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STATISTICAL ANALYSIS OF GROUNDWATER MONITORING DATA AT RCRA FACILITIES

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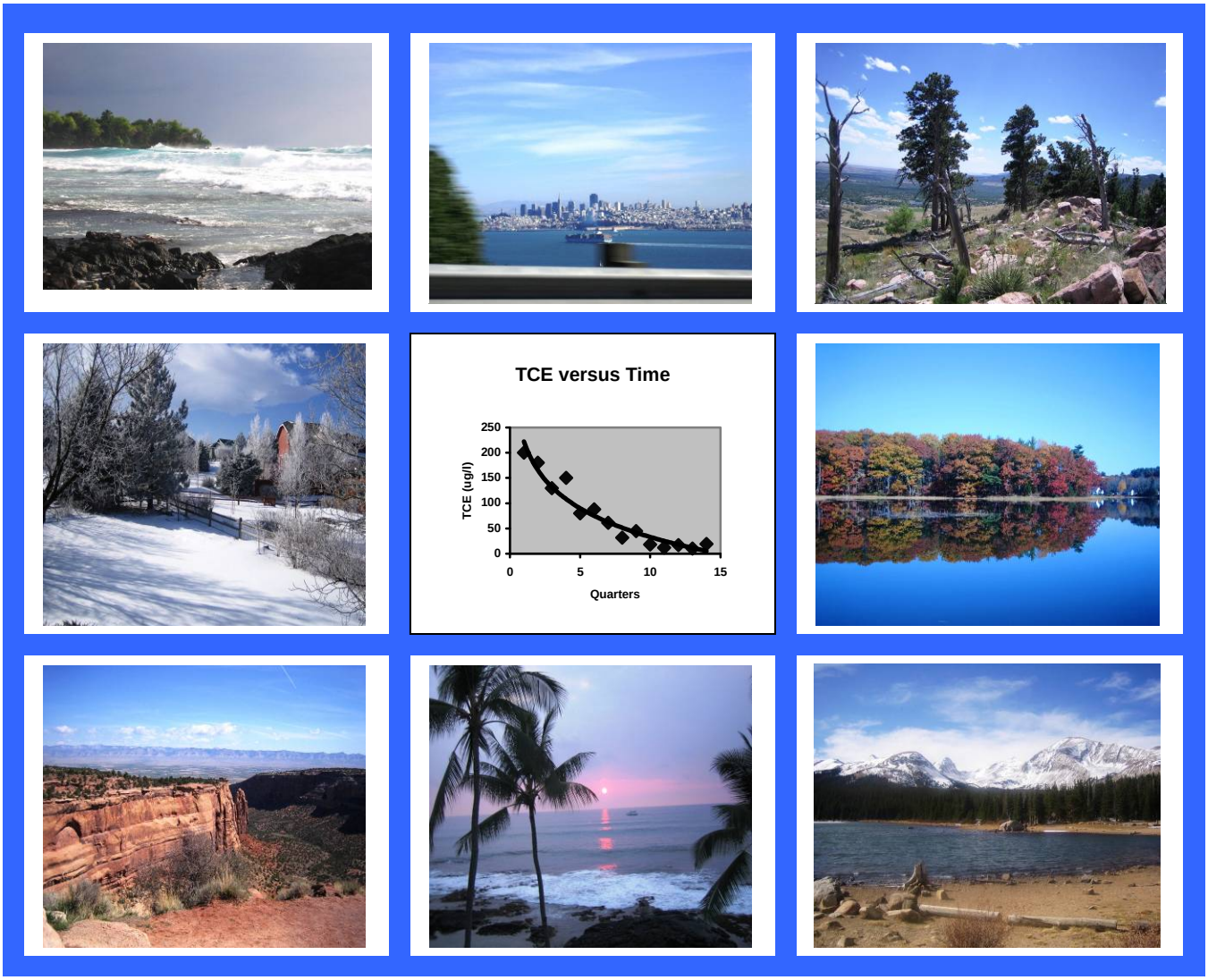

ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF RESOURCE CONSERVATION AND RECOVERY

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STATISTICAL ANALYSIS OF GROUNDWATER MONITORING DATA AT RCRA FACILITIES

