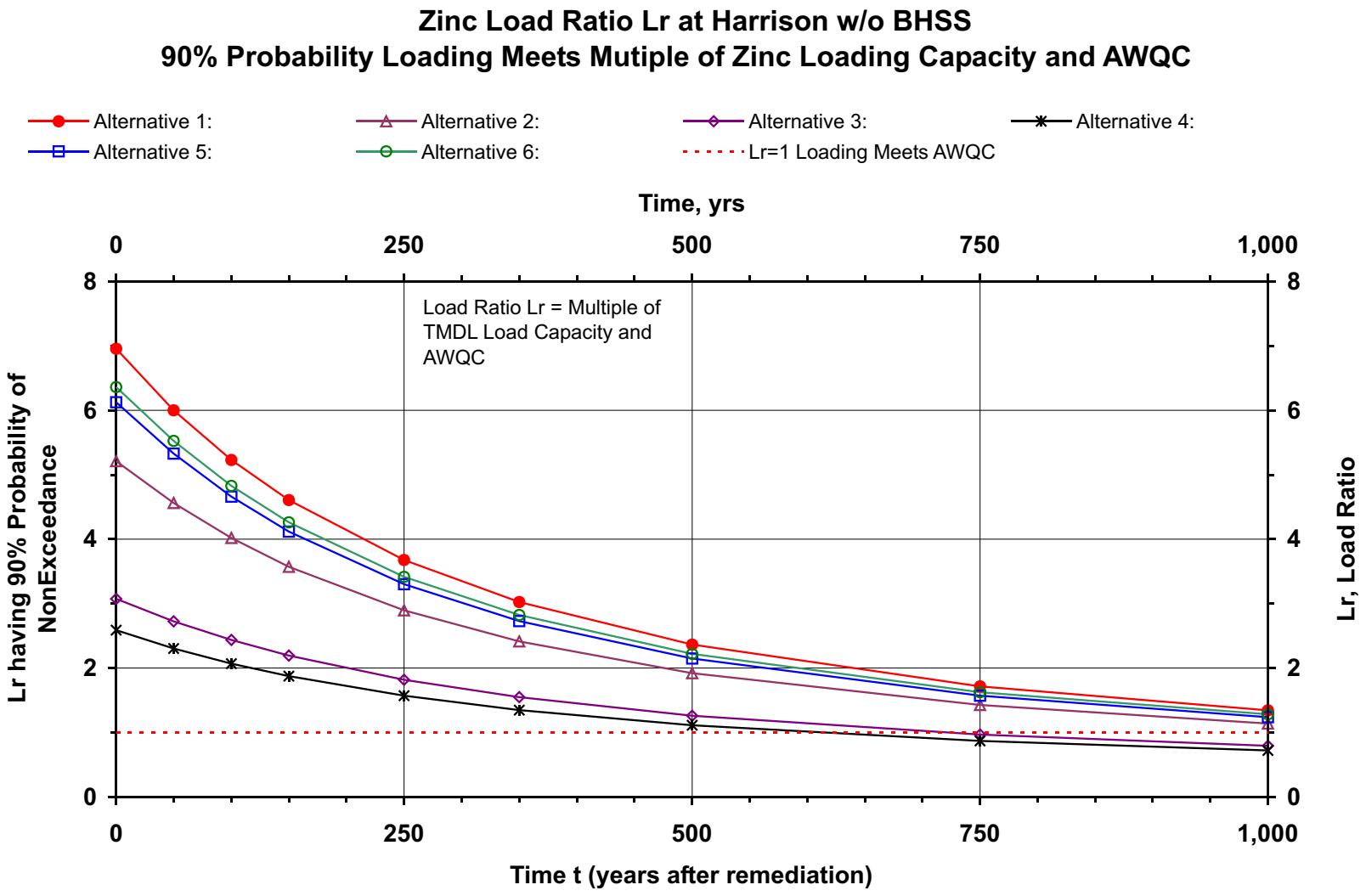


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**Figure 4-18**

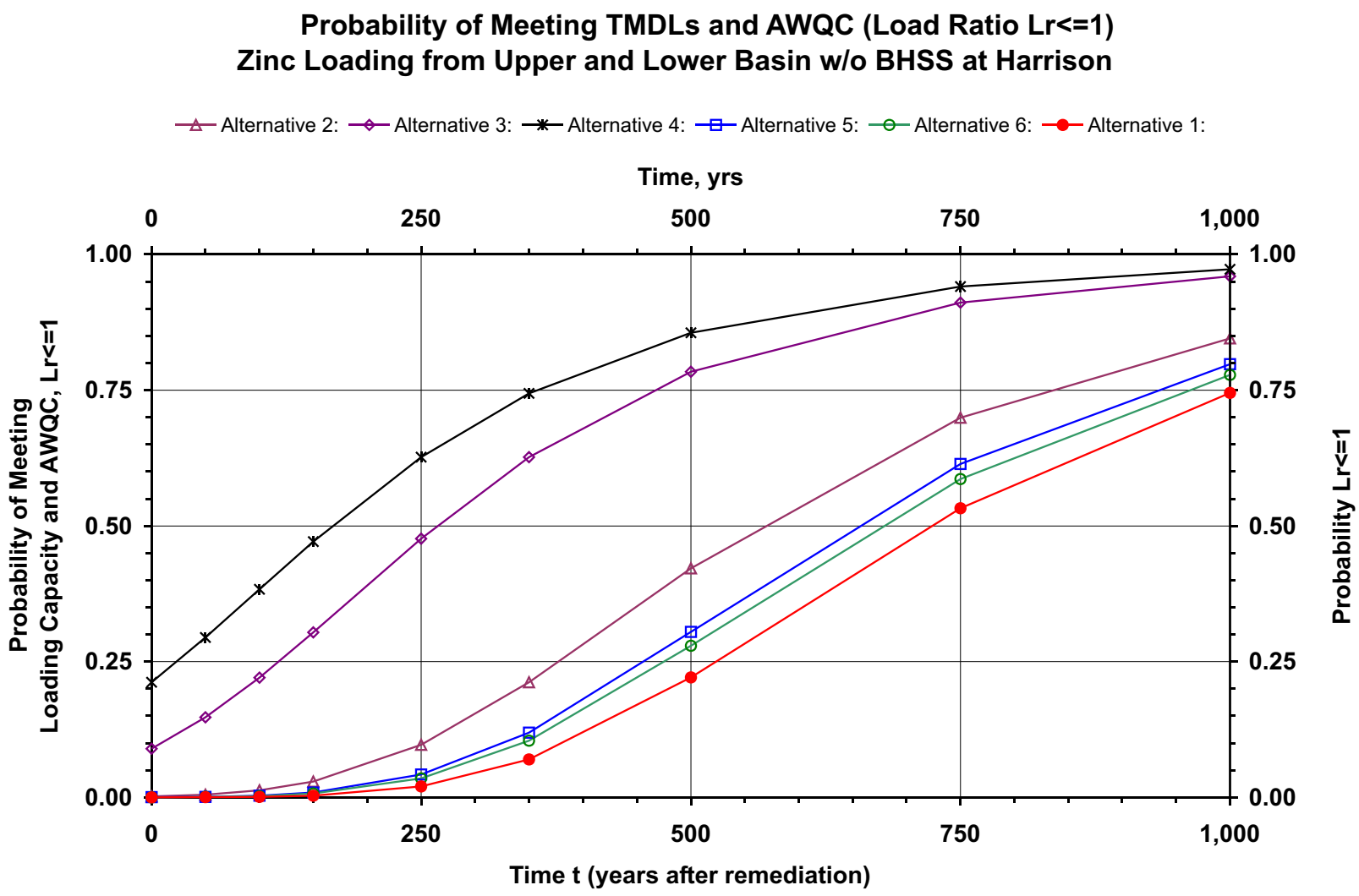


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**Figure 4-19**

