Summary — Highway Runoff Water Quality Study 1977-1982

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16. Abstract

A highway stormwater runoff pollutant loading model has been developed based on results from composite sampling of approximately 600 storms at nine locations in the State of Washington over five years. The model expresses total suspended solids (TSS) loading in proportion to the product of highway segment length, average runoff coefficient, and vehicles traveling during storm periods. It was demonstrated that loadings of contaminants such as chemical oxygen demand, nutrients and trace metals could be estimated from TSS loadings using ratios derived from the data. The model described was developed and validated for assessing total loadings over a time span encompassing a number of storms (monthly or annually). To predict pollutant concentrations and loadings in runoff from a given storm, cumulative distributions were plotted and analyzed to determine the probability of exceeding specific concentration and loading values in a given case. Bioassay studies using highway runoff indicated toxicity to aquatic life when elevated metals deposition from high traffic volumes (in excess of 10,000 - 20,000 vehicles per day) or high metals concentrations in rainfall caused runoff concentrations to exceed lethal levels. Draining highway runoff through grass channels 60 meters in length greatly reduced TSS and metals concentrations and the consequent toxic effects. The major product of this research is a guide to assessing and mitigating the impacts of highway runoff to receiving waters.

17. Key Words	18. Distribution Statement
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EXECUTIVE SUMMARY

Prior to initiation of this research, estimates of highway runoff quality varied over two orders of magnitude. Literature data were reported in conflicting units, and there was no agreement on the variables that control the quality of highway runoff. Assessment of highway runoff associated with new projects was subjected to legal challenges, and expensive control measures were required due to the uncertainty in predicted pollutant loads.

The purpose of this research was to collect enough data to develop a predictive model of highway runoff for the State of Washington (since existing models were based on high-intensity rainfall sites with generally higher pollutant loads) and to find low cost mitigation measures to control the quality of highway runoff.

The major research tasks were: 1) to compile existing knowledge on the measurement and prediction of highway runoff and to develop cost-effective methods to collect more data; 2) to design the experiment by selecting sites throughout the state providing a range of traffic, rainfall, land uses, pavements, and highway configurations, 3) to obtain a statistically significant data base to examine the impact of the experimental variables; 4) to conduct special studies to observe the aquatic life before and after the Pilchuck River channel change, for SR-2 construction; 5) to conduct a special study of trace organics in highway runoff and leachate from wood waste fills; 6) to conduct a special study on the fate of heavy metals in highway runoff and the impact of highway runoff on aquatic life; and 7) to incorporate the research results in an assessment guide for use in implementing results.

The most significant finding of this research is that highway runoff in Washington State is less contaminated than general urban runoff or highway runoff analyzed in previous studies and, in most cases, does not create a significant impact on receiving water quality. A scientifically sound data base was obtained to support the development of a predictive model of highway runoff. The dominant variable in the model is traffic during storm periods. Pollutants in highway runoff can be removed during flow over vegetated drainage courses. Thus, in areas where highway runoff contamination must be mitigated,expensive treatment facilities may not be necessary. The research results are incorporated in a guide for highway runoff assessment to facilitate implementation of these findings. A by-product of this research is a composite sampling device that reduces the cost of this and future sampling efforts by a factor of ten.

If implemented, the findings of this research should minimize or eliminate delays and related costs associated with legal challenges of the adequacy of highway runoff assessment or control, and should significantly reduce the cost of designing and operating highway runoff water quality control facilities.

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INTRODUCTION

This final project report does not conform to a traditional format due to the reporting practices adopted for this project and the large number of dissertations and summary reports issued as the project progressed. This research was performed by graduate students in the Environmental Engineering and Science Program of the Department of Civil Engineering at the University of Washington under the direction of the faculty project team. Twelve dissertations or non-thesis reports were prepared during the project (Table 1). Each dissertation is available from the University library and conforms to the style in the Washington State Department of Transportation (WSDOT) Research Manual and academic research reporting standards. Each dissertation was condensed into a short technical report or integrated into annual reports prepared throughout the project (see Table 2) and submitted to the National Technical Information Service (NTIS) for distribution. When possible, these short reports were submitted to professional journals for publication (see Table 3) to increase accessibility of the research results. This publication strategy provided a scientifically sound basis for the recommendations made in this final report and in the guidelines for environmental assessment preparation, yet condensed the findings into a concise format for technology transfer. This report is a summary of all findings reported in these project publications.

Table 1: Dissertations and Non-Thesis Papers

Horner, R.R., 1978, "Stream Periphyton Development in Relation to Current Velocity and Nutrients", Ph.D. Dissertation, 273 pp.

Tseng, W-C., 1979, "Initial Study of Highway Runoff Water Quality", M.S.C.E. Thesis, 126 pp.

Aye, R.D., 1979, 'Criteria and Requirements for Statewide Highway Runoff Monitoring Sites with Emphasis on the Tri-Cities Site", Non-Thesis Paper, 58 pp.

Clark, D.L., 1980, "Composite Sampling of Highway Runoff", M.S.C.E. Thesis, 205 pp.

Vause, K.H., 1980, "Water quality Impacts Associated with Leachates from Highway Woodwaste Embankments", M.S.C.E. Thesis, 226 pp.

Asplund, R.L., 1980, "Characterization of Highway Stormwater Runoff in Washington State", M.S.C.E. Thesis, 186 pp.

Eagen, P.D., 1980, "Views of Risk and the Highway Transportation of Hazardous Materials", Non-Thesis Paper, 44 pp.

Zawlocki, K.R., 1981, "A Survey of Trace Organics in Highway Runoff in Seattle, WA", M.S.E. Thesis, 147 pp.

Chui, T.W., 1981, "Highway Runoff in the State of Washington: Model Validation and Statistical Analysis", M.S.E. Thesis, 121 pp.

Wang, T.S., 1981, "Transport, Deposition, and Control of Heavy Metals in Highway Runoff", M.S.C.E. Thesis, 199 pp.

Portele, G.J., 1981, "The Effects of Highway Runoff on Aquatic Biota in the Metropolitan Seattle Area", M.S. Thesis, 88 pp.

Little, L., 1982, "Model Validation and Probability Distributions of Washington State Highway Runoff Water Quality", M.S.C.E. Thesis, 158 pp.

Table 2: Highway Runoff Water Quality Reports

WA-RD-39.1. Vause, K.H., J.F. Ferguson, and B.W. Mar, "Water Quality Impacts Associated with Leachates from Highway Woodwaste Embankments", September 1980.

Laboratory and field studies of a woodchip fill on SR-302 demonstrated that the ultimate amounts of COD, TOC, and BOD per ton of woodchips can be defined and that this material is leached exponentially by water. After a year the majority of the pollutant has been removed, suggesting that pre-treating of the woodchips prior to use in the fill can reduce the pollutant release from a fill. Thus, chips should be protected from rainfall and groundwater intrusion to avoid the release of leachate. Release of leachate onto tidal lands can cause beach discoloration, and an underground deep outfall may be required.

WA-RD-39.2. Horner, R.R. and E.B. Welch, "Effects of Velocity and Nutrient Alternations on Stream Primary Producers and Associated Organisms", November 1978.

Velocity and nutrient studies at 12 sites in Western Washington streams indicated that 50 cm/sec is the critical average current velocity where the productive base of the food web is impacted. Swiftly flowing stream rich in nutrients should not be slowed to this value, and slowly flowing streams should not be altered to have velocities greater than this value.

WA-RD-39.3. Horner, R.R., S.J. Burges, J.F. Ferguson, B.W. Mar, and E.B. Welch, "Highway Runoff Monitoring: The Initial Year", January 1979.

This report covers the initial 15 months of effort to review the literature, select a prototype site, compare the performance of several automatic sampling devices, and install a prototype sampling site on I-5 north of Seattle.

WA-RD-39.4. Clark, D.L. and B.W. Mar, "Composite Sampling of Highway Runoff: Year 2", January 1980.

A composite sampling device was developed that can be installed at less than ten percent of the cost of automatic sampling systems currently used in Federal highway runoff studies. This device was operated for one year, along-side an automatic sampler at the I-5 site, to demonstrate that the two systems provide statistically identical storm composites.

WA-RD-39.5. Aye, R.C., "Criteria and Requirements for Statewide Highway Run-off Monitoring Sites", July 1979.

Criteria for selecting statewide monitoring sites for highway runoff were established to provide representative combinations of climate, traffic, highway, land use, geographic, and topographic characteristics. Using these criteria, a minimum of six sites were recommended for use in this research.

WA-RD-39.6. Asplund, R., J.F. Ferguson, and B.W. Mar, "Characterization of Highway Runoff in Washington State", December 1980.

A total of 241 storm events were sampled at ten sites during the first full year of statewide monitoring of highway runoff. Analyses of these data indicate that more than half of the observed solids in this runoff is traced to sanding operations. The total solids loading at each site was correlated with traffic during the storm. The ratio of other pollutants to solids was linear when there was sufficient traffic-generated pollutants to saturate the available solids.

WA-RD-39.7. Mar, B.W., J.F. Ferguson, and E.B. Welch, "Year 3 - Runoff Water Quality, August 1979 - August 1980", January 1981.

This report summarizes findings detailed in WA-RD-39.4 and WA-RD-39.6 plus the work of Zawlocki on trace organics in highway runoff. Several hundred compounds tentatively identified by GC-MS (Gas Chromatography-Mass Spectrometer) were grouped into nine categories, which were not mutually exclusive. Major components of these categories were petroleum products used by vehicles and incompletely combusted hydrocarbons. The concentrations of these trace organics groups were low compared to criteria proposed for protection of aquatic life.

WA-RD-39.8. Eagen, P.D., "Views of Risk and Highway Transportation of Hazardous Materials - A Case Study in Gasoline", November 1980.

While gasoline represents one-third of all hazardous materials transported in the country by trucks, the risk associated with gas transportation, as viewed by the private sector, is small. Public perceptions of risk are much greater due to lack of knowledge on probabilities and consequences of spills. Methods to improve knowledge available to the public on gasoline spills and methods to improve estimates of environmental damages from gasoline spills is presented. Generalization of methodologies to hazardous materials in general are discussed.

WA-RD-39.9. Zawlocki, K.R., J.F. Ferguson, and B.W. Mar, "A Survey of Trace Organics in Highway Runoff in Seattle, Washington", November 1981.

Trace organics were surveyed using gas chromotography coupled to mass spectrometry for highway runoff samples from two Seattle sites. The characterization of the organics exhibited concentrations of aliphatic, aromatic, and complex oxygenated compounds. Vehicles, including exhaust emissions, were concluded to be the source of many of the organics.

WA-RD-39.10. Wang, T.S., D.E. Spyridakis, R.R. Horner, and B.W. Mar, "Transport, Deposition, and Control of Heavy Metals in Highway Runoff", January 1982.

Mass balances conducted on soils adjacent to highways indicated low mobility of metals deposited on well-vegetated surfaces. Grass drainage channels were shown to effectively capture and retain metals (e.g. a 60 m channel removed 80 percent of the original Pb concentration). Mud or paved channels, however, demonstrated little or no ability to remove metals from runoff. Metal release studies suggested that acid precipitation could release metals bound in the soil, especially where low buffering capacity exists.

WA-RD-39.11. Portele, G.J., B.W. Mar, R.R. Horner, and E.B. Welch, "Effects of Seattle Area Highway Stormwater Runoff on Aquatic Biota", January 1982.

The impacts of stormwater runoff from Washington State freeways on aquatic ecosystems were investigated through a series of bioassays utilizing algae, zooplankton, and fish. Algae and zooplankton were adversely affected by the soluble fraction of the runoff, while suspended solids caused high mortalities of rainbow trout fry. In addition, BOD_5 values similar to those reported in the stormwater literature were measured; however, there were indications that results were influenced by toxicity to microbial populations.

WA-RD-39.12. Chui, T.W., B.W. Mar, and R.R. Horner, "Highway Runoff in Washington State: Model Validation and Statistical Analysis", November 1981.

Results of the second year of full-time operation of nine monitoring sites in the State of Washington produced 260 observations of highway storm runoff. A predictive model was developed based on the data from two years of observation for total suspended solid loads. A high correlation was demonstrated between total suspended solids and COD, metals, and nutrients. The major factor controlling pollution loads from highways in Washington State is the number of vehicles passing during each storm, not those preceding storms.

WA-RD-39.13. Mar, B.W., J.F. Ferguson, D.E. Spyridakis, E.B. Welch, and R.R. Horner, "Year 4 - Runoff Water Quality, August 1980 - August 1981".

This report summarizes findings presented in WA-RD-39.10, 39.11, and 39.12. Included are the results of studies aimed at improving and extending Asplund's solids loading model, increasing data on the ratios of various pollutants to TSS in the runoff, investigating the fate of heavy metals in drainage systems, and conducting bioassays on sensitive organisms exposed to highway runoff.

WA-RD-39.14. Horner, R.R. and B.W. Mar, "Guide for Water Quality Impact Assessment of Highway Operations and Maintenance", August 1982.

Procedures particularly applicable to Washington State have been developed to assist the highway designer in evaluating and minimizing the impacts of highway runoff on receiving waters. The guide provides computation procedures to estimate pollutant concentrations and annual loadings for three levels of analysis which depend on the watershed, the discharge system, and traffic. It further provides means to judge the potential impacts of the runoff on receiving waters.

WA-RD-39.15. Horner, R.R. and E.B. Welch, "Impacts of Channel Reconstruction in the Pilchuck River", August 1982.

A five-year study was performed to compare conditions in the Pilchuck river before and after channel reconstruction associated with rerouting Highway SR-2. The study focused on sediment particle-size analyses, benthic macroinvertebrates, and fish. Substrates comparable to control areas developed in all portions of the new channel within one year after construction. The available data on invertebrates and fish gave no indication of deterioration in diversity, quantity or size in the reconstructed channel. The report provides recommendations for further improvements in the design of stream channel changes should there be no alternative to their construction.

WA-RD-39.16. Mar, B.W., R.R. Horner, J.F. Ferguson, D.E. Spyridakis, and E.B. Welch, "Summary -- Washington State Highway runoff Water Quality Study, 1977 - 1982", September 1982.

The final report on the research project summarizes the results presented in detail in the preceding reports and graduate student theses.

WA-RD-39.17. Little, L.M., R.R. Horner, and B.W. Mar, "Assessment of Pollutant Loadings and Concentrations in Highway Stormwater Runoff", April 1983.

This report presents the final form of the Washington State highway pollutant loading model, incorporating data from the five years of study. It also features a probabilistic analysis of concentration and loading data designed to express the chance of exceeding specific values in a given case. Other topics include further assessment of the toxicity of highway runoff and its causes.

Please send me copies of Report WA-RD-39.1, 39.2, 39.3, 39.4, 39.5, 39.6, 39.7, 39.8, 39.9, 39.10, 39.11, 39.12, 39.13, 39.14, 39.15, 39.16, 39.17.

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Table 3: Journal Publications under Highway Runoff Water Quality Project.

Horner, R.R. and E.B. Welch, "Stream Periphyton Development in Relation to Current Velocity and Nutrients", Can. J. Fish. Aquat. Sci. 38:449 - 457 (1981).

Clark, D.L., R.L. Asplund, J.F. Ferguson, and B.W. Mar, "Composite Sampling of Highway Runoff", J. Environ. Eng. Div. ASCE 107:1067 - 1081 (1981).

Asplund, R.L., J.F. Ferguson, and B.W. Mar, "Characterization of Highway Runoff in Washington State", J. Environ. Eng. Div. ASCE 108:391 - 404 (1982).

Chui, T.W., B.W. Mar, and R.R. Horner, "A Pollutant Loading Model for Highway Runoff", accepted for publication by J. Environ. Eng. Div. ASCE.

Portele, G.J., B.W. Mar, R.R. Horner, and E.B. Welch, "Toxicity of Highway Stormwater Runoff to Algae, Zooplankton, and Fish", to be submitted to Water Res.

Wang, T.W., D.E. Spyridakis, B.W. Mar, and R.R. Horner, "Transport, Deposition, and Control of Heavy Metals in Highway Runoff", to be submitted to J. Water Poll. Control Fed.

Horner, R.R. and B.W. Mar, "Guide for Water Quality Impact Assessment of Highway Operations and Maintenance", to be submitted to the Transportation Research Board.

Little, L., R.R. Horner, and B.W. Mar, "Probability Distributions of Highway Runoff Water Quality", to be submitted to J. Environ. Eng. Div. ASCE.

PROBLEM STATEMENT

Prior to the initiation of this research, knowledge of the water pollutant loads associated with operating highways was not well-focused, and loading estimates ranged over several orders of magnitude. High estimates suggested that highway runoff could be of poorer quality than municipal wastewaters and would require extensive treatment, while lower values suggested treatment was not necessary. Most of the literature values were reported for high-intensity rainfall patterns and may not be applicable to low-intensity rainfall areas such as Washington State. No standards for reporting highway runoff data existed, and many of the published data were not comparable. Furthermore, the collection and analysis of highway runoff data were very expensive due to the use of automatic sampling equipment that required considerable maintenance and care. Each new highway project would require extensive analysis and field study to define the potential water quality impacts and suitable mitigation measures, and delay in project approval could be anticipated due to questions concerning the quality of the water quality assessment.

Thus the lack of knowledge of highway runoff quality could introduce major added project costs associated with litigation to obtain project approval, assessment costs to establish that a project would meet water quality objectives, and unneeded mitigation costs if the estimates of highway runoff pollutant loads were too high.

The design of this research project sought to: 1) improve the instrumentation and reduce the cost of sampling highway runoff; 2) use this improved technology to obtain an adequate data base to characterize the pollutants in highway runoff at representative sites in Washington State; 3) analyze these data to develop a predictive model of highway runoff water quality; and 4) develop a methodology based on these models to assess the impact of highway runoff water quality.

SCOPE AND OBJECTIVES OF STUDY

The purpose of the Highway Runoff Water Quality research project was to characterize highway runoff in the State of Washington to permit the cost-effective control of such drainage when necessary. In the original proposal seven tasks were identified to meet the project objectives;

1). Assessment Tools - An assessment of the existing literature was made to establish monitoring methods and existing knowledge of highway runoff analysis.

2). Site Selection - A research design was formulated to examine factors cited in the literature related to highway runoff. Ten sites were chosen to vary traffic, precipitation frequency and intensity, adjacent land use, and highway design.

3). Prototype and Long-Term Monitoring - Three years of data were collected at the selected sites. Longer periods of observation were required at Eastern Washington Locations to obtain a statistically significant data set. Data were analyzed to obtain a predictive model of pollutant loading and frequency of occurrence of concentrations and loadings that may be of concern.

4). Critical Pollutant Study I - A five-year study of the Pilchuck River channel change for SR-2 construction was performed.

5). Critical Pollutant Study II - Intensive studies were undertaken to characterize trace organics and hydrocarbons in runoff and leachate from wood waste fills.

6). Critical Pollutant Study III - An intensive study was performed to determine the source and fate of trace metals from highway runoff and to conduct bioassays to determine the ecological response to highway runoff.

7). Workshops - Several workshops were held to present research findings as they were completed. An assessment guide book was developed to present all usable findings in future implementation programs.

The remainder of this report summarizes the conduct and findings of each of these tasks.

RESEARCH DESIGN

The research had three major components:

o Statewide Monitoring -- Tasks 1, 2, and 3 developed improved sampling technology and applied it to ten sites for several years to collect a large data base. The sites were selected to represent variation in traffic, adjacent land use, and highway design and construction. Data collected for each storm included runoff volume, rainfall, traffic, and pollutant concentrations. Analysis of these data resulted in development of predictive models for use in impact assessment.

- Special Studies -- Tasks 4, 5, and 6 were designed to define the impacts of stream channel reconstruction, leachate from woodwaste fills, and trace metal and organic pollutants. In each of these studies fundamental research was performed to examine the source and fate of specific pollutants or environmental changes.

- Implementation Efforts -- Task 7 was intended to analyze and communicate the findings of the project in order to improve the assessment of aquatic impacts created by operating highways.

The basic research methodology was to collect as many highway runoff storm samples as possible, within given time and financial constraints, to satisfy a stratified experimental design examining the effects of adjacent land use, highway design, traffic, and rainfall. Chemical analyses were performed to establish pollutant concentrations, and biological studies were conducted to define organism responses to contaminant exposure. Exhaustive analyses of these data were performed to develop models to estimate highway runoff water quality impacts and to suggest integrating measures.

CHRONOLOGY OF THE PROJECT

Examination of the titles and publication dates of the dissertations and technical reports of this project (Tables 1 and 2) indicates the chronological development of the research. The first tasks were to examine the literature of past work, to plan the general tasks, and to initiate exploratory research necessary to further develop the long-term tasks. The initial tasks were:

Task 1. Extensive review of the contemporary literature to establish the relative significance of highway runoff relative to other non-point and point pollution sources and to develop cost-effective monitoring methods (Report No. WA-RD-39.3).

Task 4. Evaluation of Pilchuck River Channel modification -- a five-year observation before, during, and after a channel relocation, monitoring fish and other elements of the food chain and their habitats (Report No. WA-RD-39.15).

Definition of the ability of receiving waters to tolerate changes in velocities (due to channel modification and increased runoff) and nutrient loadings (due to nonpoint sources) without significant changes in the food web (Report No. WA-RD-39.2).

Once the methodology was defined to measure highway runoff characteristics and impacts, a prototype monitoring station was established and a statewide sampling network (Tasks 2 and 3) was created to observe the anticipated range of highway runoff in the state. The work of Aye, Tseng, and Clark formed the nucleus of this effort (WA-RD-39.4 and 39.5). The operation of the statewide sampling network was the focus of the efforts of Asplund, Chui, and Little (WA-RD-39.6, 39.12, and 39.16) and provided a comprehensive data set of over 600 storms characterizing highway runoff. As the nature of highway runoff was identified, a series of special studies was initiated to provide a short but intensive investigation of specific problems that may be associated with highways. These were:

Task 5: Vause conducted laboratory and field studies to characterize the amounts and duration of organic pollutant loadings released by wood wastes used in construction of highway embankments (WA-RD-39.1).
Zawlocki evaluated the spectrum of trace organics associated with runoff from highways and stimulated research on this problem by other units on campus (WA-RD-39.9).

Task 6: Wang examined the fate of trace metals in the soil and vegetation adjacent to highways and investigated the transport of pollutants in various drainage systems (WA-RD-39.10).
Portele conducted bioassay tests of highway runoff waters, exposing saprophytic bacteria, algae, zooplankton, and fishes (WA-RD-39.11).

Based on results of the long-term studies and intensive projects, a model describing highway runoff water quality was developed and mitigating measures that will reduce their impacts were prescribed (WA-RD-39.6, 39.12, and 39.16). These findings were assembled (Task 7) in a guide for use in impact assessment (WA-RD-39.14) and future research implementation programs.

SUMMARY OF RESULTS

The results are presented in three major sections: 1) characterization of highway runoff, 2) impacts of highway runoff and their mitigation and 3) models of highway runoff water quality.

Highway Runoff Characteristics (Tasks 1,2,3).

Highways present large areas of impermeable surface that can increase runoff volumes, possibly leading to scour of existing channels. In addition, highway runoff can contribute significant pollutant loads to nearby receiving waters. Highways can also disrupt natural drainage pathways by blocking or necessitating the rerouting of natural channels. The Federal Highway Administration has funded Rexnord Inc. (Milwaukee, WI) to conduct multi-year research on the sources and effects of highway runoff. The Rexnord studies have focused on relatively high-intensity, short-duration storm events and on areas where the time between storms is long compared to the storm duration. The research reported here focused on conditions particular to the Pacific Northwest, where low-intensity, long-duration rainfall events are common.

The general literature tends to consider highway runoff as similar in composition to general urban runoff; in fact, few comprehensive studies, with the exception of the Rexnord efforts, have focused on highway runoff. Furthermore, most urban runoff studies have emphasized the "first-flush" phenomenon, where accumulations of debris from antecedent storms and dry periods between storms are washed from the surface by the first runoff waters. The standard monitoring procedure is to install automatic samplers that are started by rainfall or the initial runoff flow. The devices are programmed to collect a sample of runoff after equal time intervals or after a given volume of runoff has passed. These runoff studies have been complemented by street sweeping investigations to define the accumulation of dry debris between storms. These procedures are very costly and have relatively low data recovery success, since breakdowns are common and many samples must be analyzed.

Anticipating the large number of storms than occur annually in Western Washington, work was initiated in this project to develop a low cost, highly reliable sampling system. Clark (WA-RD-39.4) described the evaluation and performance of a new type of composite sampler developed for this project. The composite sampler consists of an open-channel of rectangular cross-section with vertical dividers placed parallel to the direction of flow. The dividers divert a constant fraction of the flow into a holding tank. Figures 1 and 2 illustrate the flow-splitting device and a typical installation. The storage tank is lined with a large plastic bag that is replaced after each storm to prevent cross-contamination. The storm volume is estimated from the volume in the storage tank (measured by depth) and the splitting fraction. A calibration curve was developed for each splitter using a series of calibrated flow rates. Clark demonstrated that, over a tenfold range of flows, the splitting fractions were maintained within ten percent of the desired values.