UNIFIED GUIDANCE

OFFICE OF RESOURCE CONSERVATION AND RECOVERY

PROGRAM IMPLEMENTATION AND INFORMATION DIVISION

U.S. ENVIRONMENTAL PROTECTION AGENCY

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DISCLAIMER

This Unified Guidance has been prepared to assist EPA's Regions, the States and the regulated community in testing and evaluating groundwater monitoring data under 40 CFR Parts 264 and 265 and 40 CFR Part 258. This guidance is not a rule, is not legally enforceable, and does not confer legal rights or impose legal obligations on any member of the public, EPA, the States or any other agency. While EPA has made every effort to ensure the accuracy of the discussion in this guidance, the obligations of the regulated community are determined by the relevant statutes, regulations, or other legally binding requirements. The use of the term "should" when used in this guidance does not connote a requirement. This guidance may not apply in a particular situation based on the circumstances. Regional and State personnel retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate.

It should be stressed that this guidance is a work in progress. Given the complicated nature of groundwater and geochemical behavior, statistical applications describing and evaluating data patterns have evolved over time. While many new approaches and a conceptual framework have been provided here based on our understanding at the time of publication, outstanding issues remain. The Unified Guidance sets out mostly classical statistical methods using reasonable interpretations of existing regulatory objectives and constraints. But even these highly developed mathematical models deal primarily with sorting out chance effects from potentially real differences or trends. They do not exhaust the possibilities of groundwater definition using other technical or scientific techniques (*e.g.*, contaminant modeling or geostatistical evaluations). While providing a workable decision framework, the models and approaches offered within the Unified Guidance are only approximations of a complex underlying reality.

While providing a basic understanding of underlying statistical principles, the guidance doesn't attempt to provide the reader with more thorough explanations and derivations found in standard texts and papers. It also doesn't comprehensively cover all potential statistical approaches, and confines itself to reasonable and current methods, which will work in the present RCRA groundwater context. While it is highly likely that methods promoted in this guidance will be applied using commercial or proprietary statistical software, a detailed discussion of software applications is beyond the scope of this document.

This document has been reviewed by the Office of Resource Conservation and Recovery (former Office of Solid Waste), U.S. Environmental Protection Agency, Washington, D.C., and approved for publication. Mention of trade names, commercial products, or publications does not constitute endorsement or recommendation for use.

"It is far better to have an approximate answer to the right question than a precise answer to the wrong question…" — John Hauser

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EPA's Office of Solid Waste developed initial versions of this document under the direction of James R. Brown and Hugh Davis, Ph.D. of the Permits and State Programs Division. The final draft was developed and edited under the direction of Mike Gansecki, EPA Region 8. The guidance was prepared by Kirk M. Cameron, Ph.D., Statistical Scientist and President of MacStat Consulting, Ltd. in Colorado Springs, Colorado. It also incorporates the substantial efforts on the 1989 Interim Final Guidance of Jerry Flora, Ph.D. and Ms. Karen Bauer, both — at the time — of Midwest Research Institute in Kansas City, Missouri. Science Applications International Corporation (SAIC) provided technical support in developing this document under EPA Contract No. EP-WO-5060.

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EXECUTIVE SUMMARY

The Unified Guidance provides a suggested framework and recommendations for the statistical analysis of groundwater monitoring data at RCRA facility units subject to 40 CFR Parts 264 and 265 and 40 CFR Part 258, to determine whether groundwater has been impacted by a hazardous constituent release. Specific statistical methods are identified in the RCRA regulations, but their application is not described in any detail. The Unified Guidance provides examples and background information that will aid in successfully conducting the required statistical analyses. The Unified Guidance draws upon the experience gained in the last decade in implementing the RCRA Subtitle C and D groundwater monitoring programs and new research that has emerged since earlier Agency guidance.

The guidance is primarily oriented towards the groundwater monitoring statistical analysis provisions of 40 CFR Parts 264.90 to .100. Similar requirements for groundwater monitoring at solid waste landfill facilities under 40 CFR Part 258 are also addressed. These regulations govern the detection, characterization and response to releases from regulated units into the uppermost aquifer. Some of the methods and strategies set out in this guidance may also be appropriate for analysis of groundwater monitoring data from solid waste management units subject to 40 CFR 264.101. Although the focus of this guidance is to address the RCRA regulations, it can be used by the CERCLA program and for improving remedial actions at other groundwater monitoring programs.