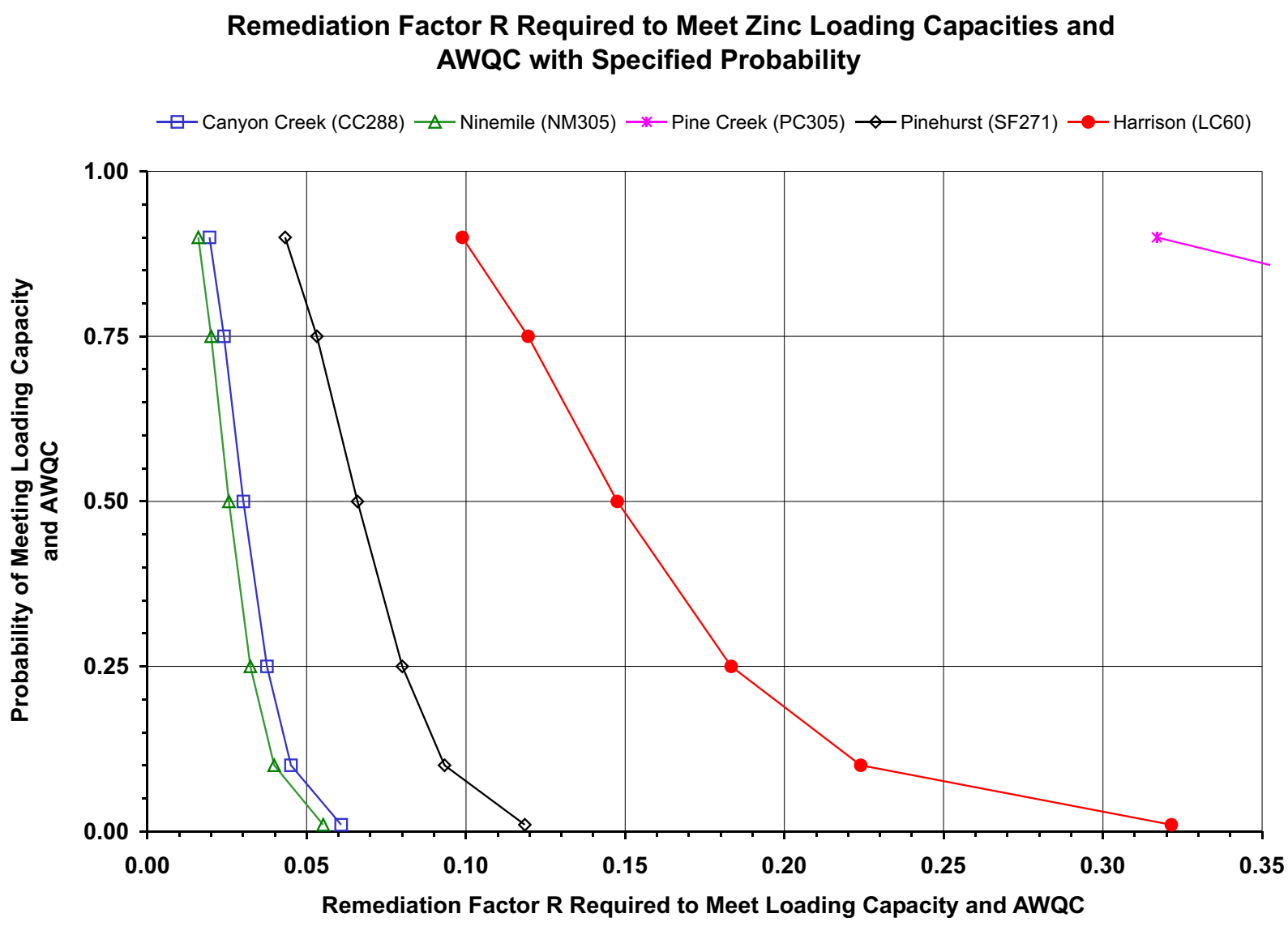


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**Figure 4-20**

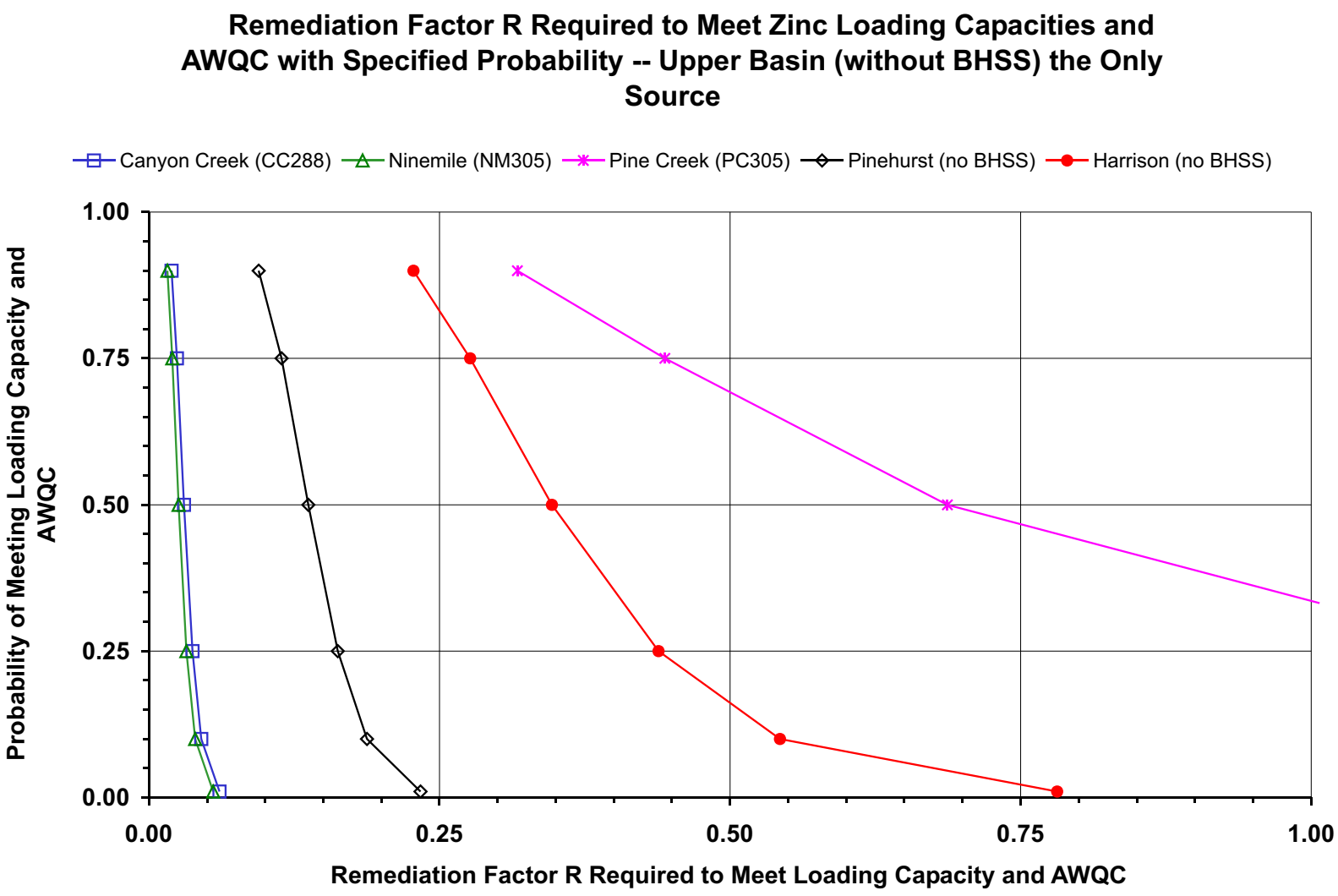