A prototype site was established at N.E. 158th Street on the northbound lanes of Interstate 5 in Seattle to compare the performance of the composite sampler with the traditional automatic sampling system. Results of over one year of side-by-side evaluations (WA-RD-39.3 and 39.4) demonstrated that the system produced composites equivalent to those made up from a series of dis-

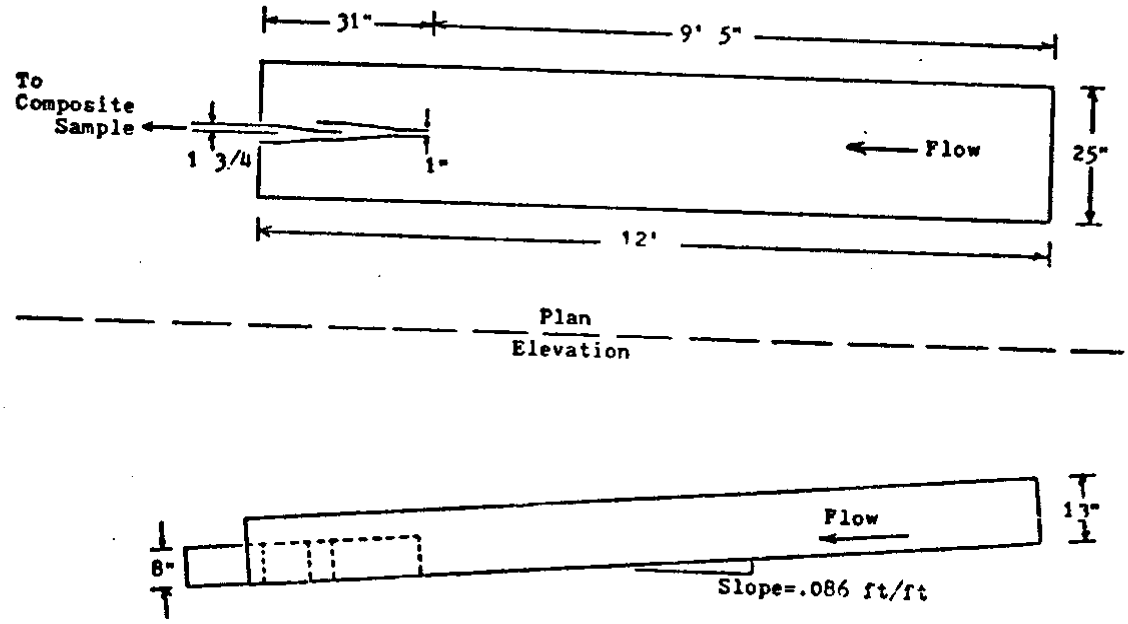

Figure 1: Diagram of a Typical Flow Splitter.

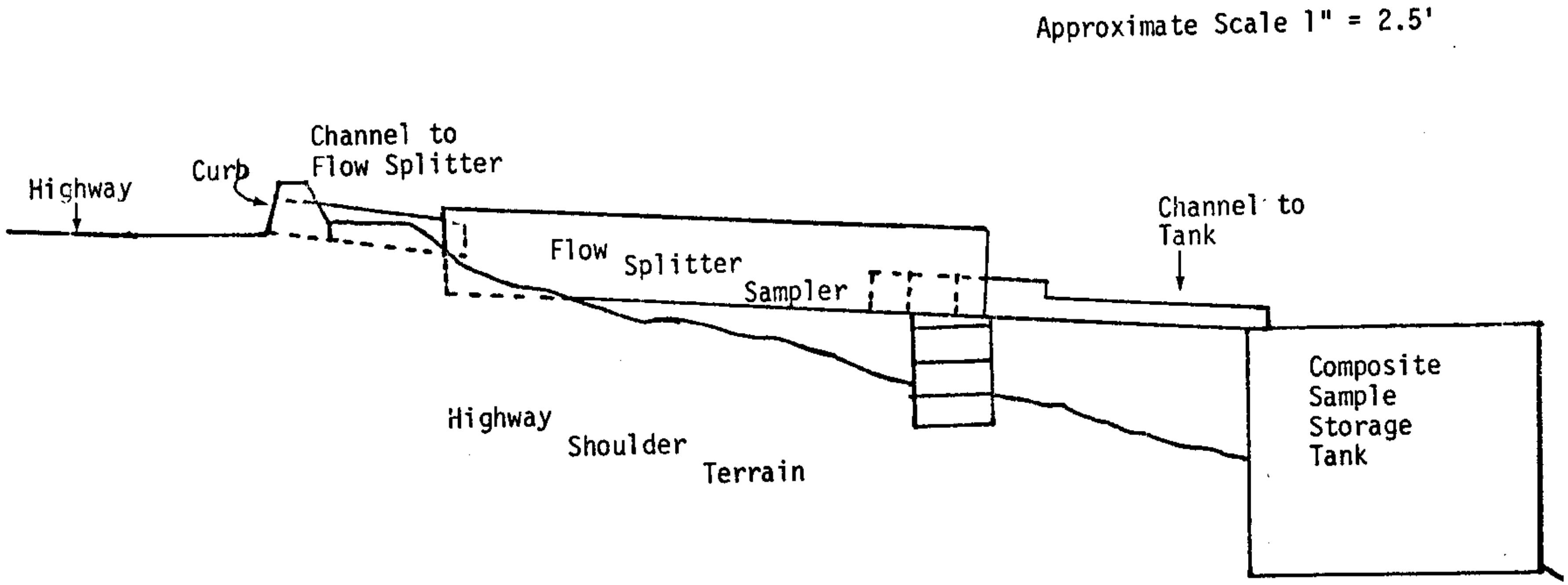

Figure 2: Layout of the Composite Sampling System on a Curbed Highway.

crete samples collected by an automatic sampler. Furthermore, the costs of installing and operating the composite sampler and analyzing samples were an order-of-magnitude less than the automatic sampling system. Based on these findings, ten sampling sites using the composite sampler were selected to observe highway runoff over a spectrum of traffic volumes, highway characteristics and climatic regimes representative of conditions in the state of Washington. These sites are described in Table 4. The experimental design included traffic volumes ranging from 2500 to 53,000 ADT (average daily traffic), annual rainfall ranging from 7 to 100 inches per year, adjacent land use ranging from natural forest to high density urban environments, single lane to multi-lane configuration, and both asphalt and concrete pavements.

Results of the discrete versus composite sampling investigation and studies by local water quality control agencies (Municipality of Metropolitan Seattle and City of Bellevue[2] demonstrated that the first-flush phenomenon was not the general rule in the Pacific Northwest and that the pollutant load associated with the initial runoff was a minor component of the total storm loading. The explanation for the lack of first-flush behavior is based on two factors. First, the rainfall and subsequent runoff patterns observed in Western Washington are quite different from national patterns. Rainfall is of low intensity (hundredths of an inch per hour) and long duration. A large initial flush of runoff to wash accumulated solids from the drainage system is uncommon. Instead, the runoff volume slowly increases and any accumulated solids are gradually carried from the system. The second factor appears to be the effectiveness of traffic- generated winds in removing debris from the highway. Most of the first-flush data in the literature are reported for urban runoff (residential streets, parking lots, etc.). Experience gained after the eruption of Mt.St. Helens demonstrated that traffic-generated winds effectively removed large volumes of ash from highways, and that the steady-state volume of solids on a highway is controlled by the width of the distress lane, the height of the curbing, and the speed of the traffic. As will be explained later, the pollutant loads from highways correlated very poorly with traffic between storms or dry days between storms. Rainfall in Eastern Washington is infrequent and also lacks the intensity required for washoff in all storms.

At no added cost to the project, sites at the Pullman sulfur extended asphalt project were included in the monitoring program. Data from these sites indicated no long-term difference in elemental sulfur or sulfate loadings in highway runoff.

The results of three years of continuous monitoring at the network of highway runoff sites are summarized in Table 5. Several general conclusions may be reached by examining the complete data set:

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[1] Dalseg, R. and G. Farris, "The Quality of Rainfall Runoff from Interstate-5 at "Seattle", Municipality of Metropolitan Seattle, Seattle, WA (1970).

[2] U.S. Environmental Protection Agency, "Preliminary Results of the Nationwide Urban Runoff Program," Vol. II, (Draft) Water Planning Division, Washington, DC (1981).

Table 4: Physical Characteristics of the Highway Runoff Sampling Sites

Site Location	Climate	Average Yearly Rainfall	Site Description	Physical Characteristics Area	Physical Characteristics Length	Highway Description # Width, Pavement Type, Barrier	Traffic Volumes (ADT)	Surrounding Land Use	Sampler	Flowsplitter # Faction Split
1. I-5 I-5 & 158th NE Northbound lanes Seattle, WA	Puget Sound Lowlands-Marine	32-45	A wide radius curve with a 1.1% grade on a limited access highway, Sample intake: from catch basin	53,140 ft^2 1.2 Ac	780' 0.15 mi	4-12' concrete lanes 10'-DL-asphalt-curb 10'-ML-asphalt-NJ	53,000	Urban Residental	U of W Seattle	0.0125
2. SR-520 SR-520 at Montlake Westbound lanes NOAA Parking Lot Seattle, WA	Puget Sound Lowlands-Marine	32-45	Elevated bridge section with 2% grade site includes runoff from on ramps, Sample intake: from NW corner drain after on-ramp	4,310 ft^2 0.099 Ac	150' 0.029 mi	2-12' concrete lanes 2'-DL-concrete-NJ 1'-ML-concrete-NJ	42,000	Urban	U of W Seattle	0.210
3. Vancouver I-205 & St.Johns St. Southbound lanes Vancouver, WA	Cascade Foothills-Marine	40-90	A wide radius horizontal curve on a limited access highway Sample intake: off existing catch basin S. of St. Johns	11,970 ft^2 0.28 Ac	220' 0.042 mi	3-12' concrete lanes 10'-DL-asphalt-curb 8'-ML-asphalt	8,600	Low Density Residential	WSDOT#4 Dist.Engr. Office Vancouver	0.044
4. Snoqualmie Pass I-90 at Mile past 41.5 Eastbound lanes North Bend, WA	West Slope Cascade Mountains	60-100	A wide radius curve with 1.2% grade on a limited access highway Sample intake: off curb	7,780 ft^2 0.18 Ac	140' 0.027 mi	3-12' concrete lanes 12'-DL-asphalt-curb 6'-ML-asphalt	7,700	Western Coastal Forest Undeveloped	WSDOT#1 Field Engr. Office North Bend	0.055
5. Montesano SR-12 0.5 miles West of SR-12 and Montesano, WA	Western Olympics-Coastal	70-100+	Curved approach to bridge section and a portion of the on-ramp, Sample intake: off curb	12,210 ft^2 0.28 Ac	310' 0.059 mi	2-12' asphalt lanes 8'-DL-asphalt-curb 6'-ML-asphalt	7,300	Agricultural Pasture Land	WSDOT#3 Field Main. Office Aberdeen	0.058, From 3-23-80 on 0.019
6. Pasco Interchange of SR-12 & SR-195 Eastbound lanes SR-12 Pasco, WA	Central Basin East Cascade Foothills	7-15	Wide radius horizonal curve in transition to a -0.9% horizontal grade, Sample intake: off existing culvert--site below grade	54,320 ft^2 1.25 Ac	1090' 0.21 mi	2-12' concrete lanes 10'-DL-asphalt-curb 4'-ML-asphalt 12'-asphalt gutter along DL	2,000	Semi-arid desert Undeveloped w/Irrigation Agriculture	WSDOT#5 Field Engr. Office Pasco	0.009
7. Spokane I-90 at Latah Cr. Bridge Eastbound lanes western pier section Spokane, WA	Northeastern	17-28	Horizontal bridge section on a limited access highway, Sample intake: from 5 bridge drains at base of middle pier.	9,590 ft^2 0.22 Ac	180' 0.035 mi	3-12' concrete lanes 3'-DL-concrete-NJ 2'-ML-concrete-NJ	17,300	Urban	WSDOT#6 Dist. Main. Office Spokane	0.051
8. Pullman-8 SR-270 2.5 mi West of city, Eastbound lanes, Pullman, WA	Palouse - Blue Mountains	10-19	-1.0% horizontal grade on 30%-70% by weight sulfur-asphalt section of sulfur extended project, Sample intake: off curb	9,750 ft^2 0.22 Ac	500' 0.095 mi	1-12' asphalt lanes 7.5'-DL-asphalt-curb asphalt: 70% reg.mix 30% sulphur mix	2,500	Agriculture	WSU Pullman	0.071
9. Pullman-9 SR-270 2.5 mi West of city, Westbound lanes, Pullman, WA	Palouse - Blue Mountains	10-19	+1.0% horizontal grade on 30%-70% by weight sulfur-asphalt section of sulfur extended project, Sample intact: off curb	10,670 ft^2 0.25 Ac	500' 0.095 mi	1-12' asphalt lane 7.5'-DL-asphalt-curb asphalt: 70% reg. mix 30% sulphur mix	2,500	Agriculture	WSU Pullman	0.071
10. Pullman-Control SR-270 2.3 mi West of city, Eastbound lanes, Pullman WA	Palouse-Blue Mountains	10-19	-1.0% horizontal grade on asphalt control section of sulfur extended project, Sample intake: off curb	13,210 ft^2 0.30	500' 0.095 mi	1-12' asphalt lane 7.5'-DL-asphalt-curb asphalt: 100% reg. mix	2,500	Agriculture	WSU Pullman	0.071

DL - Distress Lane

ML - Median Lane

Table 5: Summary of Experimental Results at Highway Runoff Sites.

Site	From	To	Number of Storms Sampled	Average Runoff Coefficient	Specific Pollutant: TSS Ratios VSS	COD	Pb ($X10^{-2}$)	Zn ($X10^{-2}$)	P ($X10^{-2}$)
I-5	9/78	1/82	202	0.72	0.17	0.41	0.46	0.17	0.23
I-5* (3)	8/80	12/80	25	0.77	0.26	0.20	0.49	0.23	0.19
SR-520	1/78	6/80	56	0.70	0.20	0.49	0.42	0.10	0.18
Vancouver	8/79	12/81	99 (1)	0.44	0.19	0.59	0.06	0.06	0.19
Snoqualmie Pass	9/79	5/81	44	0.62	0.11	0.20	0.06	0.04	0.21
Montesano	10/79	5/81	71	0.75	0.13	0.27	0.11	0.04	0.16
Pasco	9/79	12/81	47	0.77	0.24	0.50	0.17	0.10	0.12
Spokane	9/79	12/81	17	0.69	0.19	0.49	0.10	0.57	0.22
Pullman - 9	9/79	1/82	46	0.52	0.13	0.41	0.05	0.03	0.27
Pullman-Control	4/80 (2)	1/82	46	0.80	N.A.	N.A.	N.A.	N.A.	N.A.
TOTAL			653						

N.A. = not available.

Notes: (1) Plus 5 composites of several storms each.
(2) Previous control site abandoned because of poor control characteristics.
(3) I-5* is an adjacent station established to provide replication and collect larger particles (grit) removed in H-flume at initial I-5 site.

- o Runoff volumes from highways can vary significantly on elevated and curbed sections.
- o Total suspended solids (TSS) loadings on a individual storm basis are highly variable and can be predicted only within a factor of two or more. On the other hand, long-term cumulative TSS loads are highly correlated with vehicles traveling during storms.
- o Loadings of various pollutants are proportional to TSS. The coefficients of proportionality are functions of traffic for pollutants associated with vehicle wear or operation and constant for other pollutants.

Theoretically, the runoff from highways should approach the volume of rainfall incident on the paved area. In practice, the observed runoff from curbed highway sections and elevated roadways often was much less than this anticipated volume. At the Vancouver site, leakage from the catch basin permitted over half the runoff water to infiltrate into the soil rather than to enter the drainage system. At the SR-520 site, expansion joints in the elevated road sections worked free, and runoff seeped through these joints. Curbed sites provide storage capacity for runoff adjacent to the curbs, with the result that runoff from smaller storms is much less on curbed segments than equivalent noncurbed sections. Finally, the heat from high traffic volumes and the ability of traffic to spray water off the roadway removes runoff. The long-term statewide data for runoff volumes suggest that runoff coefficients for curbed and elevated roadways should be less than those for over-the-shoulder drainage.

In nationwide highway runoff studies, the emphasis has been on storms large enough to thoroughly wash impervious surfaces, for example, storms that may total several inches of rain or have intensities of 0.5 to 1.0 inch per hour. Storms of such magnitude can cleanse a roadway and would produce higher concentrations of pollutants during the early phases of the storm. In Washington State such storm events are rare, and the maritime influence creates low-intensity, long-lasting periods of precipitation. The volume and flow rates of runoff produced by such storms are insufficient to completely wash pollutants off highways. Flow along curbed sections is periodic, and pollutants can be suspended and redeposited several times before reaching a catch basin. Large variations were noted in solids accumulations between consecutive storms. These were attributed to the considerable variation in runoff flows and the inability of these fluctuating low flows to wash pollutants completely off the paved surfaces.

The results of Tasks 1, 2 and 3 were a large data base and literature survey characterizing highway water quality runoff in the State of Washington.

<u>Impacts of Highway Runoff and Their Mitigation</u> (Task 4,5,6)

Water quality criteria have been developed for pollutant concentrations in receiving waters and in waste streams assuming continuous discharge. Highway runoff is not a continual event, but a periodic phenomenon. Furthermore, runoff from highways is accompanied by drainage from adjacent lands, which may provide dilution of highway-generated pollutants. In the case of more contaminated urban drainage, highway runoff may itself produce some dilution.

Table 6 compares the concentration of pollutants found in highway runoff with treated sewage, urban runoff, EPA drinking water standards, and criteria for freshwater aquatic life. While solids concentrations in highway runoff are generally comparable to those in urban runoff and treated sewage, the nutrient levels are usually much lower and the metals concentrations are similar or lower, aside from the occurrence of extreme values. The major difference between highway runoff and sewage is that most of the pollutants are insoluble and bound to the solid particles in the highway case. Concentrations reported in the literature are for total rather than soluble fractions; and, even when the concentration of a pollutant appears to be of concern, the actual biologically available fraction is likely much lower. Tasks 4, 5, and 6 focused in the impact of highway runoff and channel changes.

Concerns with changes in velocity and other conditions resulting from river channel reconstruction were investigated in the Pilchuck River over the period preceding and following a 2300 ft modification for SR-2 construction (Task 4). The study encompassed fish, benthic macroinvertebrates, and bed sediments to provide a comparison of conditions before and after channel reconstruction. Efforts were made during construction to maintain the original length of the reach and natural meandering and pool/riffle patterns and to promote the recovery of a natural substrate. Results of the final year's sampling indicate that the new channel rapidly established habitats similar to the old channel.

The basic quality data from the statewide sampling network for highway runoff suggests that the nutrient loads of highway runoff are normally much lower than levels found in treated waste waters and urban runoff. In an attempt to provide a basis to extrapolate the impacts of highway runoff and channel modifications, Horner (WA-RD-39.2) conducted field studies at 12 natural stream sites in Western Washington. Since highway runoff can increase stream discharge and current velocities and since nutrient loadings from highways still are greater than minimum levels to stimulate eutrophication, it was important to establish the impact of velocity change and nutrient addition acting together. Horner's conclusions included:

- In low fertility streams runoff and construction activity should not increase average current velocities from less than to much more than 50 cm/sec in order to avoid shearing attached algal growths and maintain the stream's primary production capacity.
- In nutrient-rich streams the chances of avoiding nuisance filamentous growths are best if slow currents are not increased towards 50 cm/sec or rapid currents are not decreased towards this point.

Task 4 results established that design practices used in the Pilchuck River channel change do provide substitute habitat for aquatic life, but care must be taken to prevent flood flows from scouring the reconstructed channel. The results also indicated that the discharge of highway runoff must be controlled to prevent altering the receiving water current velocities beyond the 50 cm/sec critical velocity defined in this research.

Table 6: Comparison of Typical Pollutant Concentrations in Various Point and Nonpoint Source Wastewaters and Water Quality Criteria.

Category	Concentration (mg/l)							
	TSS	BOD	COD	Pb	Zn	NO_3+NO_2-N	TKN	TP
Nonpoint source:								
Highway	3-250	4-45	10-500	0-.83	0-2.5	0.1-5.5	0-10	0.04-3.8
Commercial	580-1080	80	90-500	0.2-1.7	0.1	0.08	0.8	0.7-3.0
Industrial	50	15	50	0.2	0.2	0.33	4.0	0.4
Single-Family Residential	30	8	44	0.2	0.1	0.42	1.9	0.3
Multiple-Family Residential	440	120	310	-	-	-	2.5	3.4
Point Source:								
Raw sewage	100-350	100-300	250-1000	-	-	0	20-85	6-20
Treated sewage	10-120	10-150	75-300	-	-	5	24	5-18
Criterion:								
Drinking water	-	-	-	0.5	5	10	-	-
Aquatic life	80	-	-	0.17(1)	0.32(1)	-	-	0.01

Note: (1) At total hardness = 100 mg/l as $CaCO_3$.

As part of Task 5, Zawlocki (WA-RD-39.9) surveyed trace organics in highway runoff using gas chromotography-mass spectrometry techniques. Table 7 summarizes the results. These data indicate:

o More than two-thirds (average 80 percent) of the extractable organics in runoff are associated with the particulates. Reduction of the particles in runoff would also remove a large fraction of the trace organics. Total extractable organic concentrations are similar to those of treated sewage.

o Toxic polychlorinated biphenol compounds (PCB's) were not present in detectable concentrations in the runoff samples. This result is opposite of findings in urban runoff studies, where high PCB concentrations have been measureed.

o The organic compounds observed in highway runoff are predominately vehicle-related, e.g. gasoline components and combustion products. Brominated compounds measured were traced to ethylene dibromide used in leaded gasoline. Oxygenated hydrocarbons are produced by incomplete combustion of gasoline.

o A U.S. Environmental Protection Agency Laboratory verified Zawlocki's results on one I-5 storm sample.

o The high cost of detailed trace organic analysis (~$2,000 per sample) cannot be justified at this time, with no evidence that trace organics in highway runoff are linked to health or aquatic effects.

Another potential water quality problem investigated in Task 5 was oxygen depletion caused by highway runoff. Vause (WA-RD-39.1) conducted laboratory and field studies on the leachate from wood waste fills. laboratory experiments observed bod release as a function of rainfall in both saturated and unsaturated conditions. both laboratory and field data indicated that 20 to 40 lbs of bod were released per ton of wood waste. the release occurred at exponentially decreasing rates over approximately one year and then remained at levels similar to general highway runoff. to prevent oxygen depletion problems at woodwaste fills, these actions can be taken: 1) presoak woodwaste for a year or use year old waste; 2) provide adequate dilution waters for the leachate; and 3) provide collection and treatment of leachate for one year (the one-year period is recommended to insure sufficient pollutant reduction regardless of the specific rainfall patterns immediately following fill placement). Direct discharge of wood waste leachate across the intertidal zone was observed to cause discoloration of the beach. The values observed by Vause can also be used to estimate the potential BOD loads from logging debris that accumulates along highways.

BOD concentrations in runoff from highways can be reduced to negligible values by flow through grassy channels or by dilution. No substantial oxygen depletion is anticipated in the case of low traffic highways. With more heavily traveled highways, the major problem will be encountered when drainage is through a pipe or runoff from a long length of highway is collected and discharged at a single point. Unless these storm waters can be mixed with a volume of well-oxygenated waters approximately 100:1 to achieve a dilution of

Table 7: Extractable Organics Classified Into Nine Categories.

Class of Compounds	STORM I5-87			STORM I5-131			STORM 520-43		
	Particulate (μg/l)	Soluble (μg/l)	Total (μg/l)	Particulate (μg/l)	Soluble (μg/l)	Total (μg/l)	Particulate (μg/l)	Soluble (μg/l)	Total (μg/l)
Alcohols	T	160	160	478	155	633	327	126	453
Aliphatic Hydrocarbons	3710	3220	6930[1]	1850	636	2490	913	20	933
Aromatic Compounds including Heterocyclics	2050	148	2200	297	96	393	596	128	724
Halogenated Organics	T	T	T	173	9	82	114	T	114
Ketones and Aldehydes	1130	T	1130	87	39	126	385	128	513
Organosulfur Compounds	1200	62	1260	T	5.3	5.3	4.9	T	4.9
Oxygenates excluding Alcohols, phenolics, ketones/aldehydes	3170	410	3580	3510	228	3740	2440	126	2570
Nitrogen Containing Compounds	1420	62	1480	87	28	115	325	135	460
Phenolics	2830	80	2910	T	2.9	2.9	T	T	T
Total Chromatographed	10236	6803	17039	6308	1204	7512	4083	320	4403

100:1 or more, a potential for oxygen depletion, as well as toxicity, may exist.