Part I of the Unified Guidance introduces the context for statistical testing at RCRA facilities. It provides an ***overview of the regulatory requirements***, summarizing the current RCRA Subtitle C and D regulations and outlining the statistical methods in the final rules, as well as key regulatory sections affecting statistical decisions. It explains the basic groundwater monitoring framework, philosophy and intent of each stage of monitoring — detection, compliance (or assessment), and corrective action — and certain features common to the groundwater monitoring environment. Underlying statistical ideas common to all statistical test procedures are identified, particularly issues involving false positives arising from multiple statistical comparisons and statistical power to detect contamination.

A new component of the Unified Guidance addresses issues of ***statistical design***: what factors are important in constructing a reasonable and effective statistical monitoring program. These include the establishment and updating of background data, designing an acceptable detection monitoring plan, and statistical strategies for compliance/assessment monitoring and corrective action. This part also includes a short summary of statistical methods recommended in the Unified Guidance, detailing conditions for their appropriate use.

Part II of the Unified Guidance covers diagnostic evaluations of historical facility data for the purpose of ***checking key assumptions*** implicit in the recommended statistical tests and ***for making appropriate adjustments to the data*** (*e.g.*, consideration of outliers, seasonal autocorrelation, or non-detects). Also included is a discussion of groundwater sampling and how hydrologic factors such as flow and gradient can impact the sampling program. Concepts of statistical and physical independence are compared, with caveats provided regarding the impact of dependent data on statistical test results. Statistical methods are suggested for identifying special kinds of dependence known as spatial and temporal variation, including reasonable approaches when these dependencies are observed. Tests for trends are also included in this part.

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Part III of the Unified Guidance presents a range of ***detection monitoring*** statistical procedures. First, there is a discussion of the Student's *t*-test and its non-parametric counterpart, the Wilcoxon rank-sum test, when comparing two groups of data (*e.g.*, background versus one downgradient well). This part defines both parametric and non-parametric prediction limits, and their application to groundwater analysis when multiple comparisons are involved. A variety of prediction limit possibilities are presented to cover likely interpretations of sampling and testing requirements under the RCRA regulations.

Substantial detailed guidance is offered for using prediction limits with retesting procedures, and how various retesting algorithms might be constructed. The final chapter of this Part considers another statistical method especially useful for ***intrawell*** comparisons, namely the Shewhart-CUSUM control chart. A brief discussion of analysis of variance [ANOVA] and tolerance limit tests identified in the RCRA regulations is also provided.

Part IV of the Unified Guidance is devoted to statistical methods recommended for ***compliance*** or ***assessment monitoring*** and ***corrective action***. Compliance monitoring typically involves a comparison of downgradient well data to a groundwater protection standard [GWPS], which may be a limit derived from background or a fixed concentration limit (such as in 40 CFR 264.94 Table 1, an MCL, a risk-based limit, an alternate concentration limit, or a defined clean-up standard under corrective action). The key statistical procedure is the confidence interval, and several confidence interval tests (mean, median, or upper percentile) may be appropriate for compliance evaluation depending on the circumstances. The choice depends on the distribution of the data, frequency of non-detects, the type of standard being compared, and whether or not the data exhibit a significant trend. Discussions in this part consider fixed compliance standards used in a variety of EPA programs and what they might represent in statistical terms. Strategies for corrective action differ from those appropriate for compliance monitoring primarily because statistical hypotheses are changed, although the same basic statistical methods may be employed.

Since some programs will also utilize background as standards for compliance and corrective action monitoring, those tests and discussions under **Part III** detection monitoring (including statistical design in **Part I**) may pertain in identifying the appropriate standards and tests.

A ***glossary*** of important statistical terms, ***references*** and a subject ***index*** are provided at the end of the main text. The ***Appendices*** contain additional notes on a number of topics including previous guidance, a special study for the guidance, more detailed statistical power discussions, and an extensive set of ***statistical tables*** for implementing the methods outlined in the Unified Guidance. Some tables, especially those for prediction limit retesting procedures, have been extended within the Unified Guidance beyond published sources in order to cover a wider variety of plausible scenarios.

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