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**Figure 4-21**

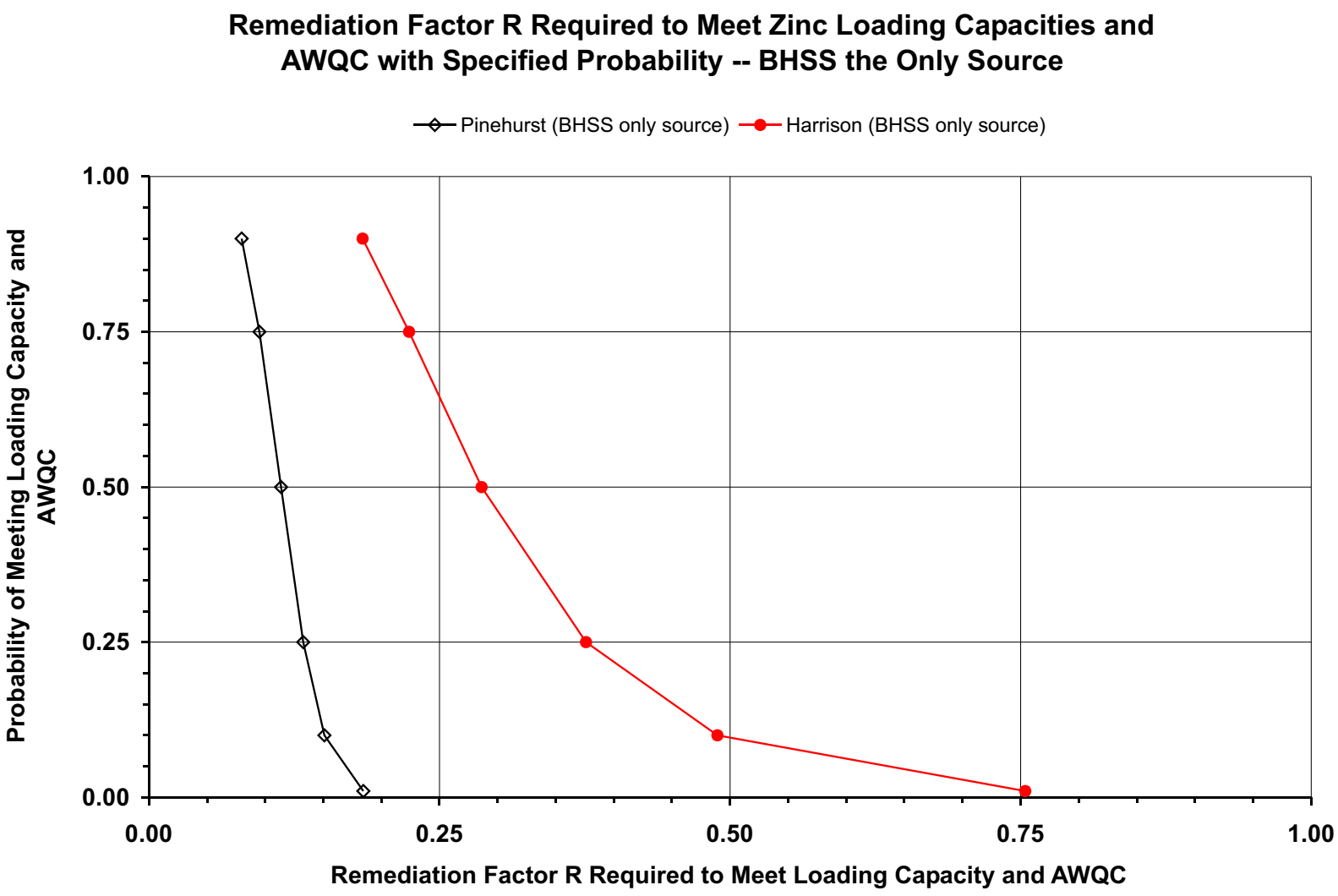


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**Figure 4-22**

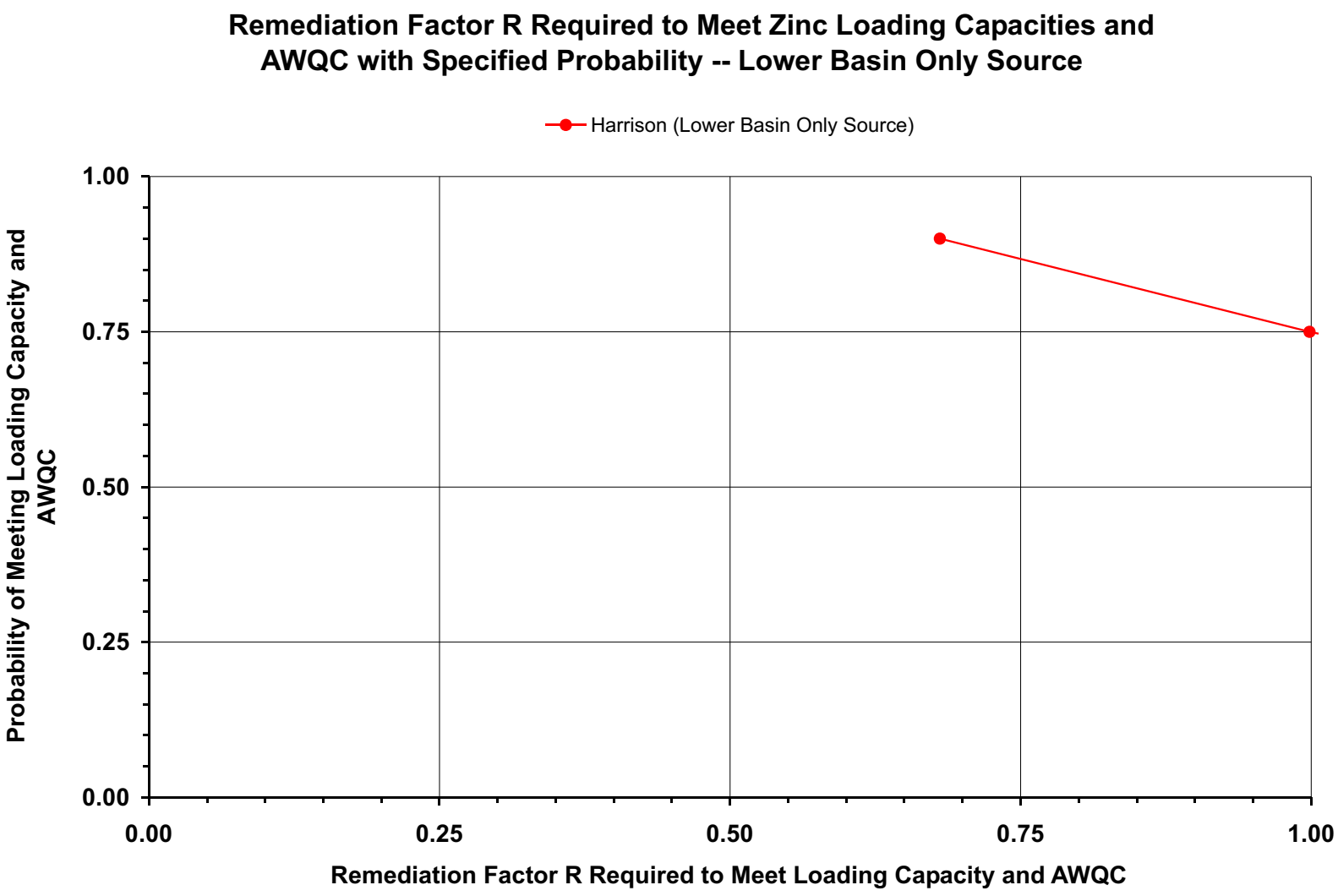


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**Figure 4-23**

## Probability of Meeting Multiples of Zinc Loading Capacity and AWQC for the SFCDR at Pinehurst -- Based on Extent of Upper Basin Cleanup