In Task 6, Wang (WA-RD-39.10) conducted a study on the sources and fate of heavy metals in highway runoff. His conclusions were:

- o A significant fraction of the solids generated by highways is blown and deposited within 15 meters of the roadway and is incorporated in the vegetation and top soil. The remainder is widely dispersed at low concentrations.
- o Metals associated with the soils can be leached by runoff waters with pH lower than 5; otherwise metals appear to be immobile.
- o Channeling runoff through approximately 60 meters of grass removes 60 - 80 percent of the lead, zinc, and copper. Very little removal results from flow through paved or bare mud ditches. Similar removal occurs when runoff flows directly over grassy shoulders. A length of 100 meters is suggested to insure maximum removal.
- o Runoff waters contain only a few percent of the heavy metals generated by highways, with the majority of these pollutants being removed by traffic-generated winds.

Figure 3 illustrates the pattern of lead reduction during flow through the drainage system at the I-5 site.

It was demonstrated that the majority of metals in highway runoff are in unavailable forms and can be immobilized in soils and vegetation. In addition, analyses showed low concentrations of the most toxic organic compounds. Nevertheless, it was desired to directly investigate runoff impacts on aquatic biota by conducting a series of bioassays. Portele (WA-RD-39.11) performed bioassays on algae, zooplankton, and fish, as well as BOD tests designed to reveal runoff toxicity to bacteria. Little (WA-RD-39.16) conducted additional algal bioassays. Figure 4 illustrates Portele's algal toxicity comparison among highway sites of different traffic volumes. Figure 5 presents Little's comparison of algal toxicity in direct runoff and runoff drained through a 90 meter long grass channel. The bioassay results overall demonstrated the following points:

- o Runoff from highways with low traffic volumes (less than 10,000 ADT) shows essentially no toxic effects.
- o The toxicity in runoff from high traffic highways can be substantially reduced by overland drainage. Portele found that suspended sediments are more harmful to small trout than dissolved metals and that survival in 100 percent highway runoff increased to nearly that in controls when the runoff was grass-filtered.
- o The source of toxicity in Washington State highway runoff seems to be heavy metals, rather than organics. Little (WA-RD-39.16) concluded that zinc in rainfall was primarily responsible for the high toxicity at I-5, which exceeded that of other highways of similar traffic volume.

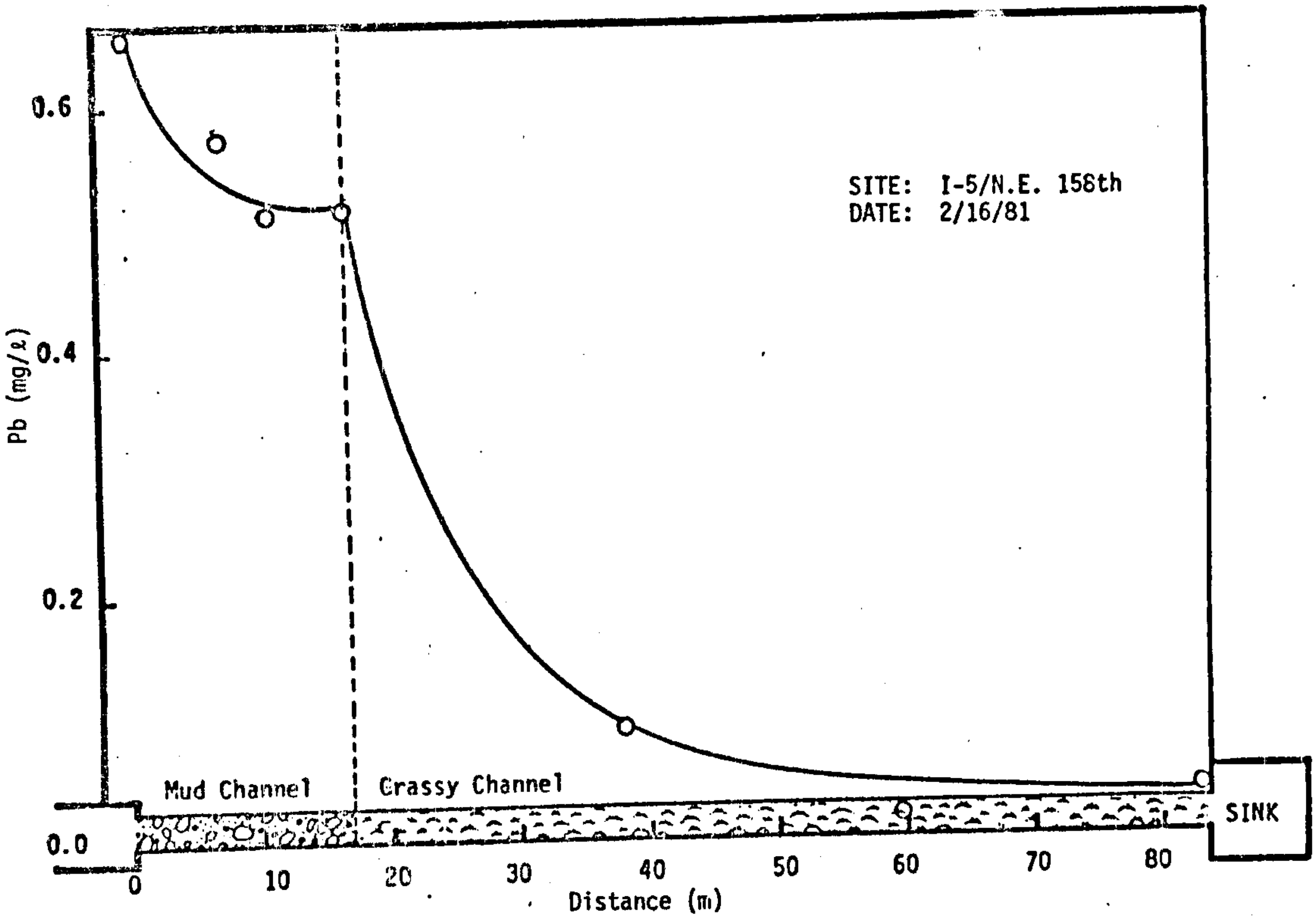

Figure 3: Typical Pattern of Reduction in Runoff Lead Concentration with Distance Traveled in Mud and Grass Channel.

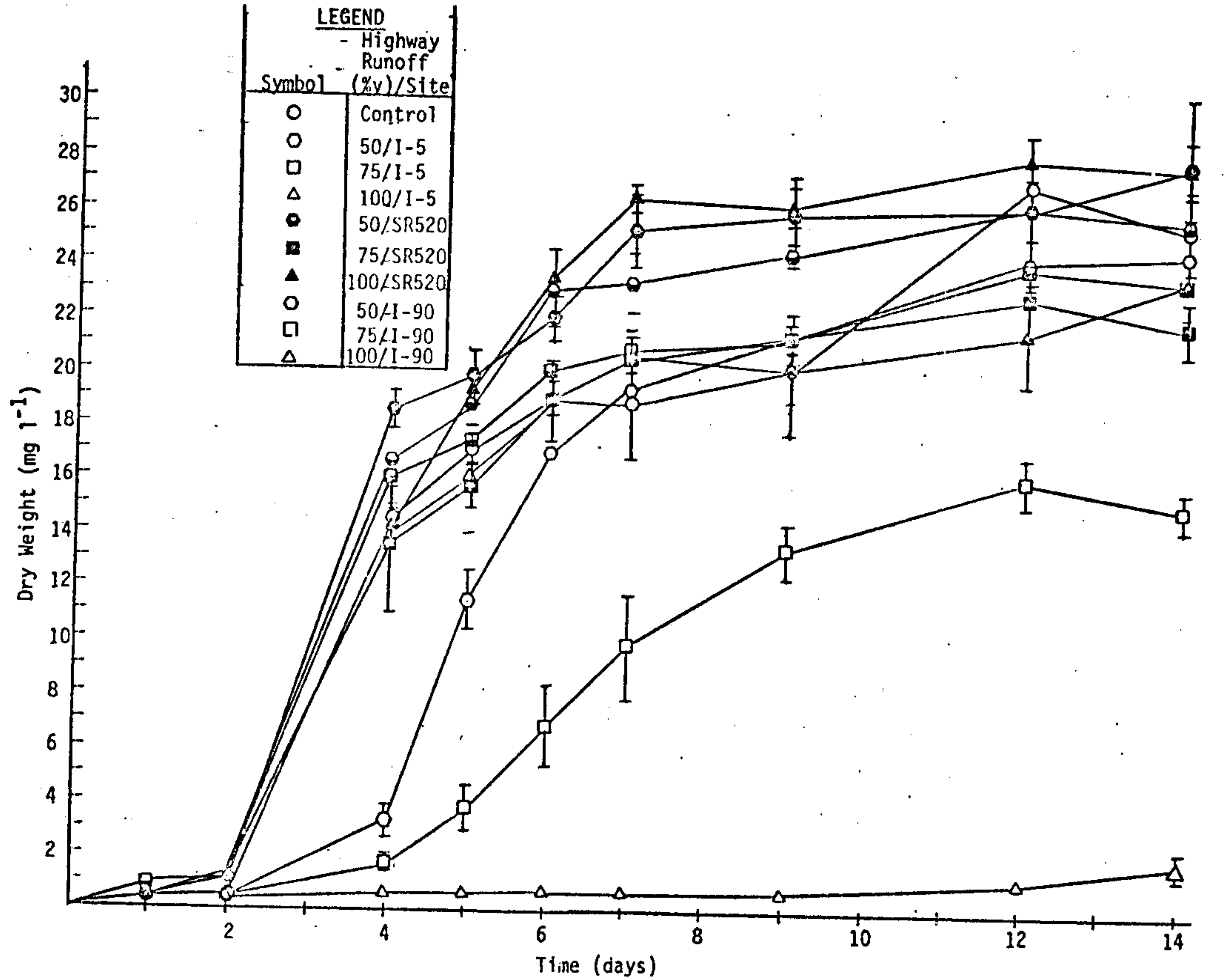

Figure 4 : Results of Algal Bioassays with Runoff from Three Highway Sites; <u>Selenastrum capricornutum</u> Mean Dry Weight (± One Standard Error).

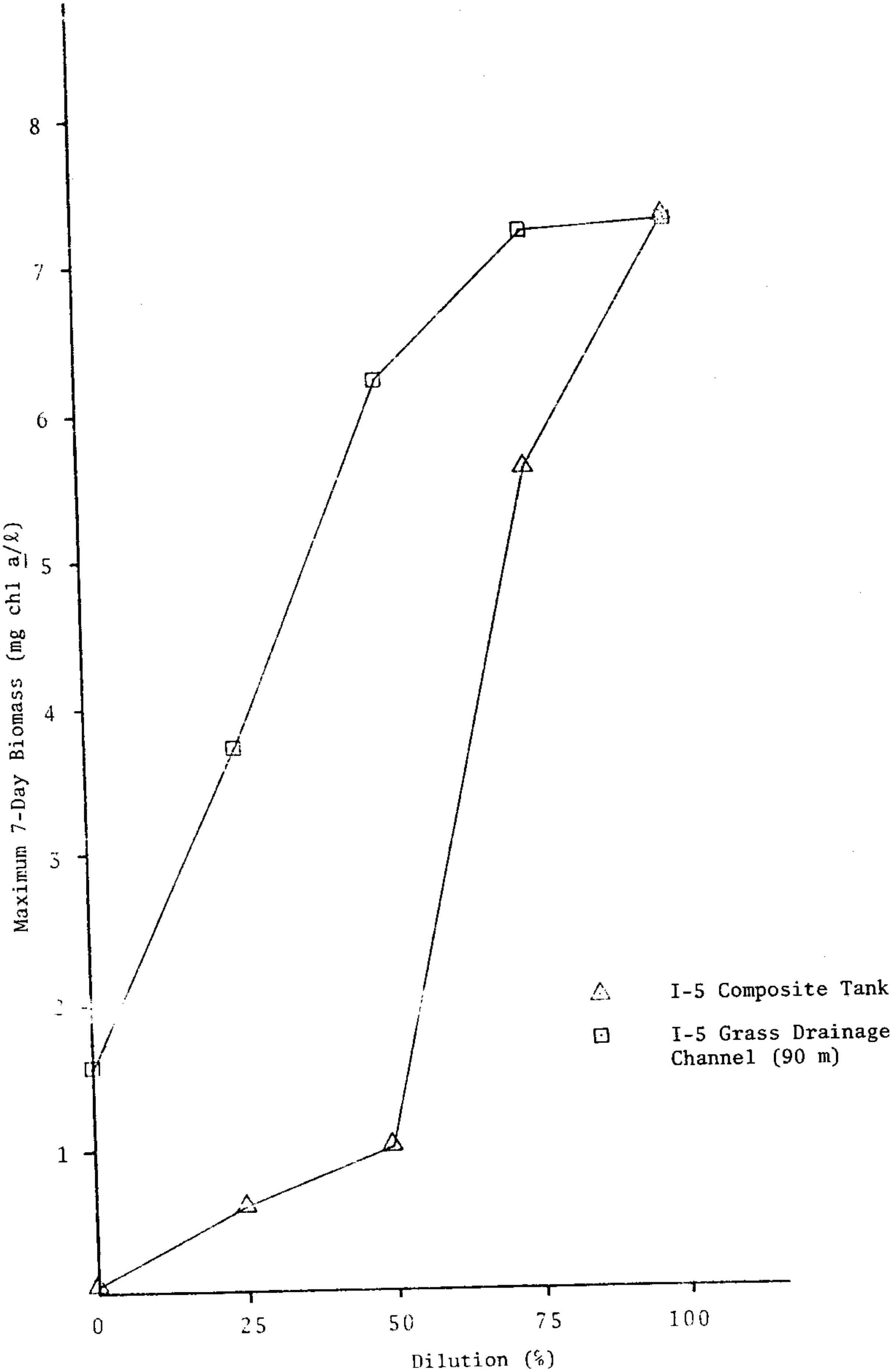

Figure 5 : Results of Selenastrum capricornutum Bioassays Comparing Untreated with Grass Channel Treated I-5 Runoff.

- The fine sediment (< 0.45 m) produced by vehicle tire wear on road surfaces is more damaging to small trout than soil particles in other runoff waters. Highway runoff should not be discharged to spawning areas unless it is filtered by vegetation. The U.S. Environmental Protection Agency[1] has suggested 80 mg/l as a total suspended solids criterion in waters receiving highway runoff, but this criterion has not been officially promulgated.

Models of Highway Runoff Water Quality (Task 7)

The large data base developed in this study permitted the analysis of cumulative pollutant loadings at each site. While prediction of the loadings from any storm at any site is a difficult task, given the problems identified in the previous section, the estimate of annual or seasonal highway runoff pollutant loadings was successful. Asplund (WA-RD-39.6) investigated the associations between pollutant loadings and volume, duration, and intensity of precipitation, the length of the antecedent dry period, total traffic, and vehicles traveling during storms. He observed that the most consistent relationship for the various sites and pollutants measured was between cumulative loadings and vehicles during storms (VDS). Contrary to nationwide observations, the precipitation patterns encountered in the State of Washington are not generally intense enough to wash away all accumulated pollutants. Instead, the major removal mechanism was observed to be traffic generated winds, which deposit most of the pollutants and debris on the adjacent right-of-ways.

Plots of cumulative TSS loadings versus cumulative VDS often assumed a step function pattern, as in Figure 6. With further investigation, the steps were associated with winter sanding, the use of studded tires, which increase pavement wear, or the deposition of volcanic ash. Between the steps the patterns were linear, with slopes varying among sites and among seasons at each site. It was apparent that these differences in slope were the result of different flow volumes responsible for delivering the pollutant masses and that the analysis should reflect the respective runoff coefficients (RC). When the slopes of the linear cumulative TSS versus cumulative VDS relationships (excluding sanding and ashfall) were plotted against average runoff coefficients, the sampling sites grouped as shown in Figure 7. Asplund (WA-RD-39.6) observed these relationships and formulated a model using one year of statewide data. Chui (WA-RD-39.12) and Little (WA-RD-39.16) verified the model with two additional years of measurements. Table 8 summarizes the individual site data underlying the model develoment. Omitted from these data are sanding and ashfall and occasions when an operating problem occurred, such as overflow of the composite tank.

As guided by the results described above, the model expresses TSS loading in proportion to the product of VDS and RC, as follows:

$$\text{TSS (lb/curb-mi)} = (K)\ (\text{VDS})\ (\text{RC})$$

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1 U.S. Environmental Protection Agency, "Guidelines for Review of Environmental Impact Statements", Volume I, Highway Projects (Draft), Office of Federal Activities, Washington, D.C., 1978.

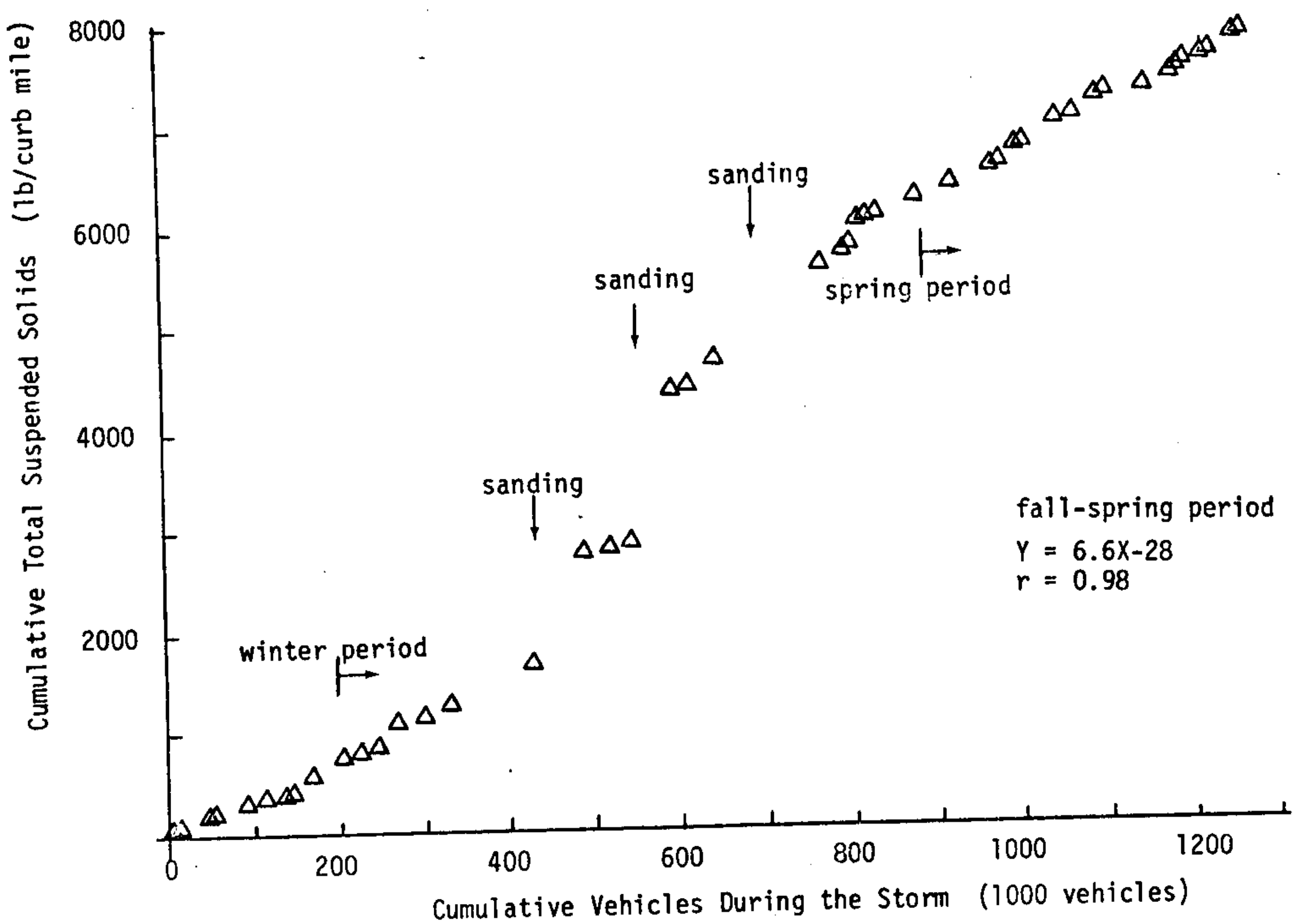

Figure 6 : Cumulative Total Suspended Solids Versus Cumulative Traffic Volumes During Storms for the SR-520 Site.

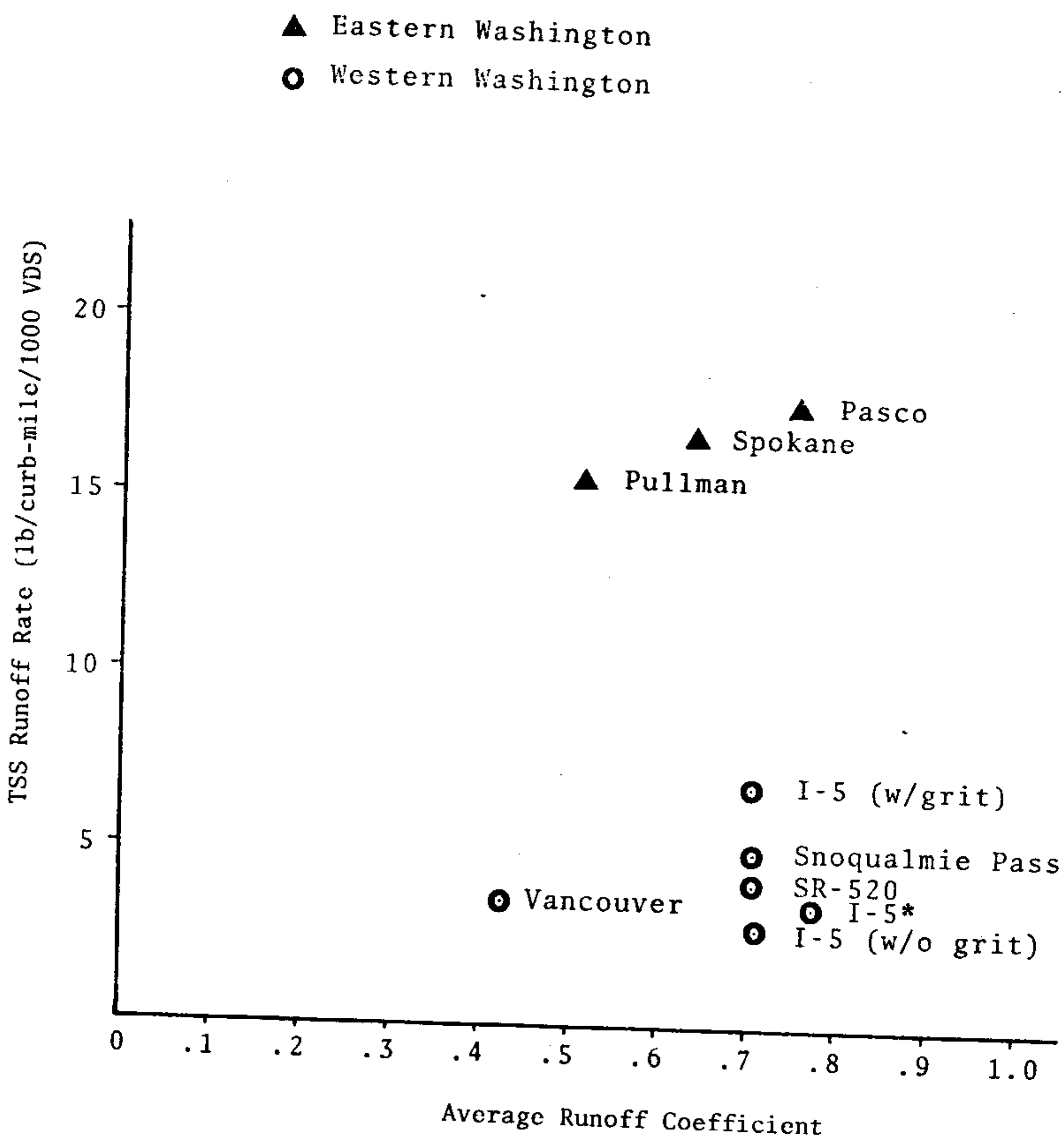

Figure 7: TSS Runoff Rate Versus Average Runoff Coefficient for All Sites.

Table 8: Highway Runoff Data Applied to TSS Loading Model Development.