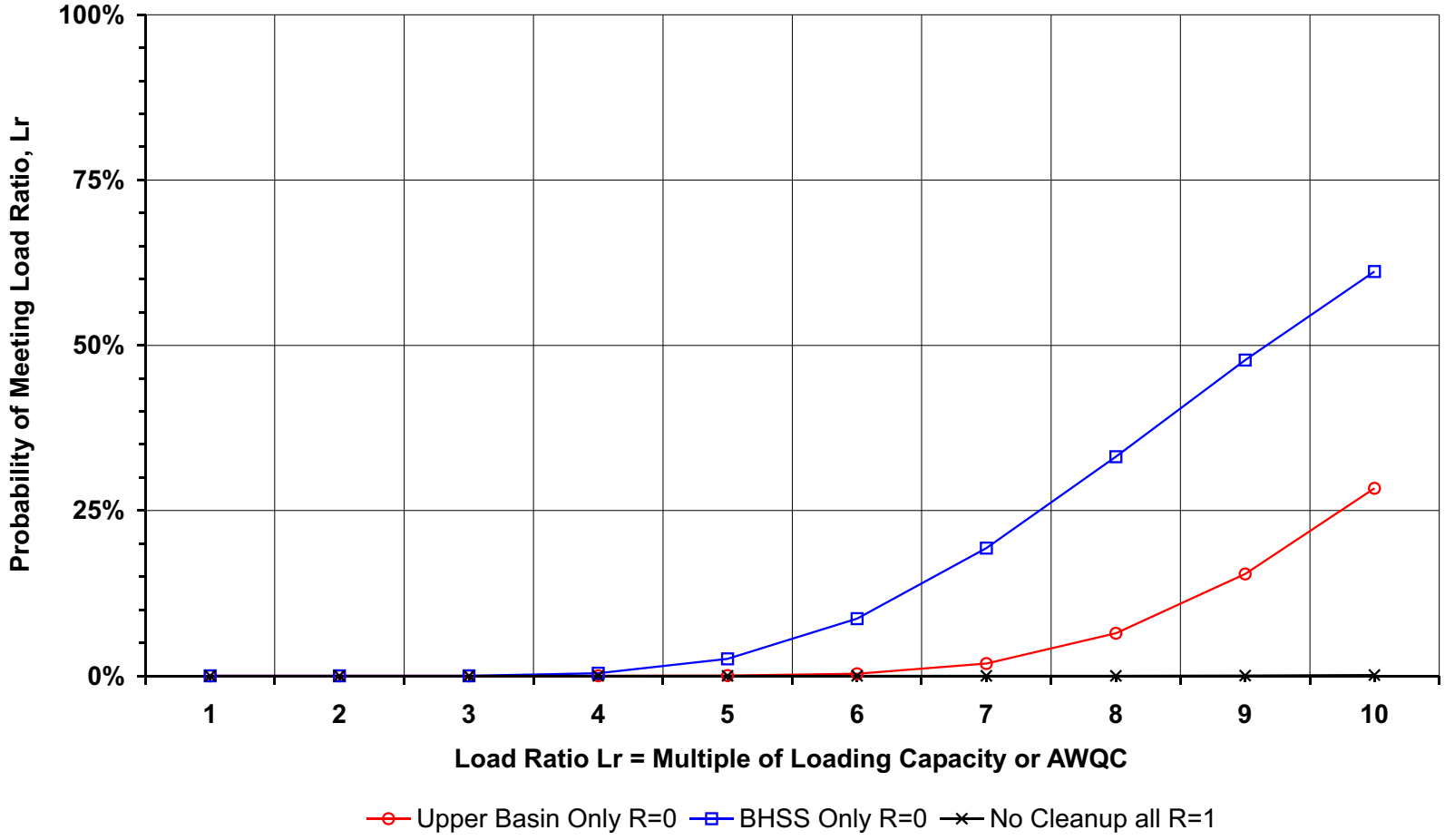


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**Figure 4-24**

## Probability of Meeting Multiples of Zinc Loading Capacity and AWQC for the CDR at Harrison -- Based on Extent of Cleanup

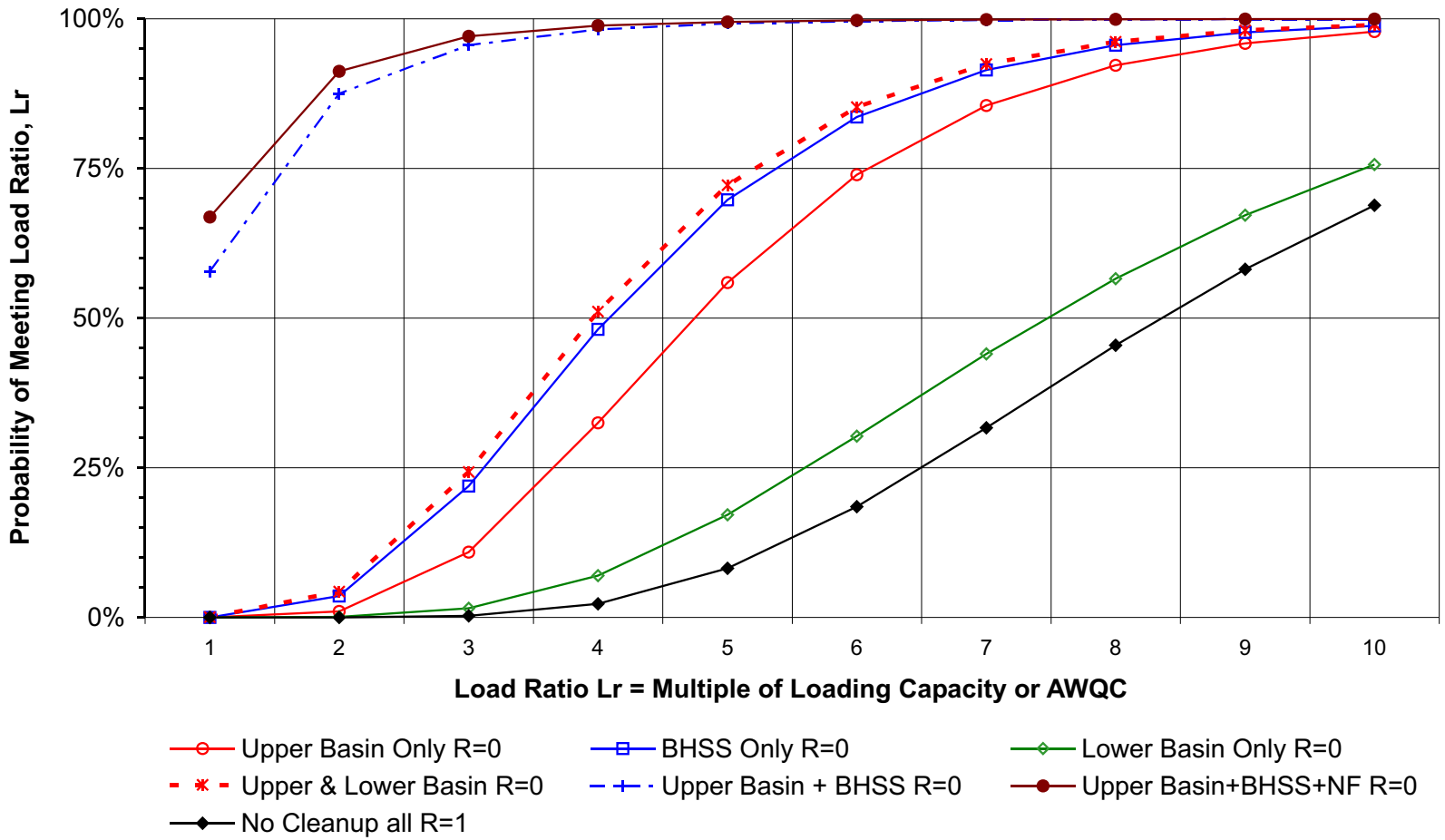


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**Figure 4-25**

# BHSS Inclusion Factor (BIF) -- Pinehurst SF271

## To Include BHSS Dissolved Zinc Loading:
## Multiply Loading F(t) & Load Ratio Lr(t) Results Without BHSS By BIF

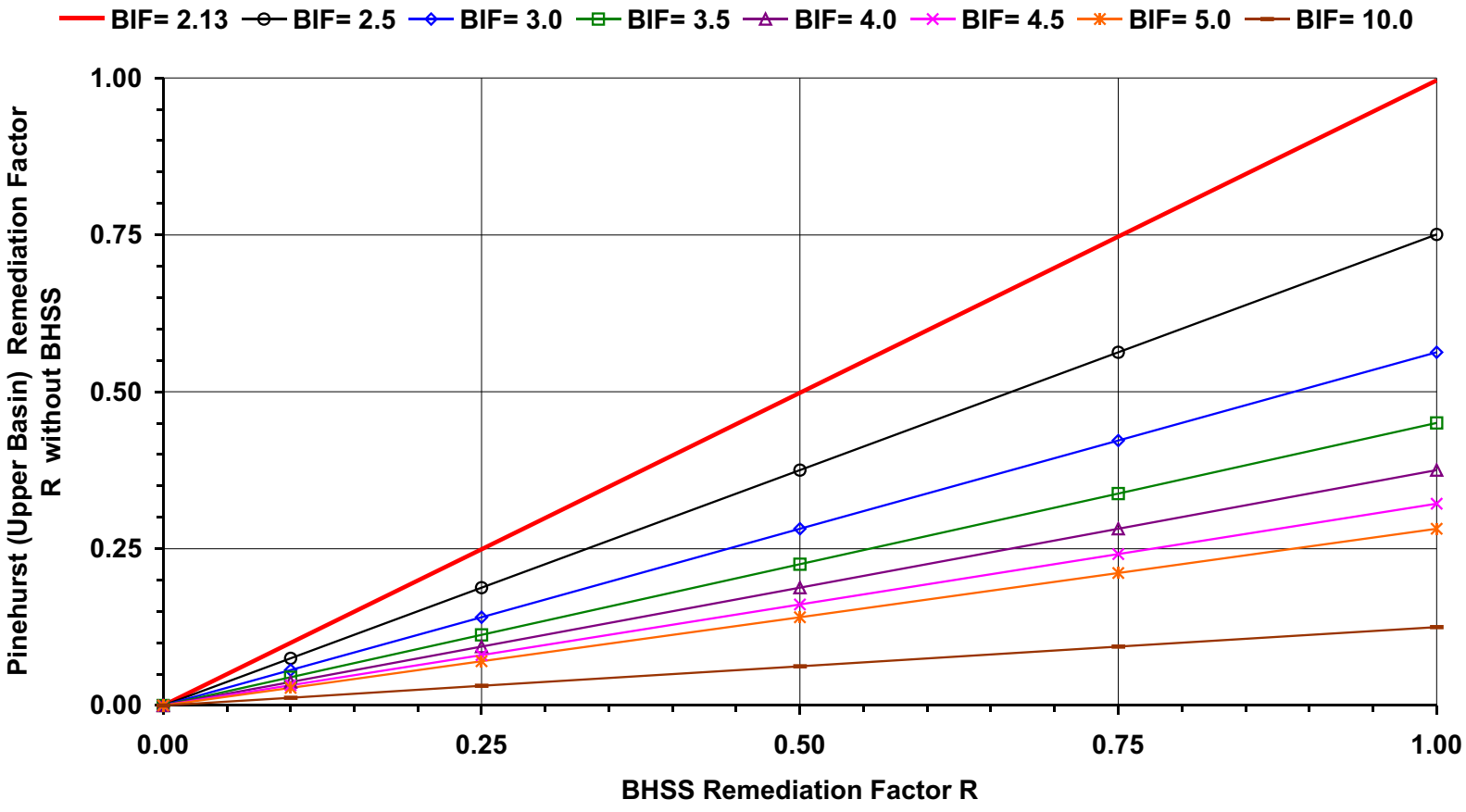