Site	Cumulative TSS (lb/curb-mi)	Cumulative VDS (thousands)	Linear Regression: Intercept (lb TSS/curb-mi)	Linear Regression: Slope (lb TSS/curb-mi/ 1000 VDS)	Linear Regression: No. Cases	Linear Regression: R^2	RC	$K_{(RC=1)}$ (lb TSS/curb-mi)
I-5	10,982	4,134	-553	2.8	120	0.99	0.72	3.8
I-5 w/grit	15,463	2,574	-888	6.7	67	0.99	0.72	9.4
I-5*	2,601	849	-317	3.4	25	0.99	0.77	4.5
SR-520	3,455	849	-100	4.1	34	0.99	0.70	5.7
Vancouver	1,818	520	- 38	3.4	78	0.99	0.43	7.9
Snoqualmie Pass	1.987	418	-286	4.9	29	0.95	0.72	6.7
Montesano (1)	2,856	327	93	8.4	29	0.98	0.75	11.2
Pasco	1,303	79	41	17.6	39	0.88	0.77	23.4
Spokane	10,085	704	-2,551	16.7	10	0.93	0.64	26.6
Pullman-9	907	52	- 62	15.5	33	0.95	0.52	30.8
Pullman-Control (2)	540	13	-296	63.7	8	0.99	0.80	N.A.

Note: (1) Montesano data eliminated from model development as a result of construction in area.
(2) Pullman-Control data eliminated from model development as a result of atypical drainage pattern.
N.A. -- not available.

where: K = TSS loading at RC = 1
VDS = cumulative number of vehicles traveling during storms (usually in one direction, since drainage is normally separated on each side of the road)

RC = average runoff coefficient

The constant of proportionality in the model was estimated separately for Eastern and Western Washington sites by extrapolating from the TSS runoff rates at the respective RC's to the expected rates at RC = 1 and averaging for the two groups of sites. The mean values of K are 6.4 lb TSS/curb-mi/1000 VDS for Western Washington sites and 26 lb TSS/curb-mi/1000 VDS for Eastern Washington locations. The higher loadings in Eastern Washington are due to larger constributions of pollutants from adjacent lands. Consideration of results following the occasional heavy storms which thoroughly cleaned highways showed that the Western Washington K declined to approximately 3 lb TSS/curb-mi/1000 VDS under those conditions (WA-RD-39.16). That value represents the contributions of vehicles during the storm alone, excluding import from surrounding areas. This estimate permits the model to be used to evaluate the impacts of increasing traffic on existing roads. It has been observed that within one dry day following a heavy storm the constant returns to the vicinity of its ordinary mean value as a result of deposition from vehicles and adjacent lands.

Based on the observed relationships of other pollutant loadings to TSS loading, the loadings of other quantities can be estimated according to:

$$\text{Loading of Pollutant } i = (P_i)\ (\text{TSS Loading})$$

where: P_i = the specific pollutant ratio (listed in Table 9)

Based on cumulative quantities, the loading model is applicable to predicting loading from normal traffic over a time span encompassing a number of storms. When applied to individual storms, substantial errors result, as illustrated in Figure 8, primarily due to the incomplete wash-off described earlier. The several large negative errors in the prediction are all associated with heavy storms which removed solids in amounts greater than usual. An approach has been developed to express individual storm loadings probabilistically, as will be explained later.

Pollutant loadings, in general, cannot be directly associated with biological responses in receiving waters. Still, they have significance in expressing the level of stress placed on the biota over an extended period. The loading concept can be appled to characterize stresses under two different conditions (e.g. before and after placement of a highway drain) on a relative basis. In addition, loadings indicate rates of contaminant accumulation in sinks such as sediments and lakes with long residence times.

The acute effects of pollutants in aquatic systems are a more direct function of concentrations than of loadings, however. To analyze the impact of pollutant concentrations, it is necessary to determine individual storm runoff values. Pollutant concentrations in storm runoff are variable, tending to rise when precipitation intensity increases and then to decline to lower and somewhat stable values. Elevated concentrations are infrequent and of short duration in Washington State and do not contribute significantly to total load-

Table 9: Expressions of Specific Pollutant Ratios Recommended for Use with Washington State Highway Runoff Model

Pollutant	Expression	R^2	Specifications
VSS	$P_{VSS} = .2$	---	For All Sites
COD	$P_{COD} = .4$	---	For All Sites
Pb	$P_{Pb} = 1.5 \times 10^{-4} + (8.7 \times 10^{-8})$ (ADT)	0.978	W. Washington Sites
	$P_{Pb} = 5.3 \times 10^{-4} + (2.8 \times 10^{-8})$ (ADT)	0.996	E. Washington Sites
Zn	$P_{Zn} = 1.5 \times 10^{-4} + (3.0 \times 10^{-8})$ (ADT)	0.864	W. Washington Sites
	$P_{Zn} = 2.0 \times 10^{-4} + (3.2 \times 10^{-7})$ (ADT)	0.932	E. Washington Sites
Cu	$P_{Cu} = 7.9 \times 10^{-5} + (2.7 \times 10^{-9})$ (ADT)	0.739	For All Sites
TKN	$P_{TKN} = 2.7 \times 10^{-3}$	---	W. Washington Sites
	$P_{TKN} = 1.2 \times 10^{-3}$	---	E. Washington Sites
NO_3+NO_2-N	$P_{NO_3+NO_2-N} = 2.0 \times 10^{-3}$	---	For All Sites
TP	$P_{TP} = 2.1 \times 10^{-3}$	---	For All Sites

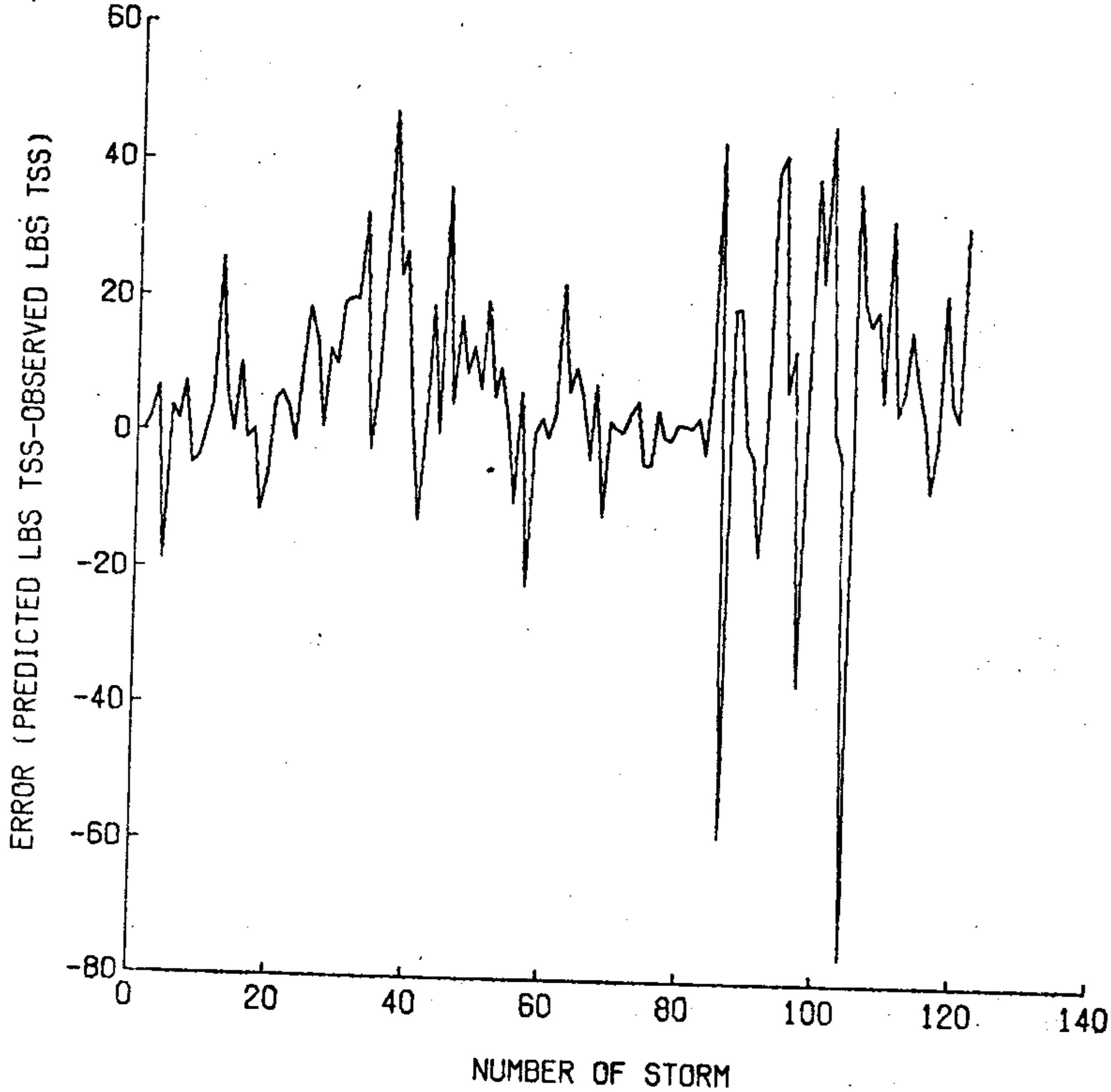

Figure 8.: Error in Predicted TSS Mass.

ings. Considering this pattern and the current lack of knowledge on how to assess impacts due to high-intensity exposures of short duration, it was decided to use composite sample concentrations, representing the event mean values, in analyzing the impact of highway runoff. It is believed that these concentrations accurately represent the stress on receiving water organisms for all but very short periods. This strategy was supplemented by performing bioassays as was reported in Task 6.

Concentrations in the composite samples exhibited some degree of variability, due to the storm frequency patterns that would partially or completely cleanse the highway. It was thus decided that concentrations and loadings on an individual event basis could only be established by stating the probabilities of achieving certain levels under given storm and site conditions. A probability analysis was then undertaken to express that data in a form that could be applied to impact assessment.

Curves were derived to indicate probabilities of reaching any concentration (or loading) of any of the measured pollutants in an individual Eastern or Western Washington storm. Curves were also included on these plots to represent reductions of the contaminants by set amounts as a result of removal by mitigation methods, dilution by receiving waters, or a combination of the two. In the case of some pollutants, established water quality criteria were indicated to provide a basis for evaluating impact. Figure 9 shows one of the graphs in this series. Use of such aids permits the expression of the impact due to highway runoff pollutant concentrations and loadings in probabilistic terms.

The most significant finding of this research is that highway runoff water quality impacts do not appear to be as severe as those of general urban runoff and that maintenance and design decisions can greatly reduce these impacts in the State of Washington. These findings were based on bioassay studies, detailed characterization of trace organics and heavy metals in highway runoff, and studies of the transport of toxic pollutants from highways.

IMPLEMENTATION OF RESEARCH FINDINGS

The results of all seven tasks are incorporated in WA-RD-39.14, "Guide for Water Quality Impact Assessment of Highway Operations and Maintenance", which will be the manual used in implementing these research findings by WSDOT and other agencies. The full guide is included as Appendix A of this report.

The assessment manual provides three levels of analysis in order of increasing precision to analyze and design highway runoff mitigation programs. In each level of analysis the guide presents stepwise procedures to assess the increas in stream flows due to impervious surface drainage and increases in pollutant loadings and concentrations anticipated as a result of the presence of the highway. Level I is a screening procedure intended to identify those cases where normal highway operations may have a significant impact on the receiving water. Levels II and III establish the probable extent of the impact and guide mitigation strategy. In each level the effect of the highway is analyzed in the context of existing or forecast conditions in the total

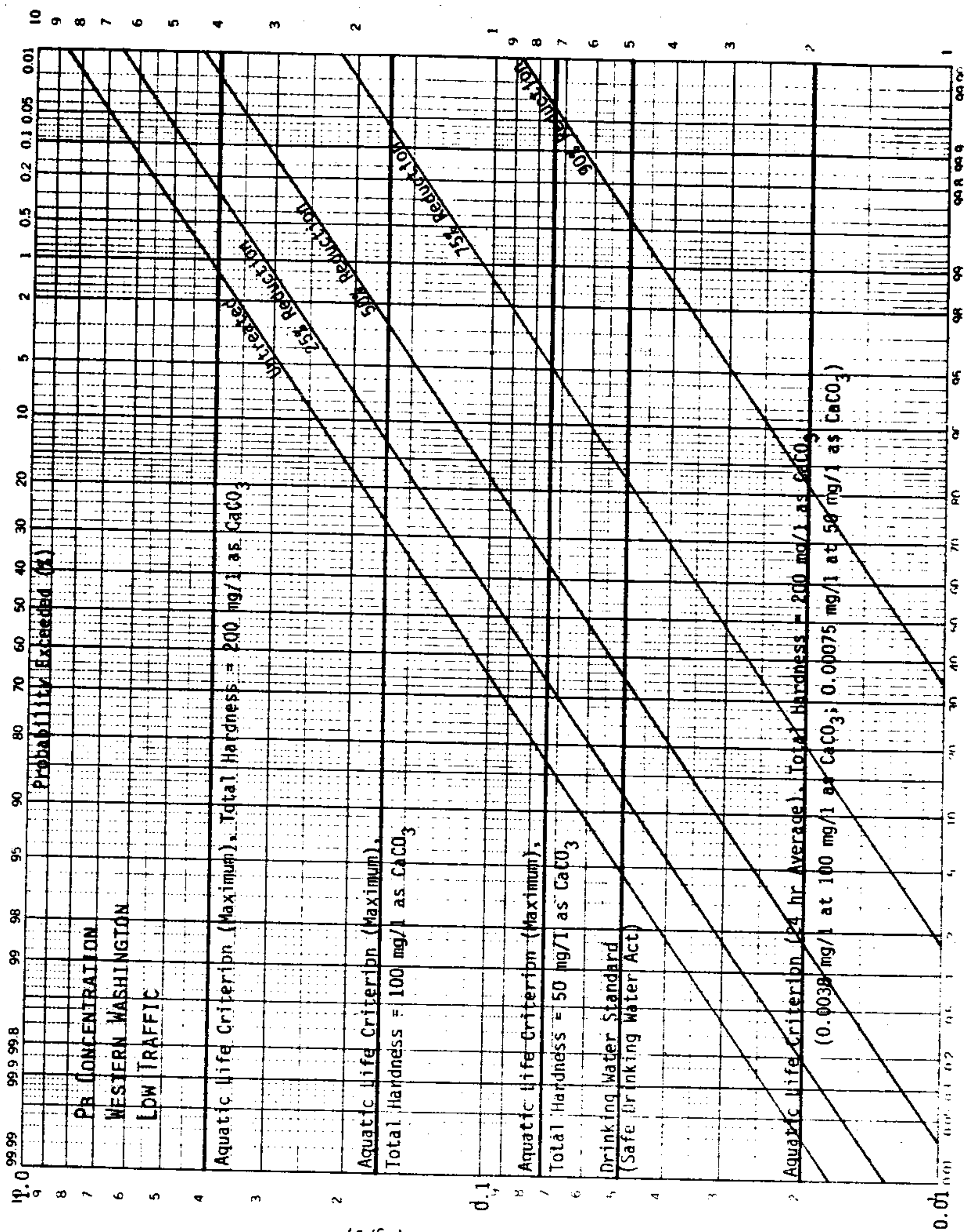

Figure 9: Lead Concentration Probability Distribution for Western Washington Low Traffic Cases

watershed. The guide further contains recommended procedures to assess the effects of periodic occurrances or special problems such as sanding, deicing, pesticide application, wood waste fills, accidental spills and involvement with groundwater.

The research results suggested several specific recommendations to maintain receiving water quality, including:

- Highway runoff must be evaluated in the context of the total runoff in a watershed.
- Runoff from high traffic highways can be successfully treated by flow over vegetated drainage courses. Accumulations of metals and trace organics in these vegetated areas should be protected from erosion.
- With the exception of sand deicing compounds, and accidental spills, highway runoff from low traffic highways (< 10,000 ADT) presents no health or environmental threats to water quality. Contributions from maintenance and spills will enter the environment, and their loadings must be examined for impact separately.
- Leachate from wood waste fills must be collected for treatment or dilution prior to discharge unless the material is aged at least one year.

It is the opinion of the principal investigator that the results of this research provide a firm scientific basis to estimate the impact of highway runoff in the State of Washington. Models based on these data are sufficiently precise to prescribe when mitigation measures are required to protect water quality. Furthermore, mitigation alternatives, such as vegetated drainage courses, have been shown to reduce highway runoff pollutants to acceptable levels. The models formulated for highway runoff pollutant loading and frequency of occurrence of specific concentrations can be extended to conditions in other states using existing data bases.

Implementation of these research results should minimize or eliminate litigation related to the adequacy of highway runoff water quality assessment and will save time and money traditionally associated with these efforts. In addition, the finding that highway runoff water quality does not contribute significantly to pollutant loadings in many instances reduces the capital investment in nonpoint source control devices that may otherwise be required. Since the cost of litigation, assessment and investment for capital mitigation devices for a single highway project could exceed the total cost of this research, the project should prove extremely cost-effective.

The implementation plan will consist of the following actions:

1.) Distribution of the impact assessment guide (WA-RD-39.14) to WSDOT headquarters and district personnel and other interested parties, such as county and municipal road department staffs.

2.) Presentation of the research findings and introduction of the assessment guide in each district office.

3.) Consultation to provide technical assistance to WSDOT personnel using the guide in project impact assessment.

4.) Updating of the guide to correct any deficiencies encountered during use by WSDOT personnel.

CONCLUSIONS

This research has exceeded the original expectations for experimental data collection (Tasks 1, 2, 3) by about a factor of ten due to the development of an inexpensive composite sampler. The availability of such a large data base has permitted the statistically significant characterization of highway runoff at ten sites in the state representing extremes of precipitation, traffic and adjacent land use. Models for pollutant loadings have been developed and verified to estimate annual loadings, as well as the probability of exceeding any given loading as a function of traffic during storms (Task 7). Special studies (Tasks 4, 5, 6) were conducted to establish the toxicity and fate of trace organic and metal compounds, the assessment at the SR-2 Pilchuck River channel change, the fate of sulfur from sulfur-extended asphalt test sections, at Pullman, and the BOD and COD loadings from wood chip fills. More experimental data were obtained in these studies than originally planned due to improvements in research methods and use of graduate dissertation research. Without the development of the composite sampler and the contributed efforts associated with dissertation research, this research project would not have been able to definitively characterize highway runoff in the State of Washington.

Based on this research, runoff from most highways in the state will not present significant water quality impacts. This finding is contrary to both literature results and current practices that assume highway runoff is similar in composition to urban runoff. The Assessment Guide (WA-RD-39.14) provides a sound methodology to estimate the pollutant loads in highway runoff and to define alternative mitigation measures to reduce these loads. These research results should drastically reduce the time, effort, and cost required to conduct an assessment of highway runoff and minimize the need for and expense of special studies to define impacts of runoff from highway projects.

APPENDIX

Report No. 14

(WA-RD-39.14)

GUIDE FOR WATER QUALITY IMPACT ASSESSMENT OF HIGHWAY OPERATIONS AND MAINTENANCE

A report prepared for the Washington State Department of Transportation Highway Runoff Water Quality Research Project

by

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EXECUTIVE SUMMARY

This guide presents stepwise procedures for assessing stormwater runoff impacts on receiving waters resulting from highway operations and maintenance. The methods were developed from the results of the Highway Runoff Water Quality research project, sponsored by the Washington State Department of Transportation (WSDOT) and conducted by the Department of Civil Engineering of the University of Washington. The assessment procedure is organized in three levels, ranging from a rapid screening method intended to identify those cases having a low probability of extensive impacts (Level I) to a detailed evaluation focusing on impact mitigation (Level III). Within each level the analysis is concerned with runoff quantity, pollutant concentrations, and cumulative contaminant loadings. In Levels II and III, runoff quantity is estimated according to the procedure specified by the WSDOT "Highway Hydraulic Manual" and compared to regulations placed on receiving stream peak flow increases. Highway runoff pollutant loadings are estimated using a model developed during the research and compared to existing receiving water loadings. A series of graphs is included to establish the probability of exceeding pollutant concentration criteria in any storm. The guide also presents methods for assessing water quality impacts of sanding, deicing, pesticide applications, woodwaste fill leachate, and accidental spills, as well as considerations where highway runoff affects groundwater.

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I. INTRODUCTION

Scope

This guide for assessment of water quality and aquatic ecological impacts of operating highways combines experience gained during conduct of the Washington State Department of Transportation (WSDOT)/University of Washington (UW) Highway Runoff Water Quality research project with relevant findings reported in the stormwater runoff literature. The basis for the recommended methods has been covered in the various reports previously issued during the project (Horner, et al., 1979; Clark and Mar, 1980; Asplund et al., 1980; Mar et al., 1981a, 1981b; Chui et al., 1981; Wang et al., 1982; Portele et al., 1982). The assessment approach is responsive to the Draft Guidelines for Review of Environmental Impact Statements, Volume I, Highway Projects, issued by the U.S. Environmental Protection Agency (1978), and is specifically oriented towards the operating requirements and conditions of Washington State highways.

The potential water quality impacts resulting from highway operations are: (1) possible increase of peak flows in receiving streams; (2) possible erosion and sediment transport into receiving waters; (3) degradation of receiving water quality, with possible impairment of beneficial uses and harm to aquatic biota, due to drainage of contaminants incidently deposited on the roadway; and (4) receiving water effects associated with maintenance procedures. The guide provides assessment techniques applicable to each of these impacts and recommends strategies for reducing the severity of the identified impacts. It also treats special problems in water quality impact assessment.

It is anticipated that this guide will be used by designers preparing environmental assessments for proposed transportation projects, with emphasis on commitments associated with mitigating measures carried out by construction and field maintenance and operations personnel. Routine maintenance and operations activities do not require environmental documentation except during the design phase.

General Approach

The guide is generally organized as follows: (1) data needed for preparation of a water quality assessment (based on U.S. Environmental Protection Agency Guidelines and the particular needs for applying the methods developed in this guide); (2) procedures applicable to assessing general water quantity and quality impacts; and (3) treatment of impacts related to maintenance and special problem areas. It defines three levels of analysis, increasing in precision, detail, comprehensiveness, and the quantity of effort required.

The first level of assessment merely screens highway area in terms of its proportion of the total watershed, the type of runoff drainage system, and the projected traffic volume. Highways with low traffic, occupying a small percentage of the watershed, and/or having drainage through a vegetated drainage course [(1)] may be declared to create minimal impact.

If the first level of analysis indicates the potential for a significant impact, the guide prescribes a Level II analysis, based on annual predictions. If necessary, a Level III analysis, based on monthly projections, can be applied to more thoroughly analyze the extent of aquatic impacts. The latter two procedures are focused on defining land uses in the watershed in some detail and establishing the drainage patterns and pollution sources. The highway impact is evaluated in the context of the aggregate burden created by all activities in the watershed.

It is not likely that Level III, the most complex procedure, will be required in many cases. It is also unlikely that more advanced techniques, such as computer-based stormwater management models, will be needed to understand most water quality impacts of highway operations. In the event that they are, the analysis will become a major effort and will require about a person-year of work to gather the necessary impact data and exercise an appropriate model to estimate detailed water quality changes and the necessary mitigating measures. The application of such models is beyond the scope of this guide.

Impact assessment at Levels II and III is conducted with reference to the

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(1) Throughout this guide, a vegetated drainage course is considered to include engineered channels or surfaces appropriate for overland flow of highway runoff which are maintained in grasses or other low plant growth.

effects of highway runoff on both receiving water quantity and quality. With respect to quantity, it is WSDOT practice to provide retention of excess runoff from new highway alignments where required by ordinance. Retention is also considered in areas having some unusual drainage characteristics. The frequency of storm retained is dependent on local policy. It usually is selected to match that of the storm sewer or functional classification criteria in the WSDOT (1972) "Highway Hydraulic Manual." This frequency is normally the 10 or 25 year mean recurrence interval storm. Therefore, in many cases there is no appreciable increase in peak rate of runoff from that of the original land use (WSDOT, 1982).

The recommended procedure for water quality analysis considers both concentrations and loadings of pollutants. Potential acute effects to aquatic organisms are a function of contaminant concentration (mass/unit volume). The assessment procedure is based on the probability that the mean concentration will exceed a designated level during any storm event. Use of the event mean concentration, while neglecting the peak value, is considered to represent the condition affecting receiving water biota during almost all of the exposure period.

Loading is a product of runoff volume and concentration and can be expressed as mass/unit time or mass/unit area/unit time. Pollutant loadings express the relative stress on biota under two contrasting conditions (e.g. before and after the placement of a highway), as well as the potential for contaminant accumulation in sinks, such as sediments and standing bodies of water. Increased loadings can result in ecological changes that may displace desirable species.

Most water quality criteria promulgated by regulations are phrased in terms of specific pollutant concentrations. Assessing highway runoff impacts requires estimating the concentrations likely to exist in waters which, in most cases, receive runoff from a wide area. As few loading criteria exist, assessing the highway contribution usually involves comparing the loadings of various pollutants in highway runoff relative to those in drainage from the remainder of the watershed. Evaluating loading effects, therefore, requires placing the highway in the context of the surrounding land uses. This is the strategy recommended for impact analysis at Levels II and III.