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Figure 4-26

# BHSS Inclusion Factor (BIF) -- Harrison LC60

## To Include BHSS Dissolved Zinc Loading:
## Multiply Loading F(t) & Load Ratio Lr(t) Results Without BHSS By BIF

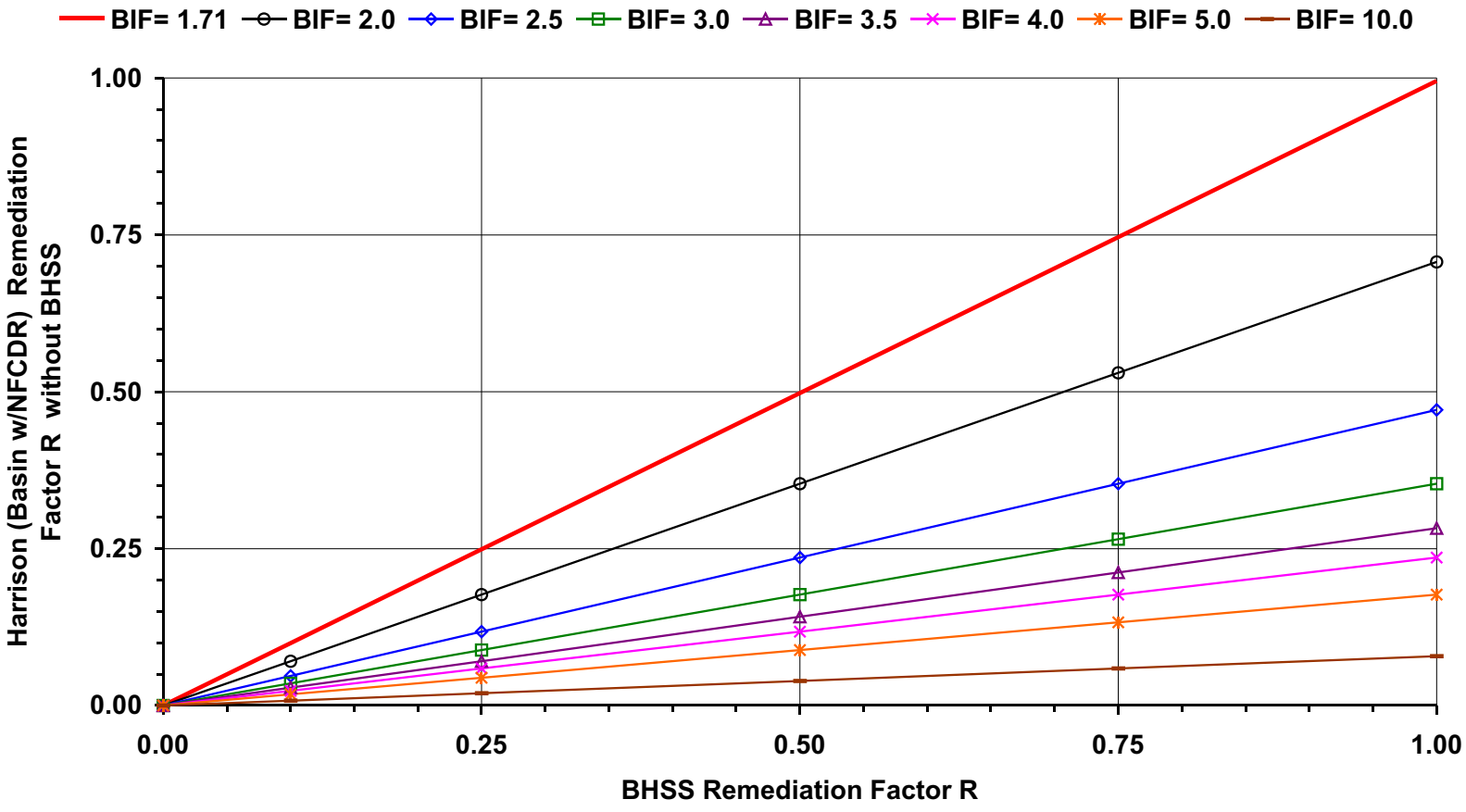


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**Figure 4-27**

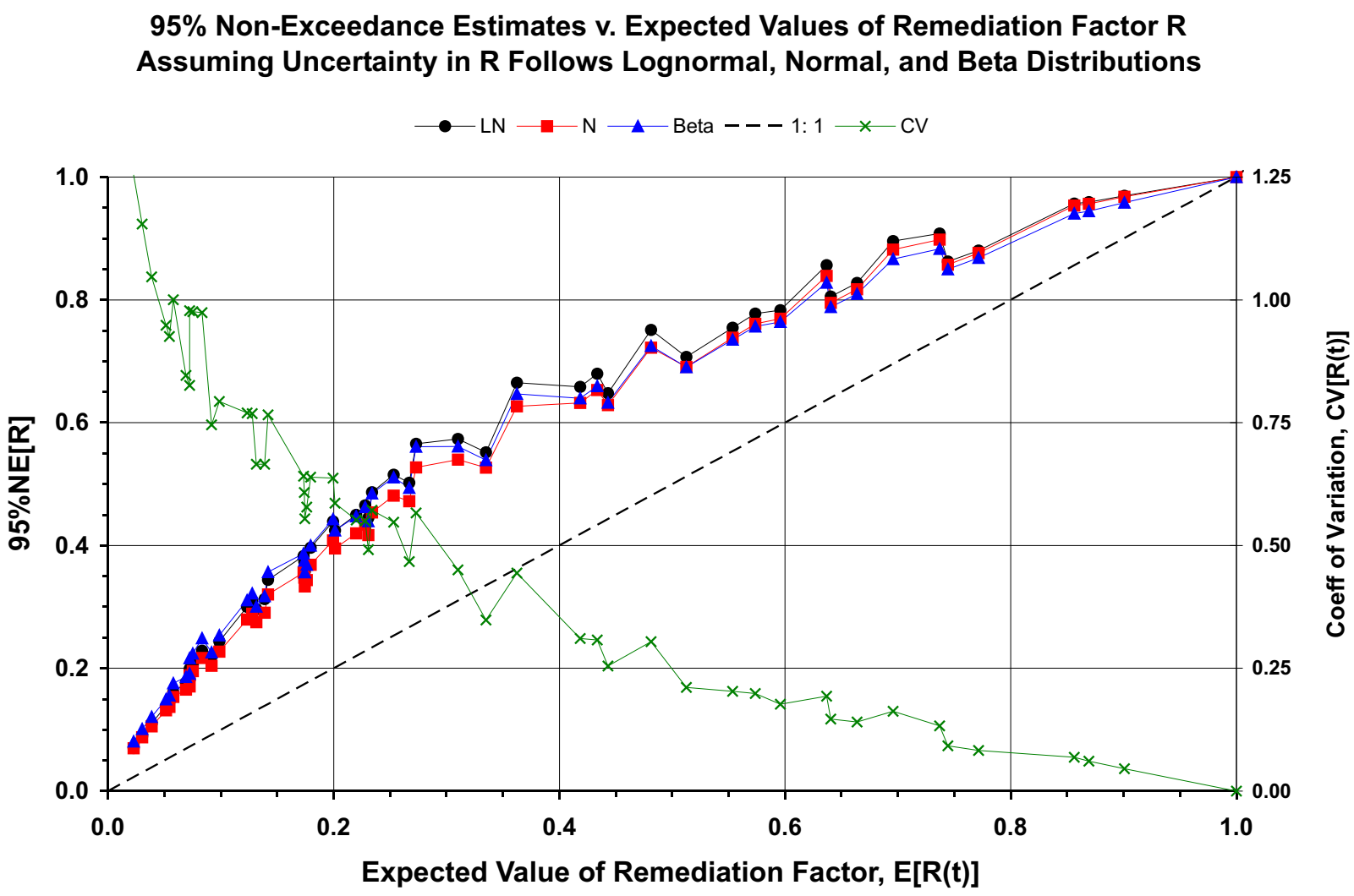


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**Figure 5-1**

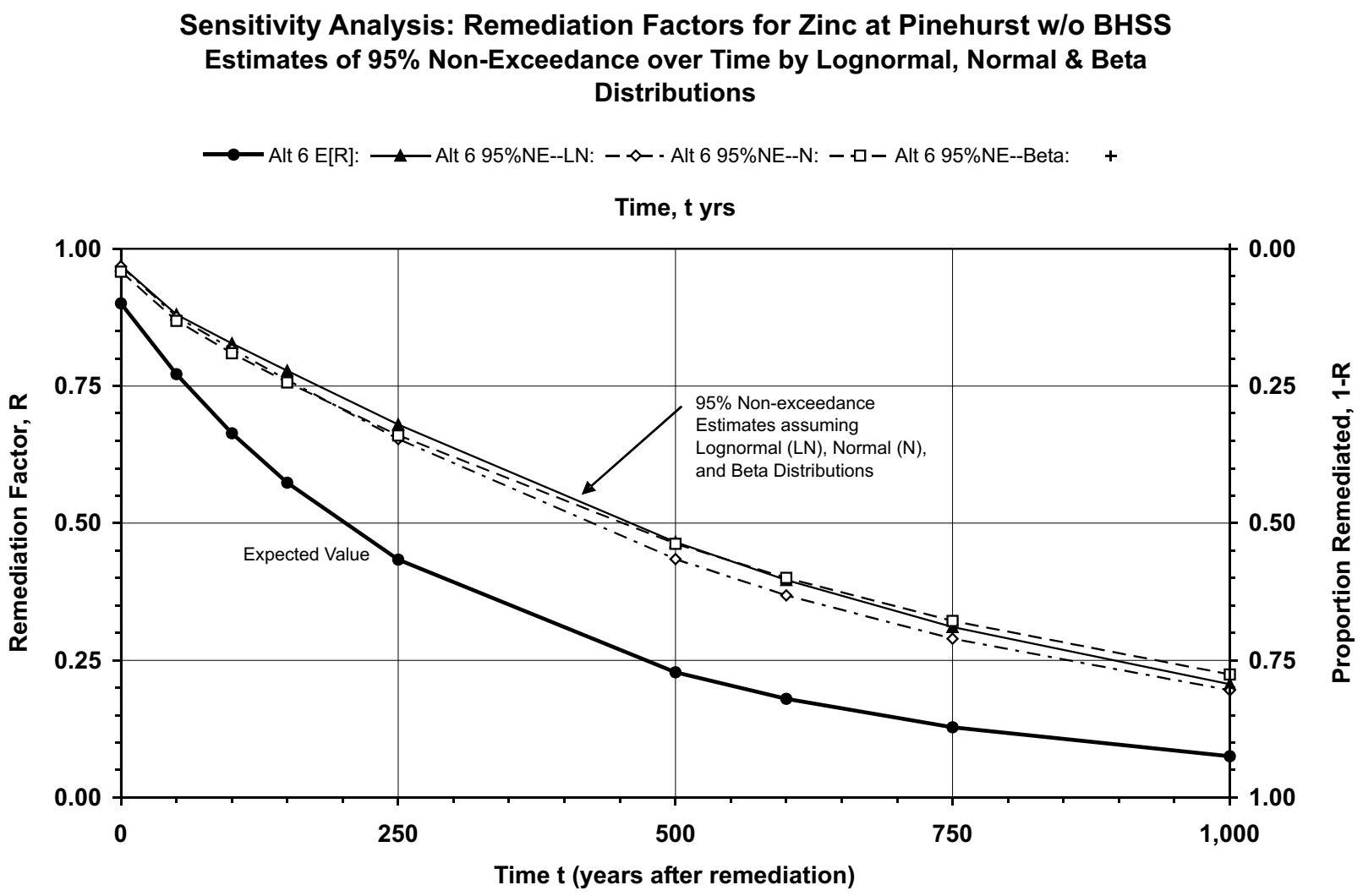


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**Figure 5-2**