The approach presented in this guide is representative of certain conditions prevalent in Washington State but not the nation as a whole. Research by the Municipality of Metropolitan Seattle (Farris et al., 1979) and WSDOT/UW (Asplund, 1980) has shown that there is a minimal "first-flush" of high pollutant concentrations in Western Washington, as opposed to findings in most other areas. The first-flush is a period at the onset of storm runoff, usually only a fraction of an hour in length, during which accumulated contaminants wash off in considerably greater concentrations than during the remainder of the storm. In Western Washington the frequent, low intensity storms continually clean surfaces and prevent heavy pollutant accumulations. In Eastern Washington the situation differs due to the combination of sparse vegetation, erosive soils and relatively high wind speeds. These factors result in the movement of considerable quantities of solids from surrounding lands to highway surfaces. First-flush concentrations would, in general, be higher in Eastern than Western Washington. Highway runoff in Eastern Washington, however, usually is distributed overland rather than directed to surface waters. In this situation cumulative contaminant loadings to any subsurface waters intercepted are of greater importance than concentrations.

The recommended impact assessment procedure omits an evaluation of dissolved oxygen depletion in receiving streams, which, in general, is a potential impact of highway runoff. This effect is not expected to occur in Washington State, since most runoff occurs in the winter, when low temperatures increase oxygen solubility and high flows provide high dilution ratios.

It has been observed during the WSDOT/UW research that the major sources of pollutants in highway runoff are deposition from vehicles, transport from adjacent lands, pavement wear, and certain maintenance procedures. The research demonstrated that vehicular deposition primarily results from the spray-washing of material adhering to the undercarriages of vehicles traveling on the wet roadway. This material is apparently impacted and retained during dry periods. Between storms, traffic also generates winds which transport a portion of the deposited material off the highway surface.

A pollutant loading model was formulated on the basis of the research data and the observation that highways serve as receptacles for contaminants transported from adjacent areas and washed from the undersides of vehicles traveling during storms (considered to be the period while the road remains wet). The model expresses cumulative runoff pollutant loadings as functions of highway geometry, drainage configuration, and vehicles during storms, as follows:

$$TSS = (K)\ (VDS)\ (C)$$

$$\text{Loading of Pollutant } i = (K_{p_i})\ (\text{TSS Loading})$$

where: TSS = loading of total suspended solids from runoff (lb/highway-mi)

K = loading constant (lb/1000 VDS/highway-mi)

VDS = vehicles during the storm (in thousands)

C = runoff coefficient (ratio of runoff volume to precipitation volume)

K_{p_i} = ratio of pollutant i to TSS

The loading relationships represent pollutants incidently deposited during normal highway operations. The impact of sand applied for winter traction must be analyzed separately, as outlined in Section IV.

The pollutant loadings estimated in this way are valid over the long-term (monthly or annually). However, little precision results if the equations are applied on a storm-by-storm basis. It is hypothesized that there is a cyclic accumulation and washoff of pollutants, the build-up being associated with small storms which wash the undersides of vehicles. Larger storms then periodically wash the road surface. Therefore, loadings in a given locale are highly variable in the short time frame but more constant in the longer span, when normalized for traffic and runoff coefficient.

In addition to assessing cumulative impacts by means of the loading model, it is necessary to evaluate acute effects on receiving waters. To do so, individual event concentrations and loadings must be expressed. Substantial variation occurs in all pollutant concentrations and loadings from storm-to-storm. Thus, the assessment of acute effects is based on a probability analysis indicating the chance of exceeding given concentration and loading values in any event. Curves have been derived from the data to illustrate the probability relationships for Eastern and Western Washington conditions at two traffic levels. Curves are also included on these plots to represent reductions of the contaminants by set amounts as a result of removal by treatment methods, dilution by receiving waters, or a combination of the two. In the case of some pollutants, established water quality criteria are indicated to provide a basis for evaluating impact.

The data indicated that the concentrations and loadings of many pollutants are proportional to those of total suspended solids. Loadings of these pollutants are modeled according to this relationship. An important consequence of this finding is that removing TSS from the runoff also reduces other contaminants. One specific result is that the most toxic organic contaminants, if detectable at all, are primarily adsorbed on solid particles. As one example, Zawlocki (1981) found that 59-98 percent of aromatic compounds occurring in Washington State highway runoff are associated with solids. That being the case, absence of an impact due to TSS is presently regarded as a valid indication that organics would likewise not impair the receiving water. The toxicity demonstrated in certain highway runoff samples (Portele et al., 1982) is thought to be caused chiefly by dissolved metals.

The most cost-effective means of removing solids and associated pollutants appears to be directing runoff over a vegetated drainage course. It was demonstrated that a grass-lined ditch 200 ft in length is capable of decreasing the total suspended solids, chemical oxygen demand, and total lead by approximately 80 percent. More soluble metals, such as zinc and copper, were reduced by approximately 60 percent (Wang et al., 1982). Unvegetated channels do not provide filtering action, and residues deposited in them are easily entrained by subsequent runoff.

Maintaining vegetated drainage systems may require modified cleaning procedures to achieve both acceptable hydraulic performance and runoff treatment. One possible strategy would be to clean only a portion of a ditch each year and hydroseed to promote regrowth if scraped bare. In the case of a highway adjacent to an ecologically sensitive receiving water in an arid area, it may be warranted to protect the water by cultivating and, if necessary, irrigating a vegetated drainage area.

General Highway Design and Operating Recommendations

Project design features and subsequent maintenance practices can frequently eliminate or greatly reduce runoff receiving water impacts, thus alleviating the need to employ more costly impact mitigation techniques. Several design strategies which would serve this purpose emerged during the course of the WSDOT/UW research; generally stated, they are:

1.) Highway corridors should be as distant as possible from potential receiving waters and should occupy a minimum proportion of the drainage area of a specific receiving water. This guideline is particularly important for ecologically sensitive waters.

2.) Avoid, if at all possible, direct discharge of highway runoff to receiving waters, especially via long pipes, concrete conduits or bare ditches, unless it will be immediately diluted to acceptable levels by natural waters (as determined by the Level II concentration analysis). It is recommended that runoff be channeled over vegetated drainage courses 200 ft or more in length. Vegetated drainage system design is especially recommended when ecologically sensitive receiving waters are involved.

3.) Minimize the use of fine sands and road salts in winter operations, since these materials greatly increase the suspended and dissolved solids loads, respectively, on receiving waters. Coarse particles are not nearly so effectively transported by runoff as are fine grains.

II. DATA REQUIREMENTS

A highway project environmental assessment should contain information concerning highway design features, drainage system details, physical and hydrologic characteristics of the receiving water, baseline water quality and biological data, anticipated impacts and proposed mitigating measures and their expected effectiveness. Table 1 lists the data that should be assembled for presentation and use in conducting the water quality assessment. Appendix A provides a listing of possible sources for the environmental data.

Additional detailed information must be presented when a highway impinges upon an EPA-designated sole-source aquifer. These requirements are listed under the topic "Involvement with Groundwater" in Section IV.

Table 1: Data for Assessing Water Quality Impacts of Highway Operations.

Highway Design Features
- Length
- Number of lanes and lane widths
- Type of access
- Access ramps or intersecting roads
- Paving material
- Type of section(s) involved (at grade, cut, fill)
- Slopes (longitudinal and side)
- Median characteristics (width, paving, barrier type)
- Shoulder characteristics (width, paving, barrier type)
- Characteristics of area outside the shoulders but within the right-of-way (dimensions, topography, vegetation)
- Total impervious surface area

Operating Conditions
- Design average daily traffic (ADT)
- Projected vehicle composition
- Expected daily, weekly and seasonal traffic patterns
- Anticipated average speeds and braking characteristics
- Summary of applicable accident and spill data (from records on similar highways; also see Eagen, 1980; Andrews et al., 1981)

Drainage System Characteristics (to the extent available during environmental assessment)
- Channel types (closed conduit, paved open channel, bare open channel, vegetated open channel, unchanneled overland flow, etc.)
- Channel dimensions and slopes
- Soils and vegetation characteristics in flow path
- Discharge points
- Collection systems (type, dimensions and spacings of drop boxes, etc.)
- Design flow rates

Hydrologic Characteristics (see Appendix A for information sources)
- Average annual precipitation (rain and snow) and monthly distribution of precipitation
- Receiving water and ground water data --
  - Streams (base flow, annual average flow, peak flow, flood plain maps)
  - Lakes and reservoirs (surface area, mean depth, water residence time); Reference: Washington State Department of Conservation, 1961a, b.
  - Wetlands (surface area)
  - Groundwater (locations of aquifers, recharge characteristics)
- Summary of available data on point and nonpoint source flows in the watershed

Water Quality and Aquatic Biological Data (see Appendix A for information sources)
- Summary of available receiving water and groundwater monitoring data (water quality; microflora; microfauna, aquatic plants, benthic macroinvertebrates; fish populations, migrations and spawning areas)
- Sensitive or unique habitats
- Threatened and endangered species
- Summary of available data on effluent quality of sources in the watershed
- Beneficial use classification
- Established water quality criteria

Surrounding Land Use Characteristics
- Total watershed area
- Percentage of total area in each land use category (organized as in Tables 3 and 4)

Projected Highway Maintenance Characteristics
- Sanding application (quantity, frequency, particle size description)
- Deicing agent application (type, quantity, frequency, additives used)
- Pesticide application (type, quantity, frequency, toxicity)
- Roadway maintenance (sweeping, washing)
- Right-of-way maintenance (mowing, ditch cleaning, fertilizing, irrigation)

Description of Special Features
- Construction on woodwaste fill
- Detention basins
- Oil and grease traps
- Other mitigative features

III. GENERAL IMPACT ASSESSMENT PROCEDURES

This section contains a stepwise guide to estimating and evaluating highway runoff impacts of stormwater constituents incidently deposited on most Washington State highways. Figure 1 presents a flow chart of the assessment procedure through the three levels of detail. Analysis of special cases and the effects of maintenance applications is covered in Section IV.

<u>Level I</u>

1.) If all runoff discharges via a vegetated drainage course at least 200 ft in length [(1)], go to step 3. Otherwise, proceed to step 2.
2.) If projected traffic volume is less than 10,000 ADT [(2)], proceed to step 3. Otherwise, perform Level II analysis.
3.) Determine the total area of the watershed located upstream from the highway runoff discharge point. If there are multiple discharge points, base the determination on the one located farthest downstream.
4.) Determine the total area of impervious roadway surface contributing runoff to the stream.
5.) If the ratio of impervious roadway surface/total watershed area is less than 0.01 [(3)], declare no impact from ordinary runoff and

---

(1) Length identified by Wang et al. (1982) as reliably providing 60-80 percent reduction of major pollutants in highway runoff.

(2) Traffic volume below which no toxic effects appeared in bioassays (Portele et al., 1982).

(3) The 0.01 factor was selected on the basis of the research data. It is assumed that the dilution ratio is approximately equal to the ratio of areas. Highway runoff can contain concentrations of toxicants comparable to LC_{50}'s (concentration lethal to 50 percent of the organisms in an acute bioassay). A common means of protecting aquatic life is to limit receiving water concentrations to 0.01 X LC_{50}. In addition, investigation of the concentration-probability distributions (Figures 4-7) indicates that dilution of the order 100:1 is generally required to insure only a slight probability (< 0.1 percent) that established water quality criteria will be exceeded. With a high dilution ratio and either low traffic volume or drainage over a vegetated drainage course, it can be stated with assurance that the impact would be insignificant, thus avoiding more detailed analysis.

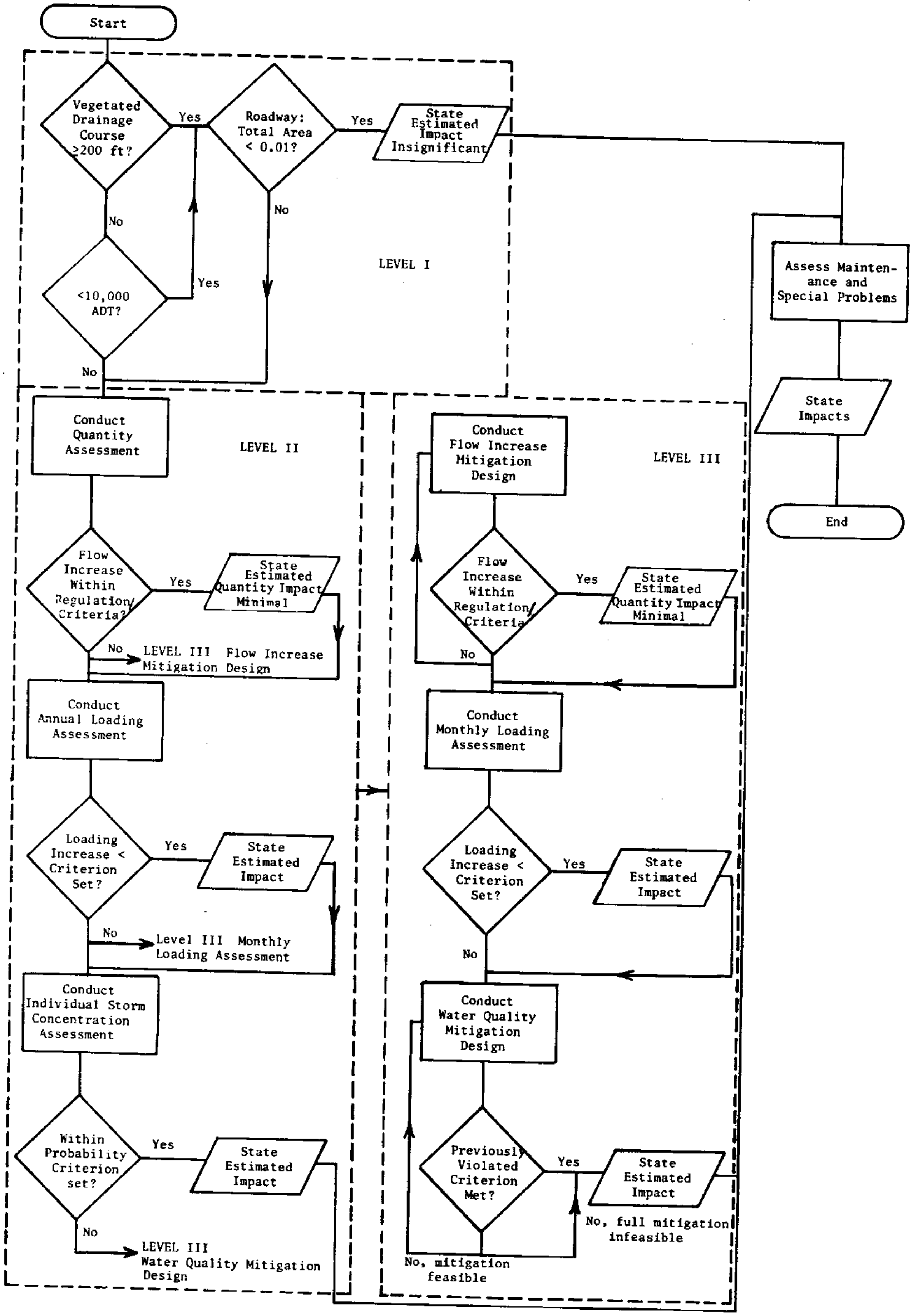

Figure 1: Flow Chart of Assessment Procedure

proceed to step 6. Otherwise, perform Level II analysis.

6.) Analyze impacts associated with the particular maintenance practices anticipated or any special problem areas (see Section IV).

Level II

1.) Runoff quantity assessment (when receiving water is a stream):

a.) Estimate runoff rate (Q, cfs) from the total area where normal permeability is expected to be modified by highway construction according to the Rational Method in the "Highway Hydraulic Manual" (Washington State Department of Highways, 1972):

$$Q = CIA$$

Where: C = runoff coefficient (ratio of runoff volume to precipitation volume)

I = design storm rainfall intensity (in/hr) (use storm of recurrence interval 25 yr and duration = time of concentration)

A = area where normal permeability is expected to be modified by highway construction (acre)

Note: In estimating time of concentration according to given procedure, use the average slope of the highway section. A value of 0.016 is typical for Manning's n for highway paving and storm sewers.

In addition to the guidance provided in the "Highway Hydraulic Manual" for selecting the runoff coefficient the following values were established during the research:

For right-of-ways constructed at grade and entirely paved and curbed, C = 0.75

For elevated sections, C = 0.70 (if leakage through expansion joints occurs, this value must be adjusted)

For other situations, C can be estimated from (after Hydrologic Engineering Center, 1974):

$$C = C_P + (C_I - C_P)(X)$$

where: C_P = runoff factor for pervious surfaces (use 0.45 as default value)

C_I = runoff factor for impervious surfaces (use 0.70 as default value)

X = fraction of total right-of-way surface which is impervious

b.) If detention facilities will be provided, modify Q to the anticipated release rate during the design storm flow. If the facilities will not release water during periods of peak receiving streamflow, declare no impact on streamflow. Otherwise proceed to step 1.c.

c.) Determine peak flow rate (cfs) in the receiving stream for the design storm condition in one of the following ways:

(1) For streams having a gaging record, estimate the design peak streamflow rate according to the probability procedure in Appendix B.

(2) Consult "Magnitude and Frequency of Floods in Washington" (U.S. Geological Survey, 1975), using the appropriate equation for the 25-yr recurrence interval storm. (Note: Be sure to apply the equations only under the conditions stated. Use only the precipitation data in the manual).

(3) Apply the procedure described in step 1.a. to the entire watershed in its state prior to highway construction.

d.) Express the impact on streamflow in terms of the estimated increase due to highway runoff as a percentage of the original peak streamflow. If the estimated increase exceeds that permitted under the regulations existing at the location in question, reconsider detention facilities, as advised in Level III, step 1.

2.) Annual pollutant loading assessment:

The flow chart in Figure 2 provides a guide to the loading assessment.

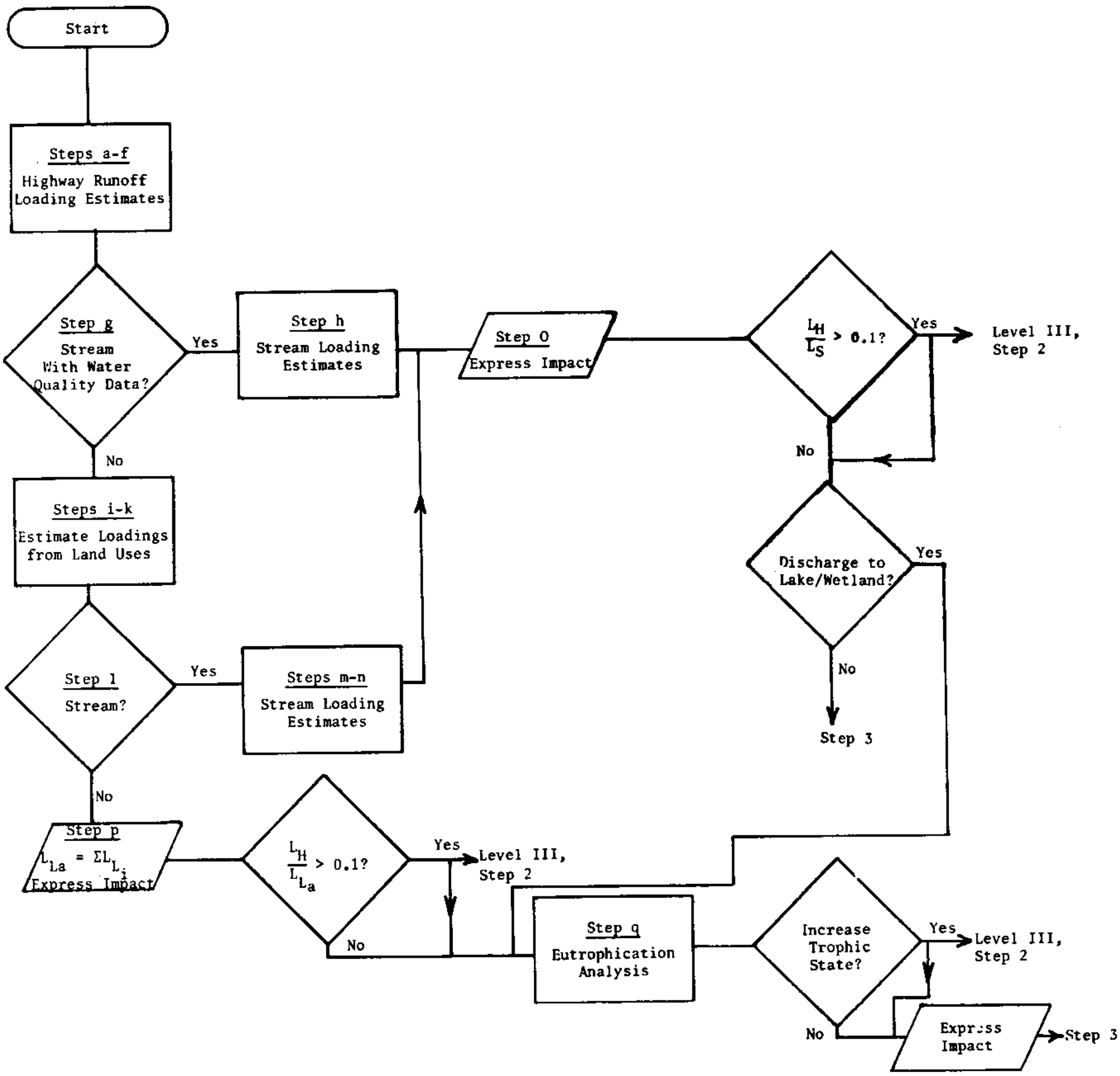

Figure 2: Flow Chart of Pollutant Loading Assessment Procedure

a.) Estimate the hr/yr during which the roadway is expected to be wet as equal to the hr/yr of recorded precipitation [(1)], using data in Appendix C for the location closest to the proposed construction site.

b.) Estimate the total annual vehicles passing during storms (VDS/yr) as follows:

$$VDS/yr = ADT \left(\frac{\text{wet hr/yr}}{\text{24 hr/day}}\right)$$

where: ADT = projected average daily traffic on highway lanes draining to receiving water

c.) Estimate annual highway runoff TSS loading according to:

$$TSS(\text{lb/highway - mi/yr}) = (K)\left(\frac{VDS/yr}{1000}\right)(C)$$

where: K = 6.4 lb TSS/highway-mi/1000 VDS for Western Washington [(2)]

K = 26 lb TSS/highway-mi/1000 VDS for Eastern Washington [(2)]

C is from step 1.a.

Note: If the lanes in one direction only drain to the receiving water, adjusted ADT accordingly.[(3)]

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(1) The reported hr/yr of recorded precipitation ($\geq$ 0.01 inch) represents the mean of a number of years of data (1948-1964). Trace quantities are eliminated from consideration since they do not generally produce runoff. The tabulated data are recommended as an estimate of the hr/yr of wet roadway, recognizing that two counteracting factors are operating: (1) the highway remains wet for some time after precipitation stops; however (2) precipitation does not necessarily fall throughout a recorded hour.

(2) The loading constants given apply to new highways and existing highways where traffic increase is anticipated. On existing highways the constants apply whether or not additional lanes are constructed, up to a maximum of four lanes in a single direction, representing the cases contributing to the data base (Little, 1982). With greater widths, pollutants deposited on innermost lanes may be transported less effectively into shoulder drainage such that K would tend to decrease; however, there was no sampling to test this hypothesis.

(3) The research demonstrated that pollutant loadings were better correlated with highway-mi than highway surface area or lane-mi.

d.) Express total annual highway loading (L_H) by multiplying by number of highway-mi.

e.) If a mitigation device such as a detention basin is provided, reduce the TSS loading according to the solids removal capability of the device. If highway runoff is discharged to receiving water via a vegetated drainage course, multiply the estimated TSS loading by the appropriate fraction, as follows (after Wang, 1981). Interpolate as necessary.

Length of Vegetated Drainage Course (ft)	Fraction of Pollutant Remaining
$\leq$ 30	1
31- 60	0.50
61- 90	0.40
91-120	0.30
121-150	0.26
151-180	0.23
$\geq$ 180	0.20

Use the modified TSS loading in further calculations.

f.) Estimate annual highway loadings of other pollutants from:

$$\text{Loading (lb/yr)} = (K_p)(\text{TSS Loading})$$

where: K_p = ratio of pollutant P to TSS (Table 2)
TSS Loading is estimate from step 2.d. or 2.e.

g.) If the receiving water is a stream <u>and</u> if a comprehensive water quality record exists for the stream, proceed to step 2.h. Otherwise, go to step 2.i.

h.) Estimate the mean annual loading of each pollutant transported by the stream prior to the presence of the highway (L_S, lb/yr) according to:

$$L_S = 1965\ \overline{Q}_S\ \overline{C}_S$$

where: $\overline{Q}_S$ = average stream discharge (cfs)

$\overline{C}_S$ = average pollutant concentration (mg/l) (see Appendix A for potential data sources)

Table 2: K_p (Pollutant:TSS Ratios) for Various Contaminants in Highway Runoff.

Pollutant	Abbreviation	K_p
Chemical Oxygen Demand	COD	$K_{COD} = 0.4$
Lead (Western Washington) (Eastern Washington)	Pb	$K_{Pb} = 1.5 \times 10^{-4} + (8.7 \times 10^{-8})(ADT)$ $K_{Pb} = 5.3 \times 10^{-4} + (2.8 \times 10^{-9})(ADT)$ (Note 1)
Zinc (Western Washington) (Eastern Washington)	Zn	$K_{Zn} = 1.4 \times 10^{-4} + (3.0 \times 10^{-8})(ADT)$ $K_{Zn} = 2.0 \times 10^{-4} + (3.2 \times 10^{-7})(ADT)$
Copper	Cu	$K_{Cu} = 7.9 \times 10^{-5} + (2.7 \times 10^{-9})(ADT)$
Nitrate + Nitrite-Nitrogen	NO_3+NO_2-N	$K_N = 2.0 \times 10^{-3}$
Total Kjeldahl Nitrogen (Western Washington) (Eastern Washington)	TKN	$K_{TKN} = 2.7 \times 10^{-3}$ $K_{TKN} = 1.2 \times 10^{-3}$
Total Phosphorus	TP	$K_{TP} = 2.1 \times 10^{-3}$

Note: (1) Base predicted lead loading on the lead concentration in gasoline at the time in proportion to that during the years of research. During those years, the concentration was 0.13 grams/liter. That concentration is scheduled to be reduced under U.S. Environmental Protection Agency regulations, and that agency can provide information on adherence to the schedule. For estimation purposes, it should be assumed that the proportion of vehicles using leaded gasoline remains constant.

If the stream is gaged, obtain $\overline{Q}_S$ in the U.S. Geological Survey <u>Water Resources Data for Washington</u>, Vol. 1 (Western Washington) or Vol. 2 (Eastern Washington) for a recent water year. If the stream is not gaged, estimate $\overline{Q}_S$ from the record of a nearby stream with similar watershed characteristics, as follows:

$$\overline{Q}_S = \overline{Q}'_S \frac{A_W}{A'_W}$$

where: $\overline{Q}_S$ = average discharge in runoff receiving stream (cfs)

$\overline{Q}'_S$ = average discharge in stream of record (cfs)

A_W = runoff receiving stream watershed area (any area units)

A'_W = stream of record watershed area (any area units)

Go to step 2.0.

i.) Determine annual areal loading (lb/acre/yr) of each contaminant from each land use in the receiving water basin from local data, if they exist, or Table 3. Where a range is given, use the lower value if a conservative estimate of highway contribution to total loading is desired; otherwise, use the midpoint of the range.

j.) Determine the areas (in acres) in General Urban, General Residential, General Agricultural and Forested or Open land uses in the watershed draining to the highway runoff discharge point located farthest downstream. If it is projected by the planning agency for the location that development will modify land uses substantially in coming years, conduct the analysis for both present and ultimate land uses.

k.) Multiply loadings in lb/acre/yr by the respective areas to obtain annual loadings from each land use (L_{L_i}). Then sum over all land uses for each pollutant (ΣL_{L_i}).

l.) If the receiving water is a stream, proceed to step 2.m. If the receiving water is a lake or wetland, go to step 2.p.

m.) Estimate point source loadings (L_P) of each pollutant as follows:

$$L_P \text{ (lb/yr)} = 1965\ Q_P\ C_P$$

where: Q_P = point source effluent flow rate (cfs) (average over year if not continuous)

C_P = average point source effluent pollutant concentration (mg/l)

See Appendix A for potential sources of effluent data.

n.) Estimate total stream loadings prior to the highway presence (L_S) as:

$$L_S = \Sigma L_{L_i} + L_P$$

Table 3: Storm Runoff Pollutant Loadings for General Land Use Categories

Land Use	Loading (lb/acre/yr)							
	TSS	COD	Pb	Zn	Cu	NO_3+NO_2-N	TKN	TP
General Urban	400	18-240	0.13-0.45	0.3-0.5	0.04-0.12	0.3-4.0	7.1	1.8
General Residential	375	27-270	0.05	0.02	0.03	0.3-3.4	5.4	1.6
General Agricultural	17,900-44,000	NA	0.002-0.07	0.004-0.3	0.002-0.08	0.3-7.1	0.3-30	0.1-8.0
Forested or Open	6-76	1.8	0.01-0.03	0.01-0.03	0.02-0.03	0.3-0.5	1.5-2.7	0.06-0.08

Notes: (1) Means given where available; otherwise ranges are reported. References include Wiebel et al., 1964; Avco Economic Systems Corporation, 1970; U.S. Army Corps of Engineers, 1974; Heany et al., 1976; Reese, 1976; Omernik, 1977; Wanielista, 1978; Browne and Grizzard, 1979.

(2) NA -- Not Available.

o.) Express the impact on stream pollutant loadings in terms of the estimated increase due to highway runoff (L_H) as a percentage of the original stream loadings (L_S). If the estimated increase exceeds ten percent for any pollutant, it is recommended that a Level III analysis be conducted for that contaminant to confirm the projected impact with a more exact procedure. If the stream eventually discharges to a lake or wetland, also evaluate the impact on that water body according to steps 2.p. and 2.q. Otherwise, go to step 3.

p.) If the immediate or eventual receiving water is a lake or wetland, estimate total annual loadings prior to the highway presence (L_{La}) as equal to ΣL_{L_i} plus any point source loading (1965 $Q_p C_p$). Express and evaluate the impact on lake or wetland pollutant loadings as in step 2.o.

q.) If the immediate or eventual receiving water is a lake, conduct a special analysis to assess the potential impact of phosphorus loading on trophic state as follows:

(1) Convert L_H and L_{La} to kg/yr by dividing by 2.2 lb/kg.

(2) Find the contributions of the highway and all other sources to the lake areal total phosphorus (TP) loading (Kg/ha/yr) by dividing L_H and L_{La} respectively, by the lake surface area (A_{La}, ha). (Note: 1 hectare, ha = 2.47 acres.)

(3) Divide lake mean depth (m) by water residence time (yr), where water residence time = lake volume (any volume units)/outflow rate (any consistent volume/yr units).

(4) Locate the lake on Figure 3, the trophic state graph (Vollenweider and Dillon, 1974) by using L_{La}/A_{La} as ordinate and the result of step 2.q.(3) as abscissa.

(5) Note the change in status that would be expected from the addition of highway runoff loading in the amount L_H/A_{La}.

(6) If the highway loading addition does not move the status point near or into a higher trophic category, declare minimal impact on lake eutrophication and go to step 3. Otherwise, reevaluate according to Level III, step 2.

3.) Individual storm event concentration assessment:

a.) Determine pollutant reduction factor due to mitigation measures according to step 2.d.

b.) Assume instantaneous mixing of runoff in receiving water. If the immediate receiving water is a stream, proceed to step 3.c. If the immediate receiving water is a lake or wetland, go to step 3.d.

c.) Approximate the mean dilution ratio as $Q/(Q + \overline{Q}_S)$, where $\overline{Q}_S$ is determined as in step 2.h. (1) For this calculation Q should be estimated from the Rational Method using for I the average intensity of the 25 yr recurrence interval, 24 hour duration storm. Consult NOAA, Atlas 2, Volume IX, Washington (U.S. Department of Commerce, 1973), which contains an isopluvial map for the given storm (divide quantity from map by 24 hours to get average intensity). Go to step 3.e.

d.) Approximate the dilution ratio as $QT/(QT + V)$, where Q is determined as described in step 3.c., T = 24 hr, the duration of the design storm (expressed as 86,400 seconds), and V = lake or wetland water volume (ft^3) (see footnote associated with step 3.c.). For lakes, V = mean depth x surface area.

e.) Determine the overall pollutant reduction factor as the product of the factor due to mitigation (step 3.a.) and the dilution ratio (step 3.c. or 3.d.)

---

(1) The exact mass balance relationships for stream and lake concentrations (C'_S and C'_{La}, mg/l), respectively are:

$$C'_S = (QC + \overline{Q}_S\overline{C}_S)/(Q + \overline{Q}_S) \text{ and } C'_{La} = (QTC + V\overline{C}_{La})/(QT + V)$$

where: C = pollutant concentration in highway runoff for a given event, which must be expressed probabilistically as in subsequent steps (mg/l)

$\overline{C}_{La}$ = mean lake concentration (mg/l)

Since the dilution ratio C'_S/C (or C'_{La}/C) cannot be exactly determined without a definite value of C, the approximation implicitly assume $\overline{C}_S$ (or $\overline{C}_{La}$) is negligible relative to C.

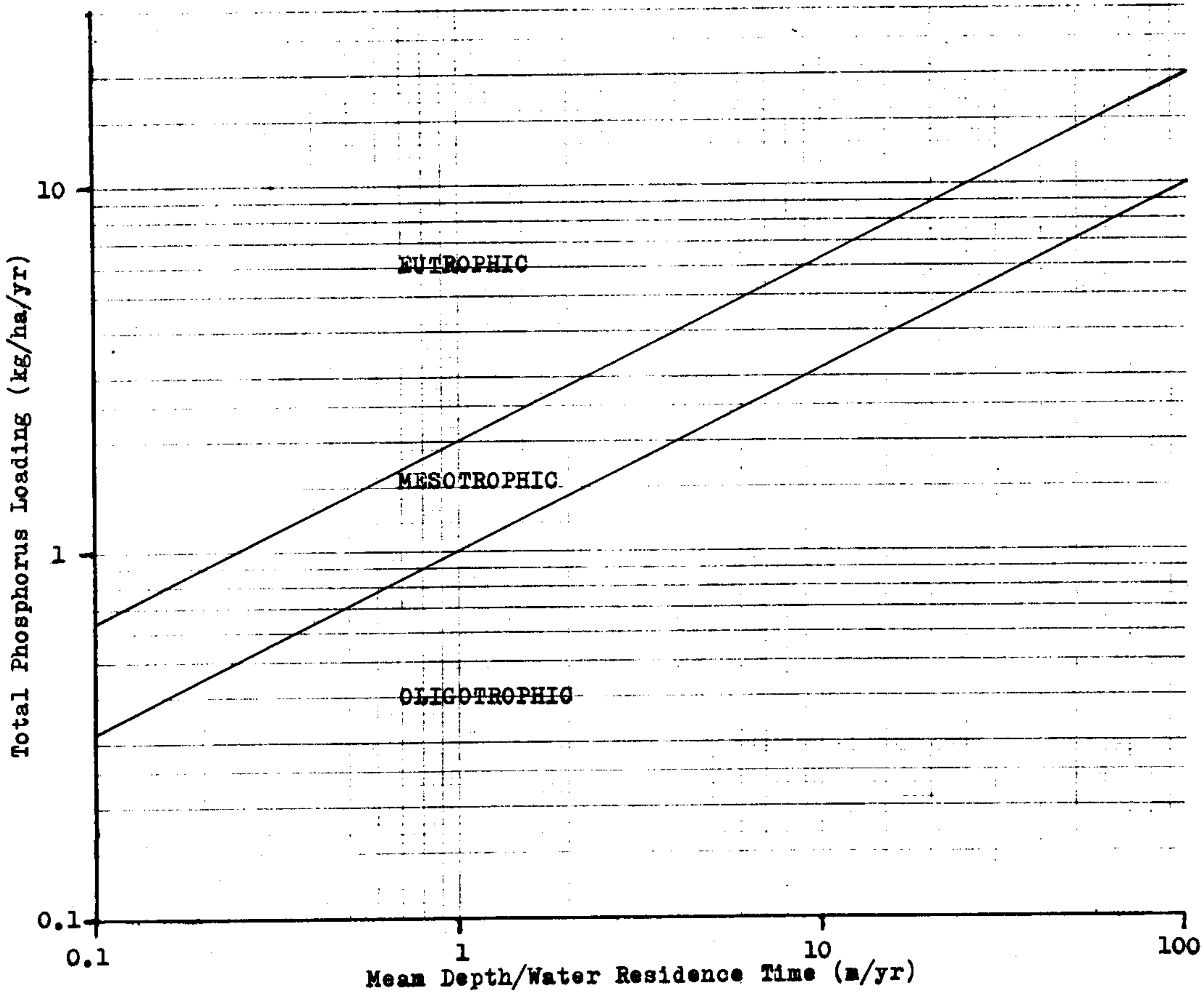

Figure 3: Lake Trophic State in Response to Phosphorus Loading (Vollenweider and Dillon, 1974).

f.) For the pollutant reduction factor, location, and traffic levels [(1)], determine for each pollutant the probability of exceeding a given concentration in any storm event by referring to Figure 4, 5, 6, or 7. The given concentration should be the water quality criterion if one has been set. If not, the given concentration should be referred to existing receiving water conditions to provide a basis for expressing impact (for example, equal to current mean concentration, maximum concentration, ten percent above current mean concentration, etc.). Express the impact on receiving water concentration in terms of the identified probability. An effective demonstration of minimal impact would be a low probability of exceeding a criterion or present contamination level.

g.) If a substantial probability exists for violating the selected concentration condition, reconsider mitigation measures, as described in Level III, step 3.

4.) Analyze impacts associated with the particular maintenance practices anticipated or any special problem areas (see Section IV).

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(1) Traffic level breakdowns are based on data from sites having the following ADT:

Western Washington, High Traffic -- 42,000-53,000
Wastern Washington, Low Traffic -- 7,700-8,600
Eastern Washington, High Traffic -- 17,300
Eastern Washington, Low Traffic -- 2,000-2,500

At this stage of development of the methodology, linear interpolation is recommended to make estimates for intermediate traffic levels. The respective high traffic curves are recommended for traffic volumes greater than or equal to the ADT at the sites providing the data base. Except as noted, the source of aquatic life water quality criteria is the Federal Register, 45 FR 79318-79379, November 28, 1980.

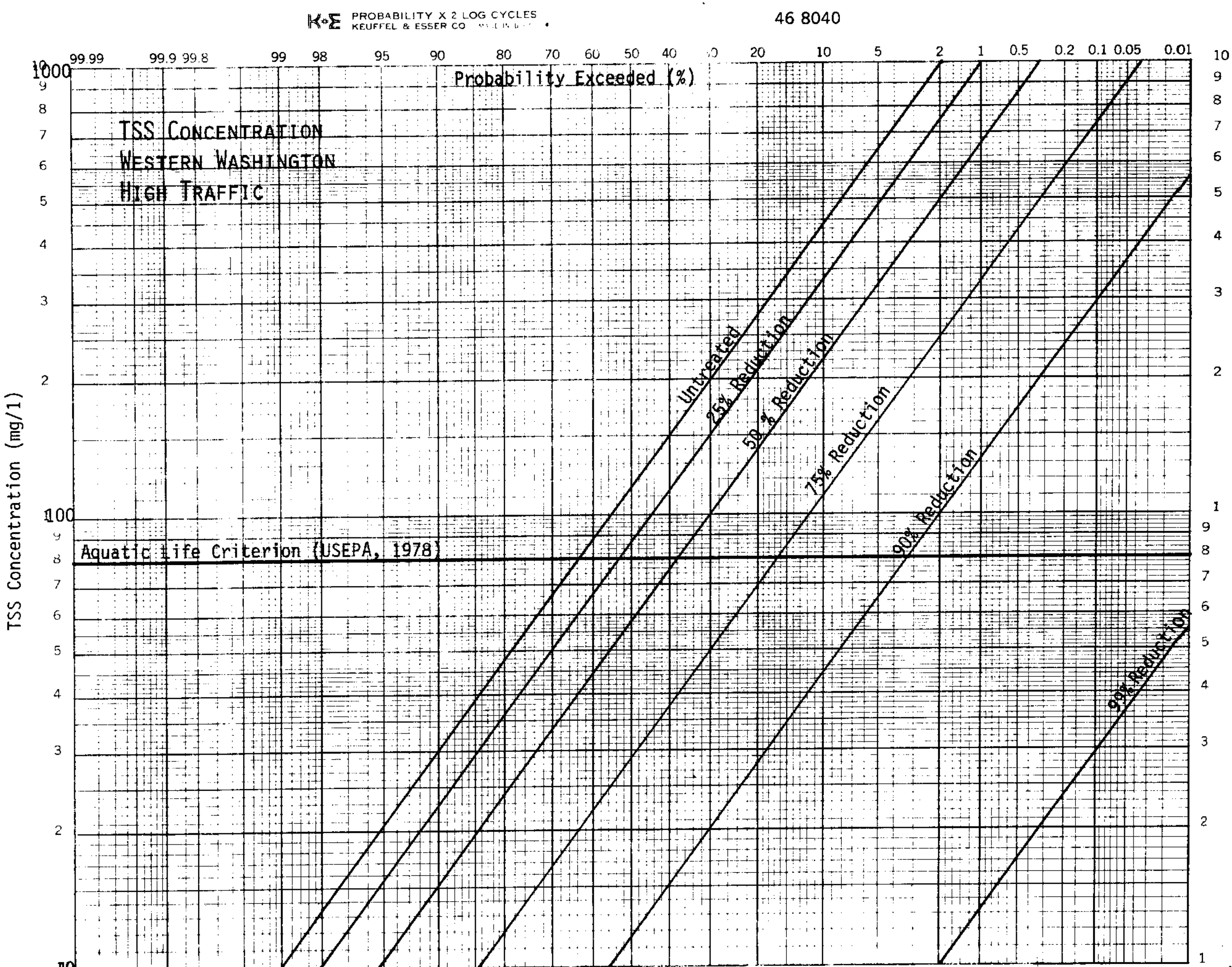
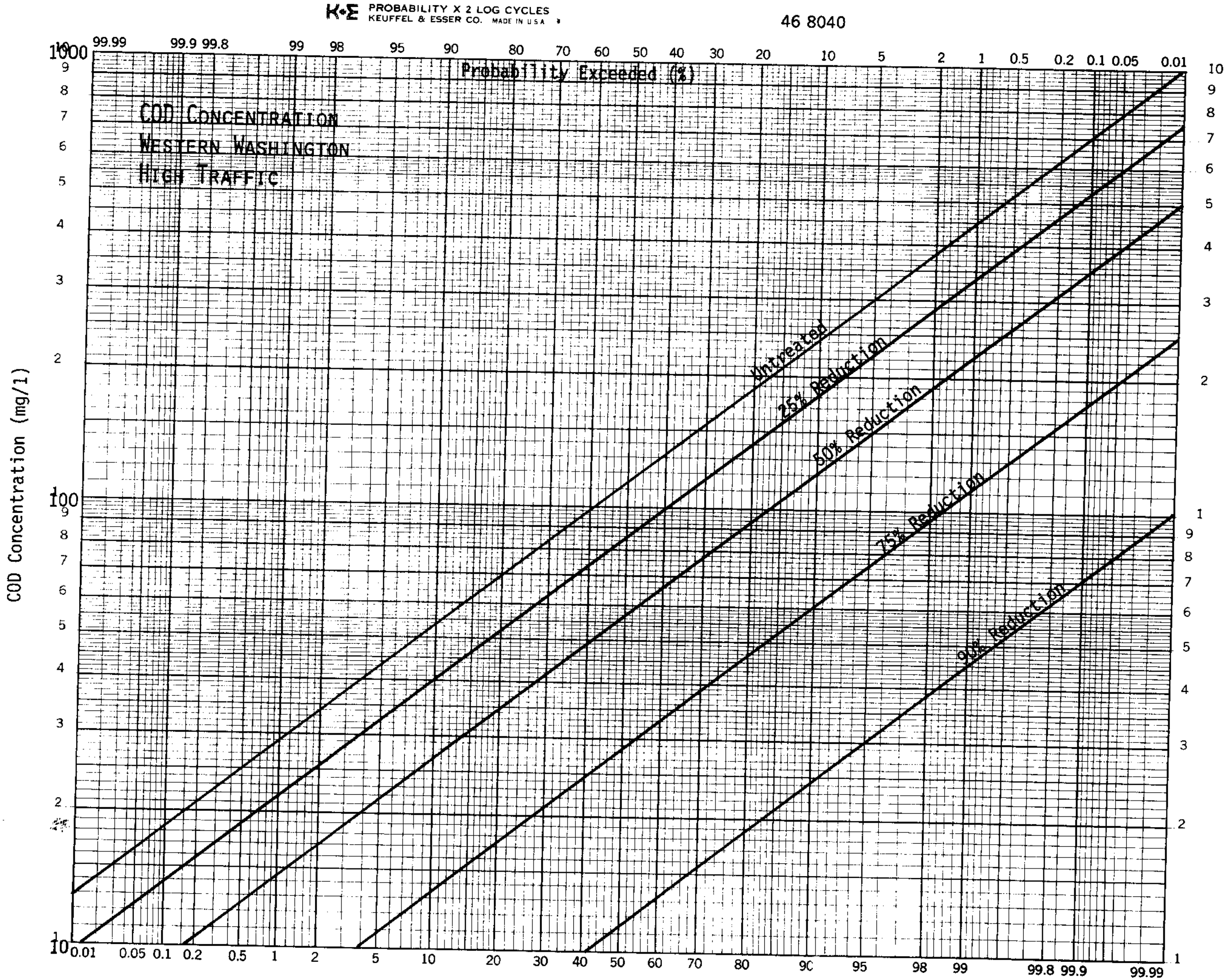
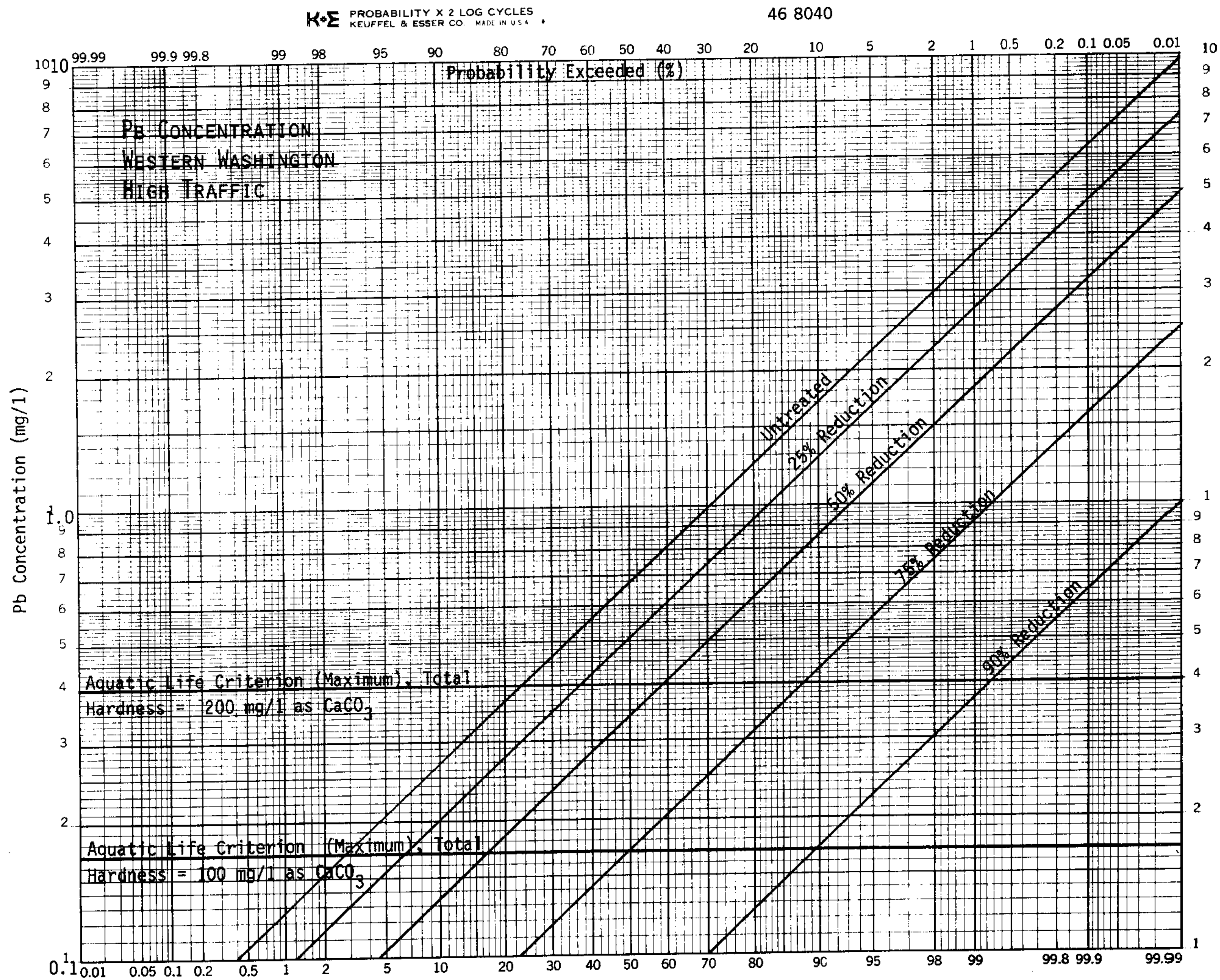
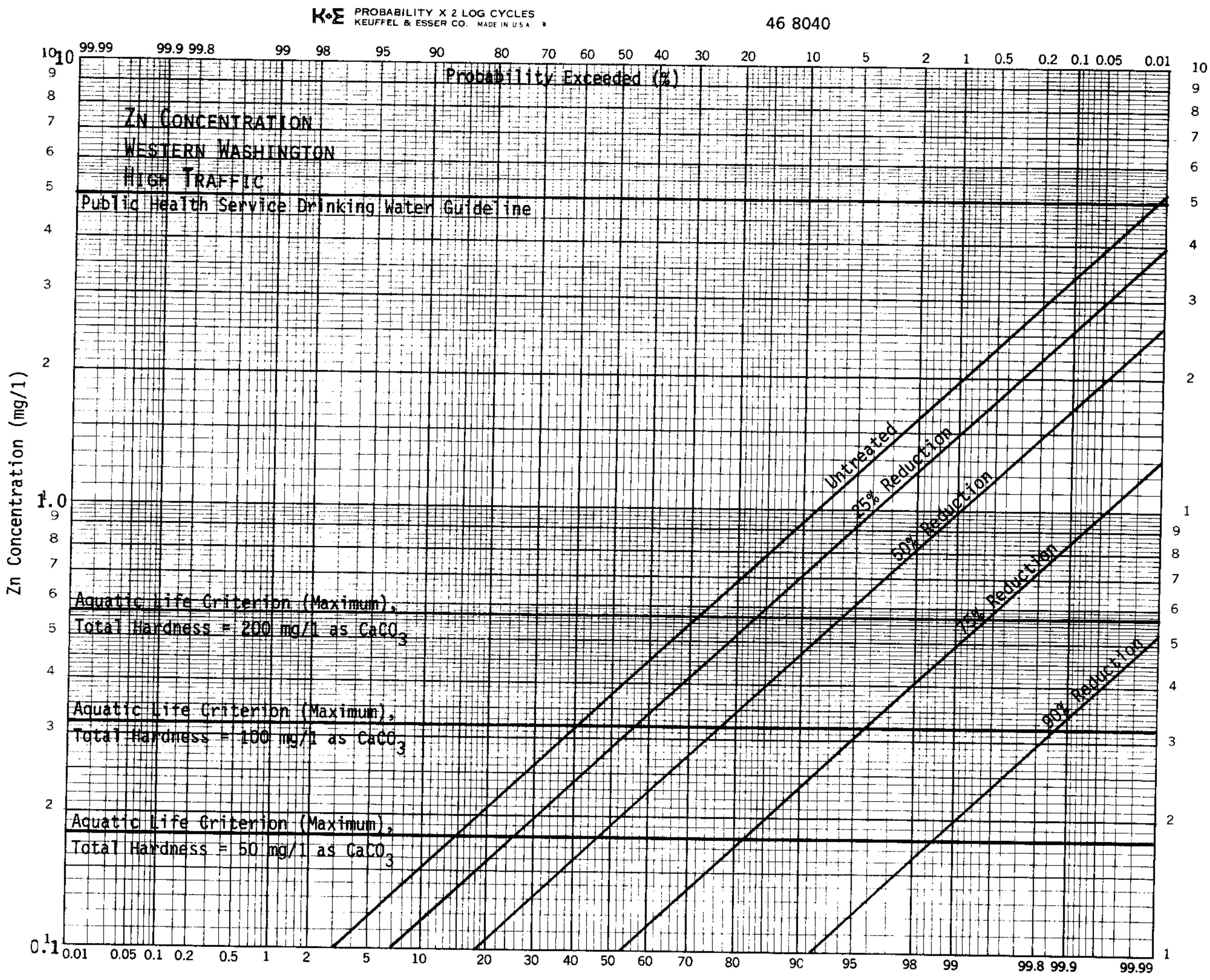
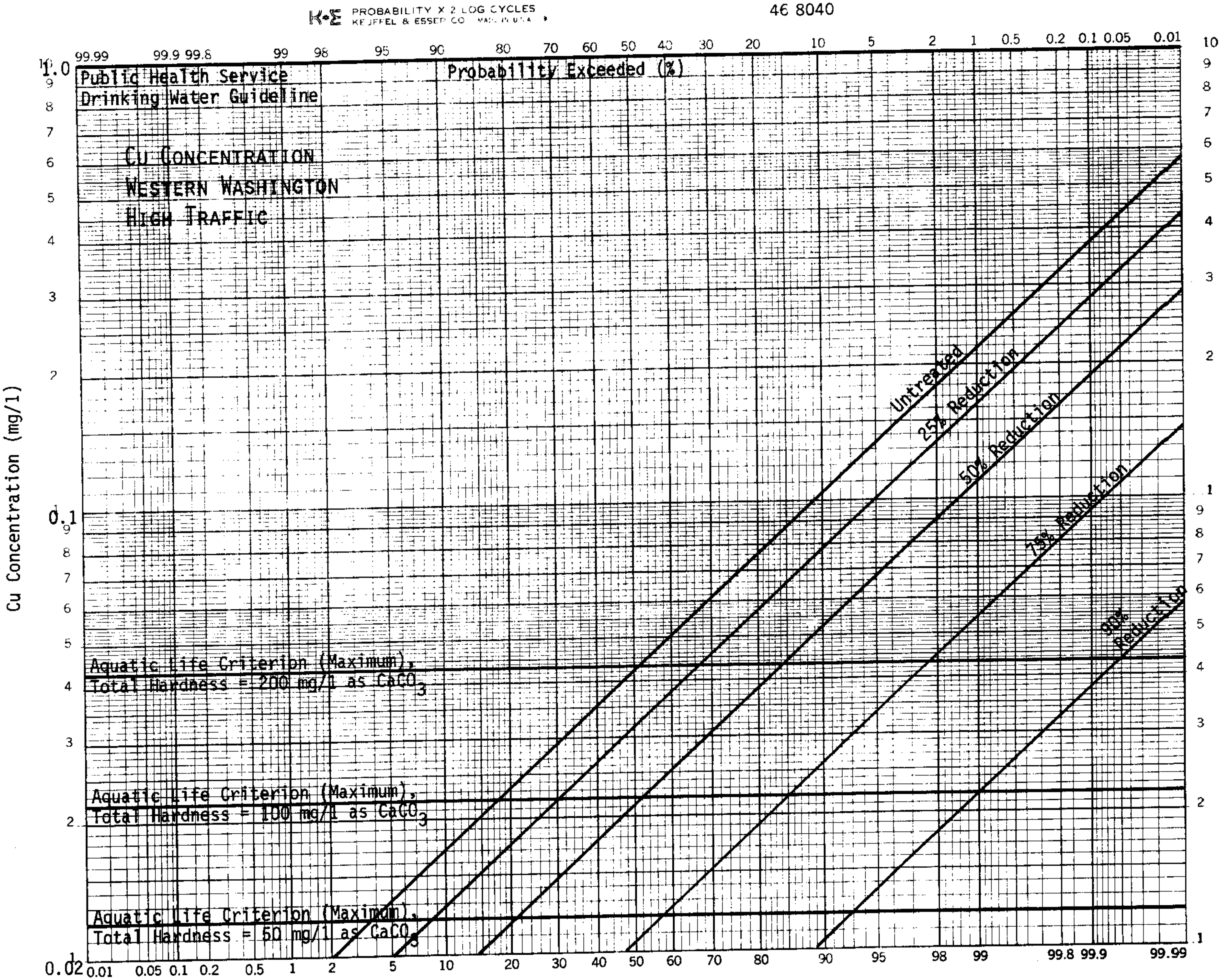


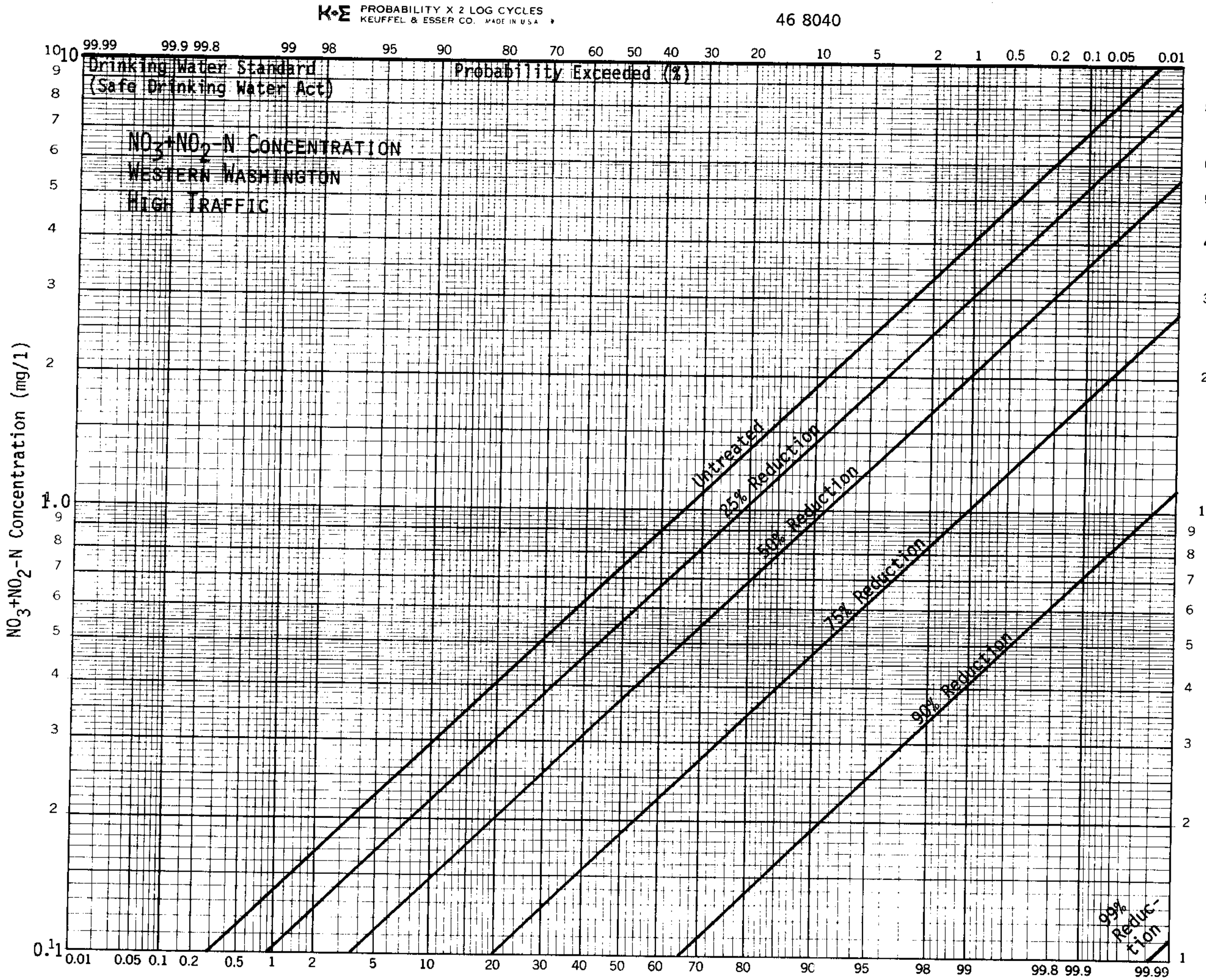
Figure 4. Concentration - Probability Distributions for Western Washington; High Traffic Volume (Continued next 6 pages)

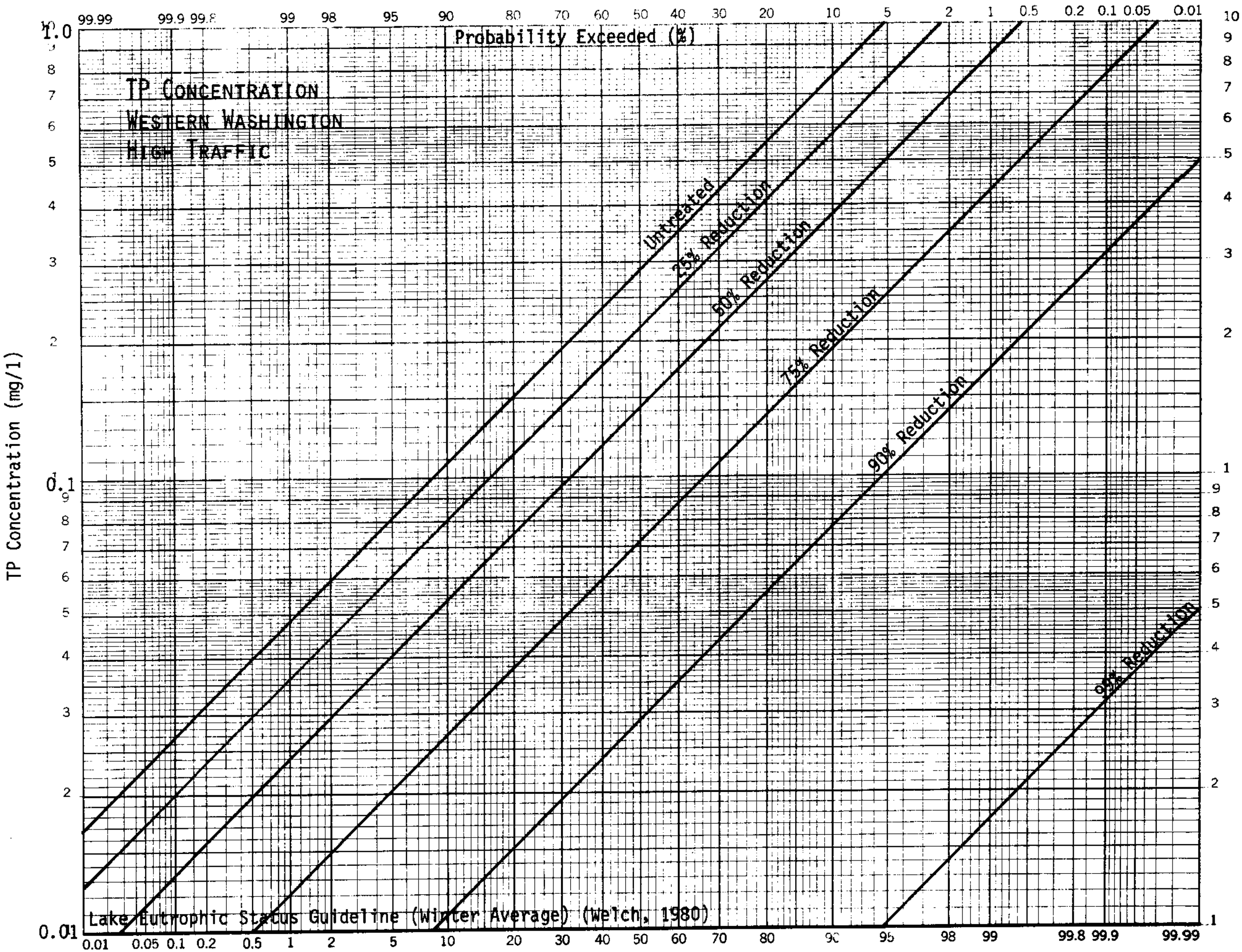

K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
COD CONCENTRATION
WESTERN WASHINGTON
HIGH TRAFFIC
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
COD Concentration (mg/l)


K•E PROBABILITY X 2 LOG CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
Pb CONCENTRATION
WESTERN WASHINGTON
HIGH TRAFFIC
Pb Concentration (mg/l)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
Aquatic Life Criterion (Maximum), Total
Hardness = 200 mg/l as CaCO3
Aquatic Life Criterion (Maximum), Total
Hardness = 100 mg/l as CaCO3


K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
Zn Concentration
Western Washington
High Traffic
Public Health Service Drinking Water Guideline
Aquatic Life Criterion (Maximum),
Total Hardness = 200 mg/l as CaCO3
Aquatic Life Criterion (Maximum),
Total Hardness = 100 mg/l as CaCO3
Aquatic Life Criterion (Maximum),
Total Hardness = 50 mg/l as CaCO3
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
Zn Concentration (mg/l)


K•E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO.
46 8040
Probability Exceeded (%)
Public Health Service
Drinking Water Guideline
Cu Concentration
Western Washington
High Traffic
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
Aquatic Life Criterion (Maximum), Total Hardness = 200 mg/l as $CaCO_3$
Aquatic Life Criterion (Maximum), Total Hardness = 100 mg/l as $CaCO_3$
Aquatic Life Criterion (Maximum), Total Hardness = 50 mg/l as $CaCO_3$
Cu Concentration (mg/l)
1.0
0.1
0.02
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99


K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Drinking Water Standard
(Safe Drinking Water Act)
Probability Exceeded (%)
NO3+NO2-N CONCENTRATION
WESTERN WASHINGTON
HIGH TRAFFIC
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduc-tion
NO3+NO2-N Concentration (mg/1)


TP CONCENTRATION
WESTERN WASHINGTON
HIGH TRAFFIC
Probability Exceeded (%)
TP Concentration (mg/l)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
Lake Eutrophic Status Guideline (Winter Average) (Welch, 1980)
1.0
0.1
0.01

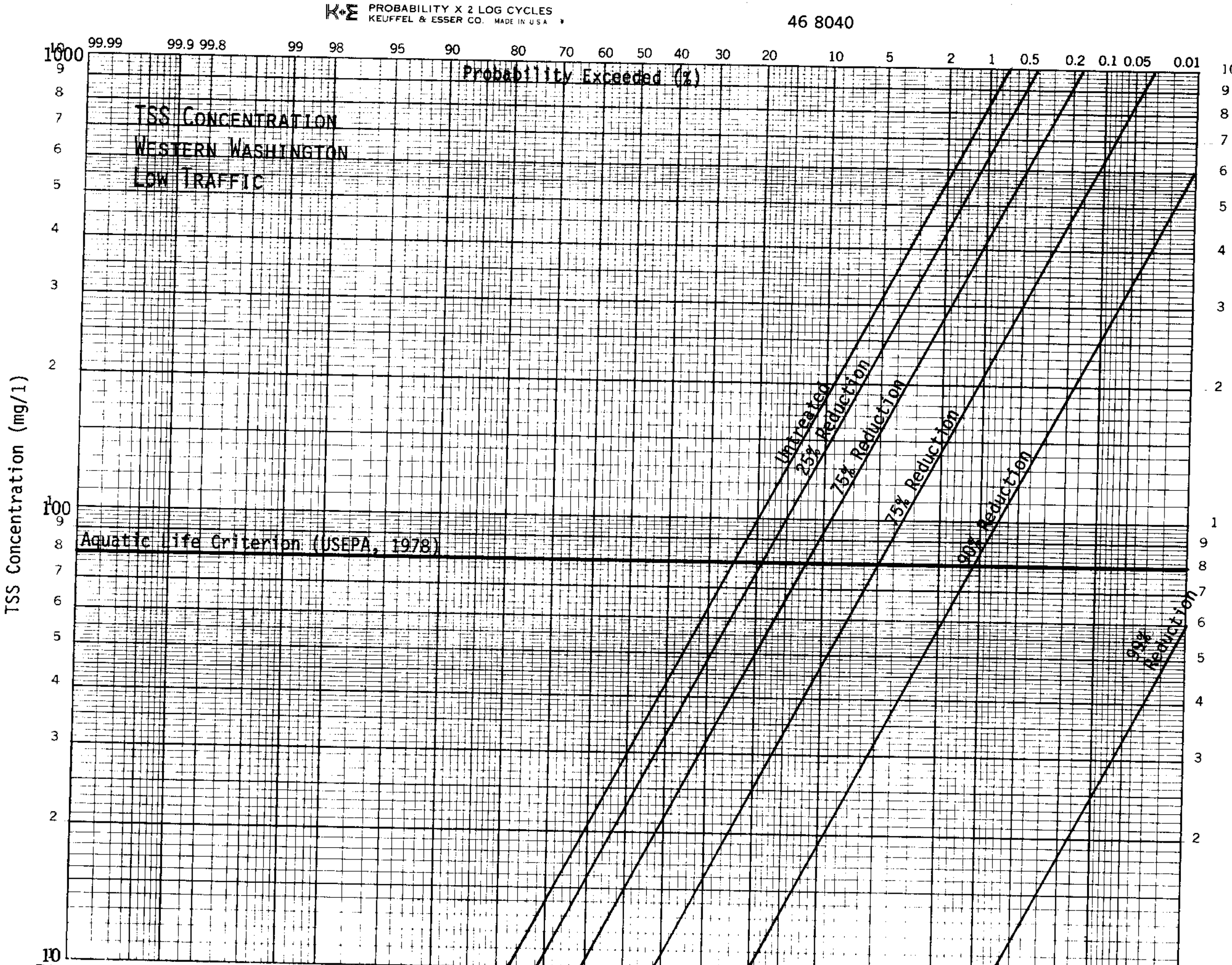
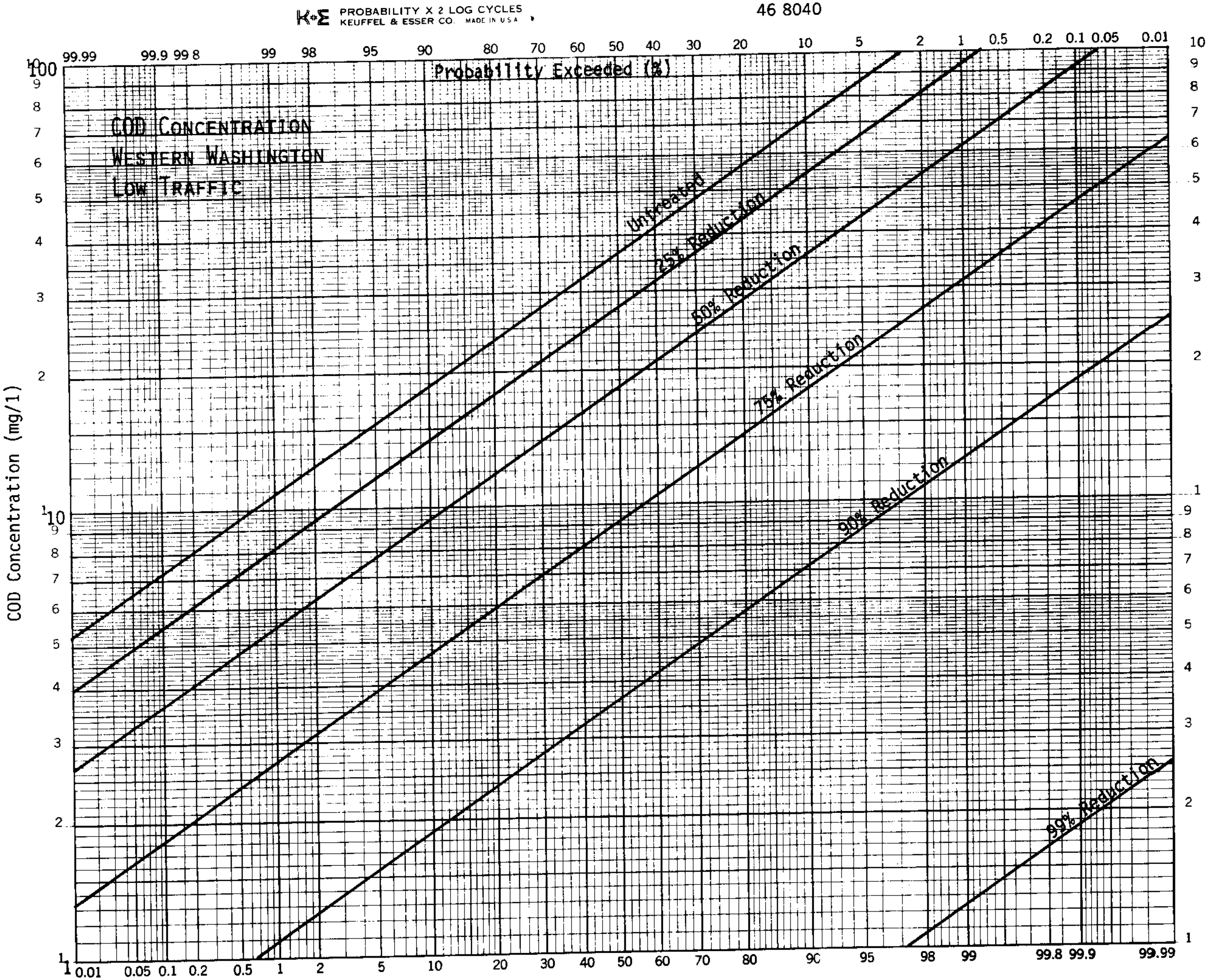
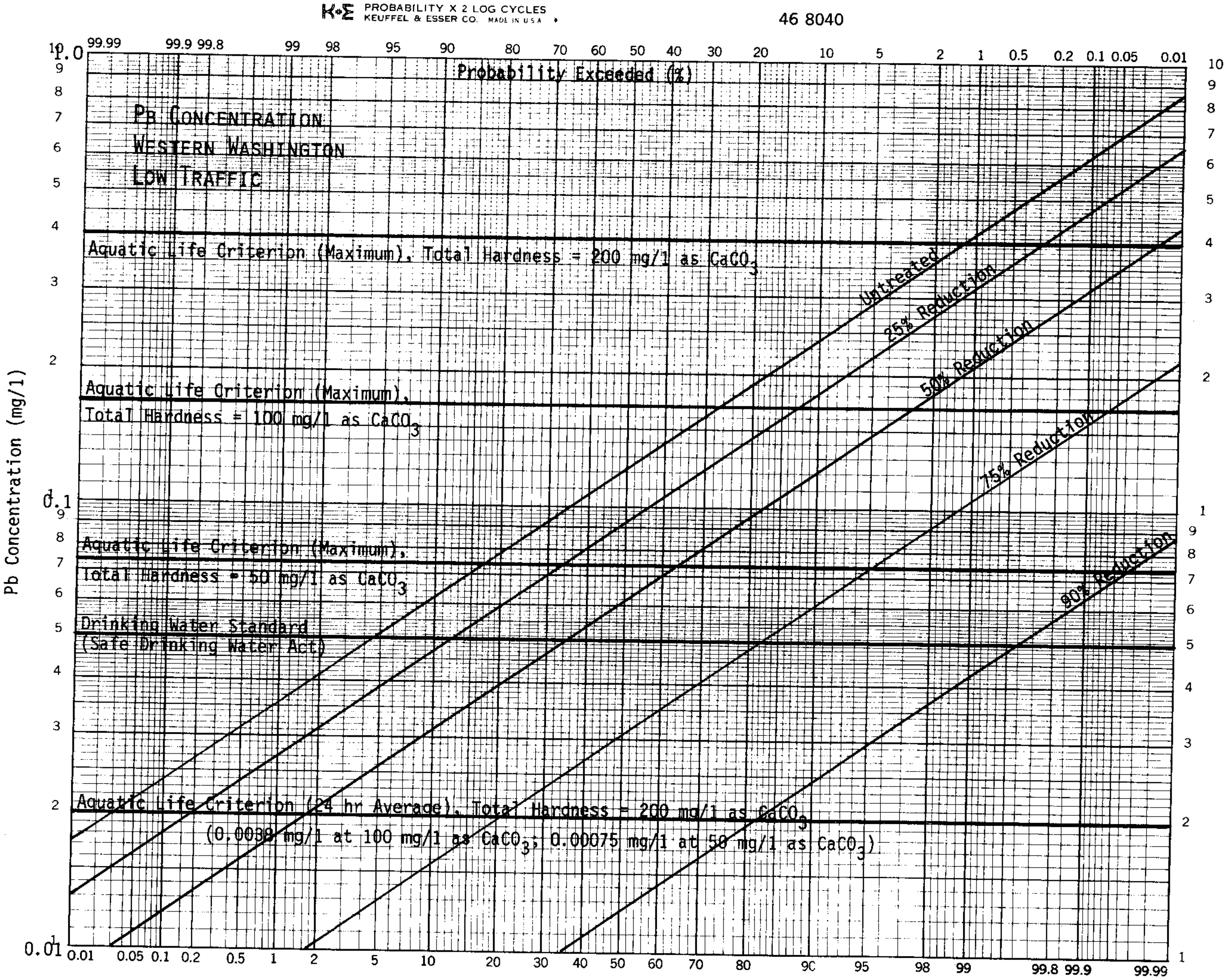
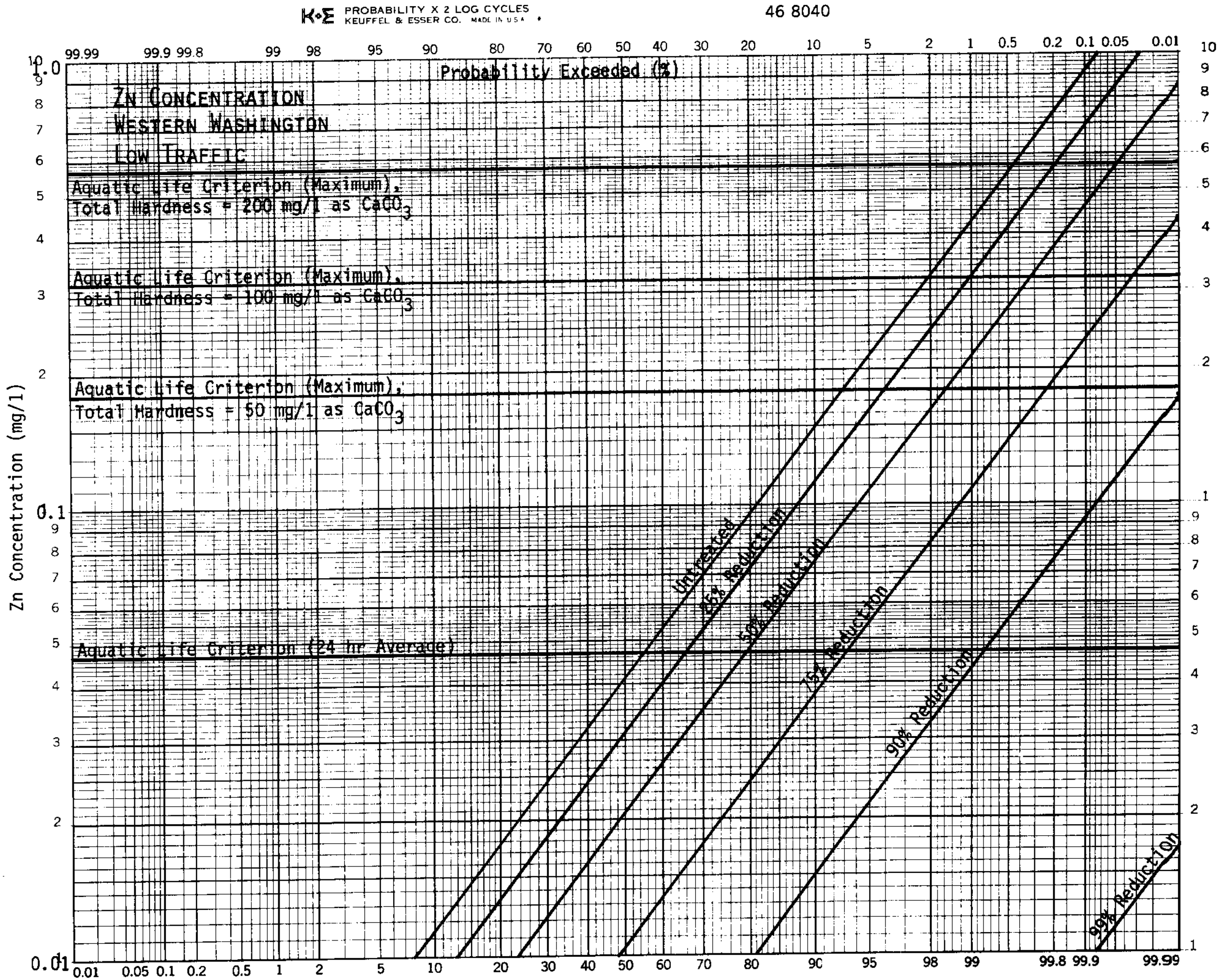


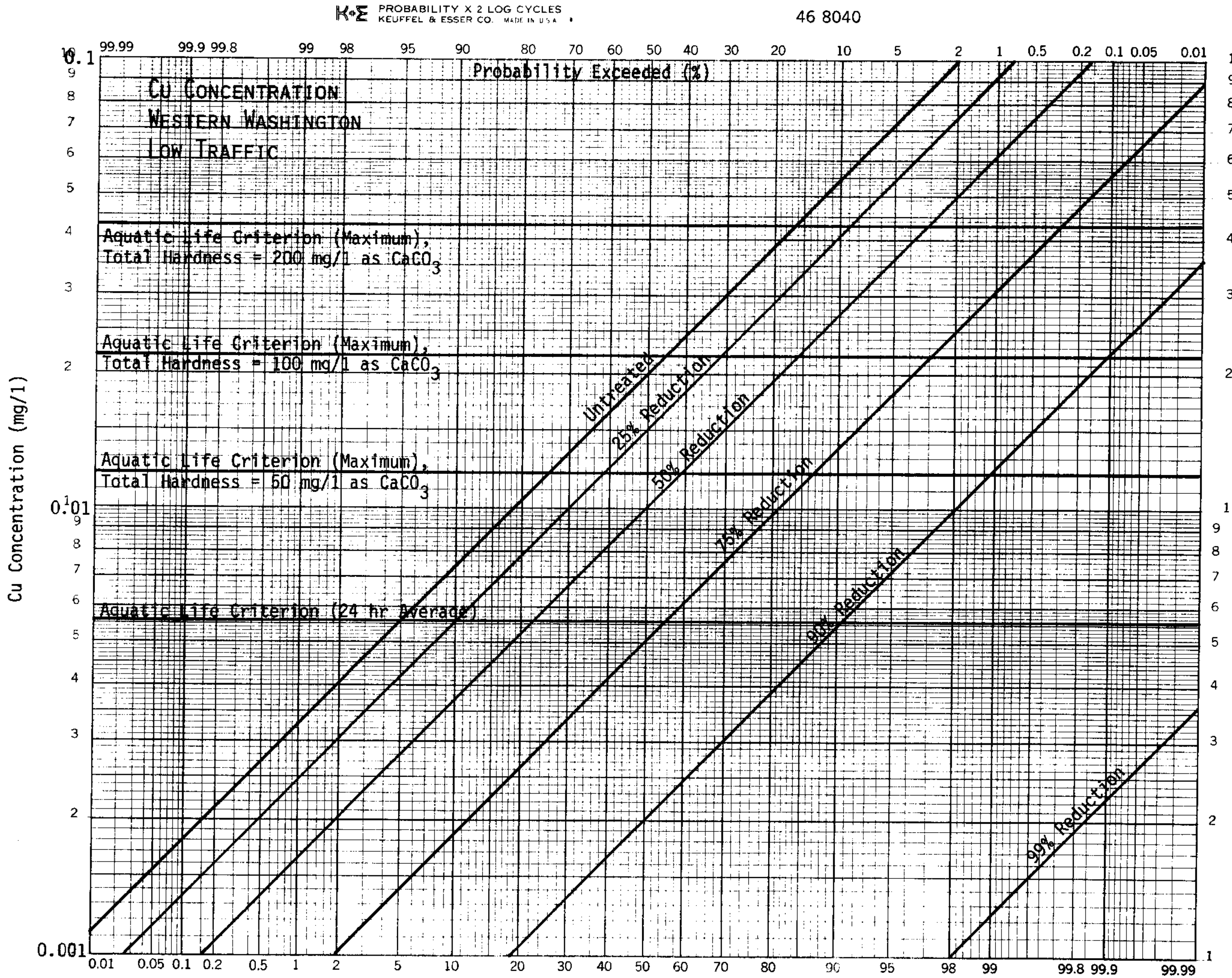
Figure 5. Concentration - Probability Distributions for Western Washington; Low Traffic Volume (Continued next 6 pages)

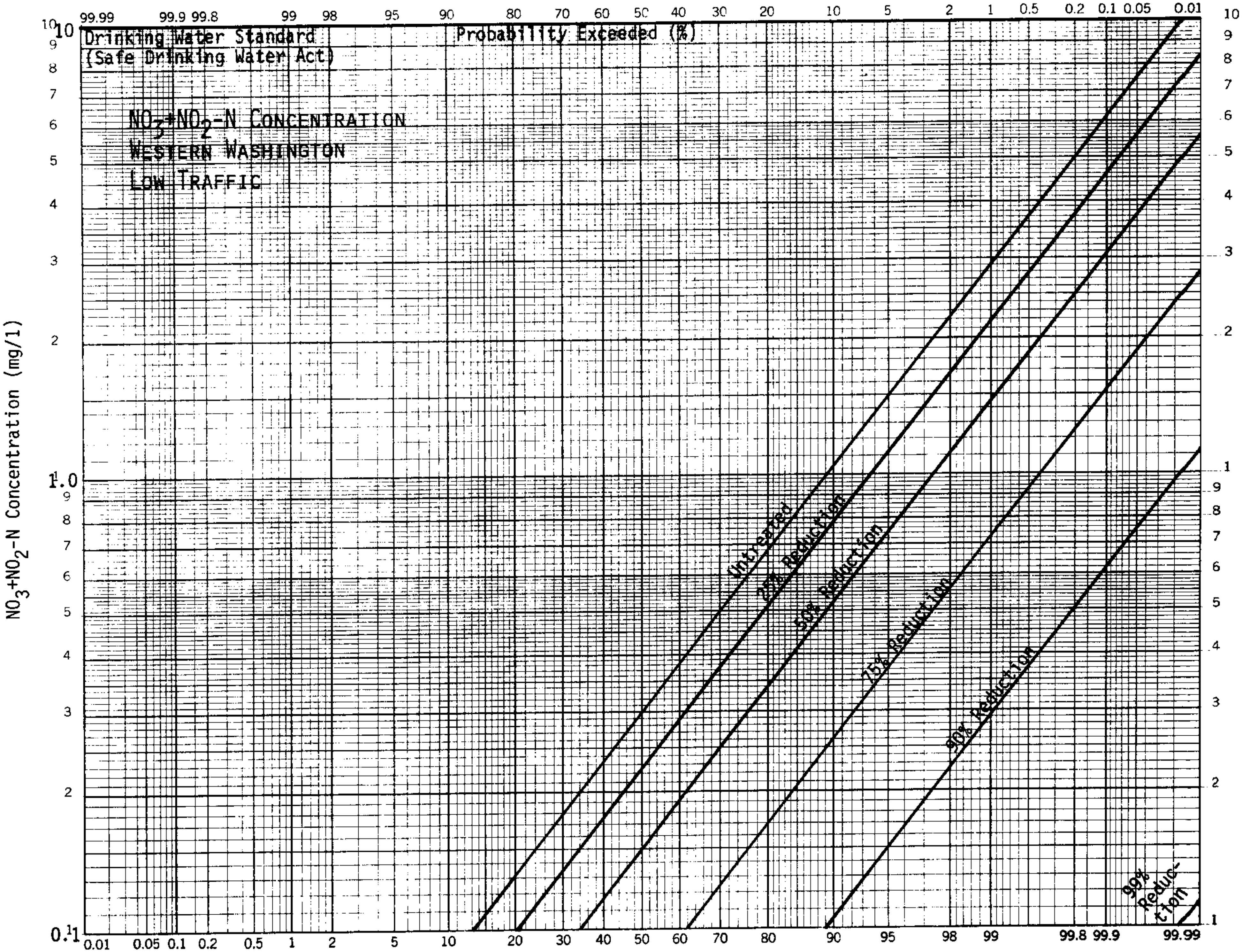

K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
COD Concentration
Western Washington
Low Traffic
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
COD Concentration (mg/1)


K•E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
Pb Concentration
Western Washington
Low Traffic
Aquatic Life Criterion (Maximum), Total Hardness = 200 mg/l as $CaCO_3$
Aquatic Life Criterion (Maximum),
Total Hardness = 100 mg/l as $CaCO_3$
Aquatic Life Criterion (Maximum),
Total Hardness = 50 mg/l as $CaCO_3$
Drinking Water Standard
(Safe Drinking Water Act)
Aquatic Life Criterion (24 hr Average), Total Hardness = 200 mg/l as $CaCO_3$
(0.0038 mg/l at 100 mg/l as $CaCO_3$; 0.00075 mg/l at 50 mg/l as $CaCO_3$)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
Pb Concentration (mg/l)

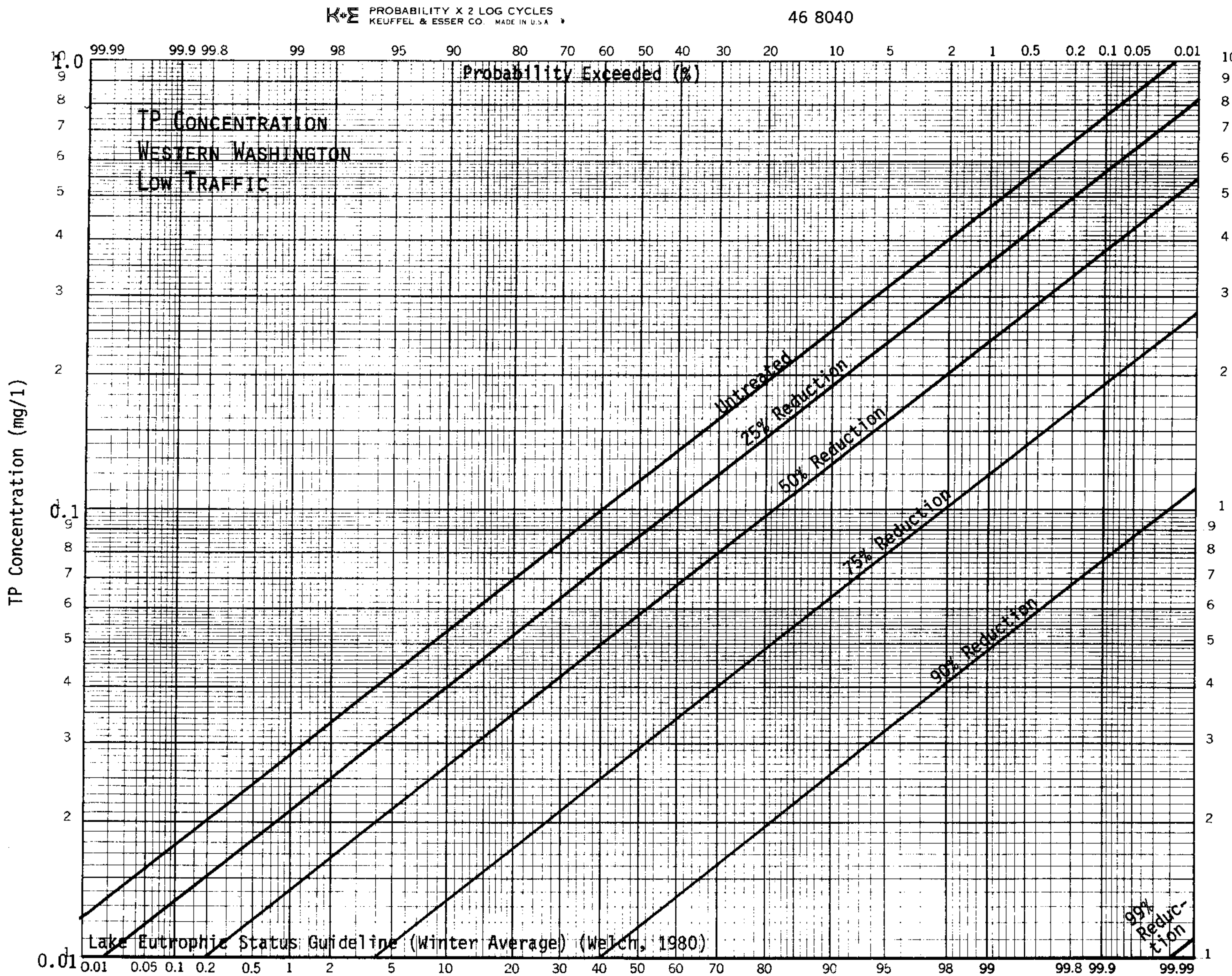


K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
Zn Concentration
Western Washington
Low Traffic
Aquatic Life Criterion (Maximum), Total Hardness = 200 mg/1 as $CaCO_3$
Aquatic Life Criterion (Maximum), Total Hardness = 100 mg/1 as $CaCO_3$
Aquatic Life Criterion (Maximum), Total Hardness = 50 mg/1 as $CaCO_3$
Aquatic Life Criterion (24 hr Average)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
Zn Concentration (mg/1)
1.0
0.1
0.01


K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Cu CONCENTRATION
WESTERN WASHINGTON
LOW TRAFFIC
Probability Exceeded (%)
Cu Concentration (mg/1)
Aquatic Life Criterion (Maximum), Total Hardness = 200 mg/1 as CaCO3
Aquatic Life Criterion (Maximum), Total Hardness = 100 mg/1 as CaCO3
Aquatic Life Criterion (Maximum), Total Hardness = 50 mg/1 as CaCO3
Aquatic Life Criterion (24 hr Average)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
0.1
0.01
0.001



Drinking Water Standard
(Safe Drinking Water Act)
Probability Exceeded (%)
NO_3+NO_2-N CONCENTRATION
WESTERN WASHINGTON
LOW TRAFFIC
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduc-tion
NO_3+NO_2-N Concentration (mg/l)


K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
TP CONCENTRATION
WESTERN WASHINGTON
LOW TRAFFIC
TP Concentration (mg/l)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduc-tion
Lake Eutrophic Status Guideline (Winter Average) (Welch, 1980)

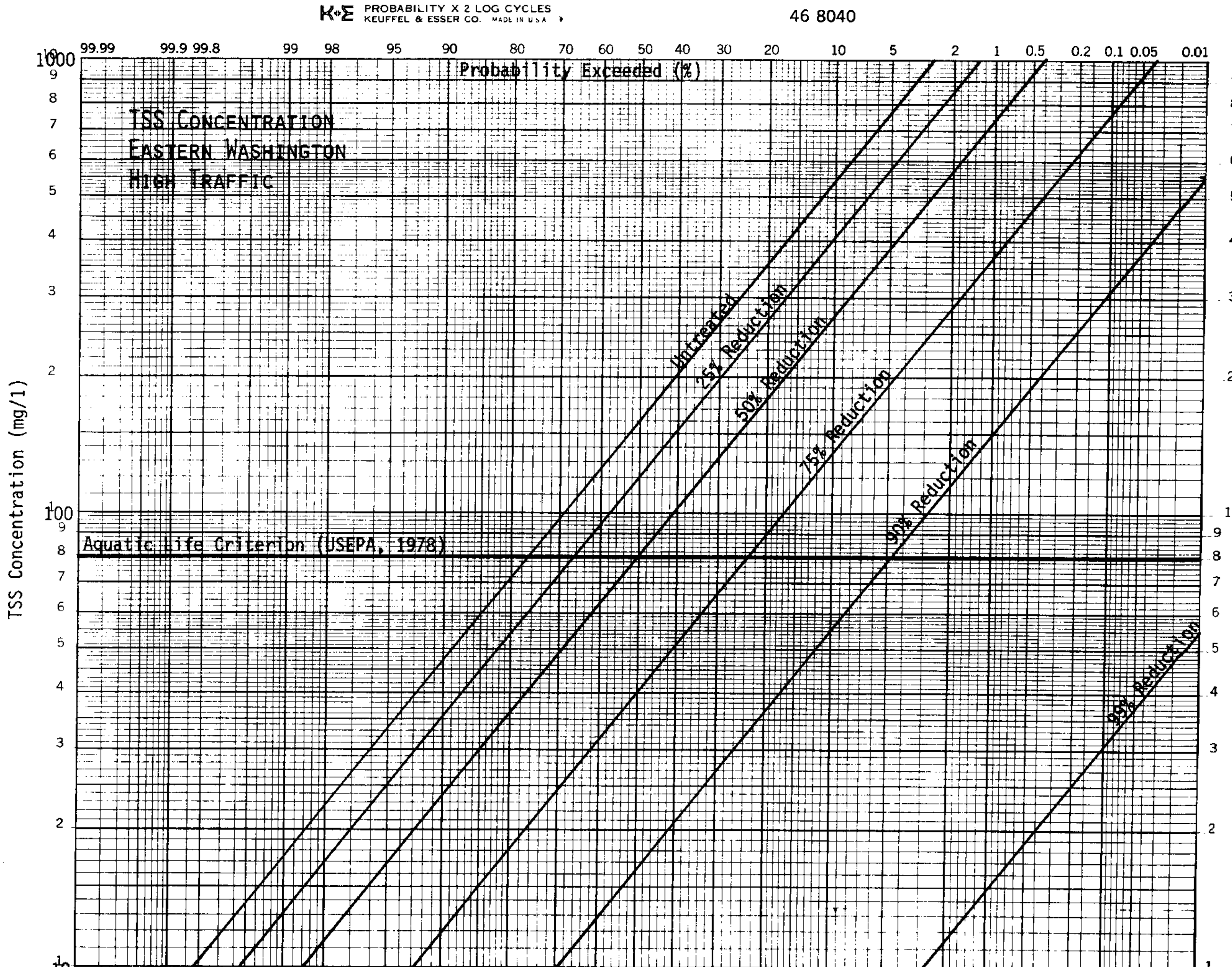
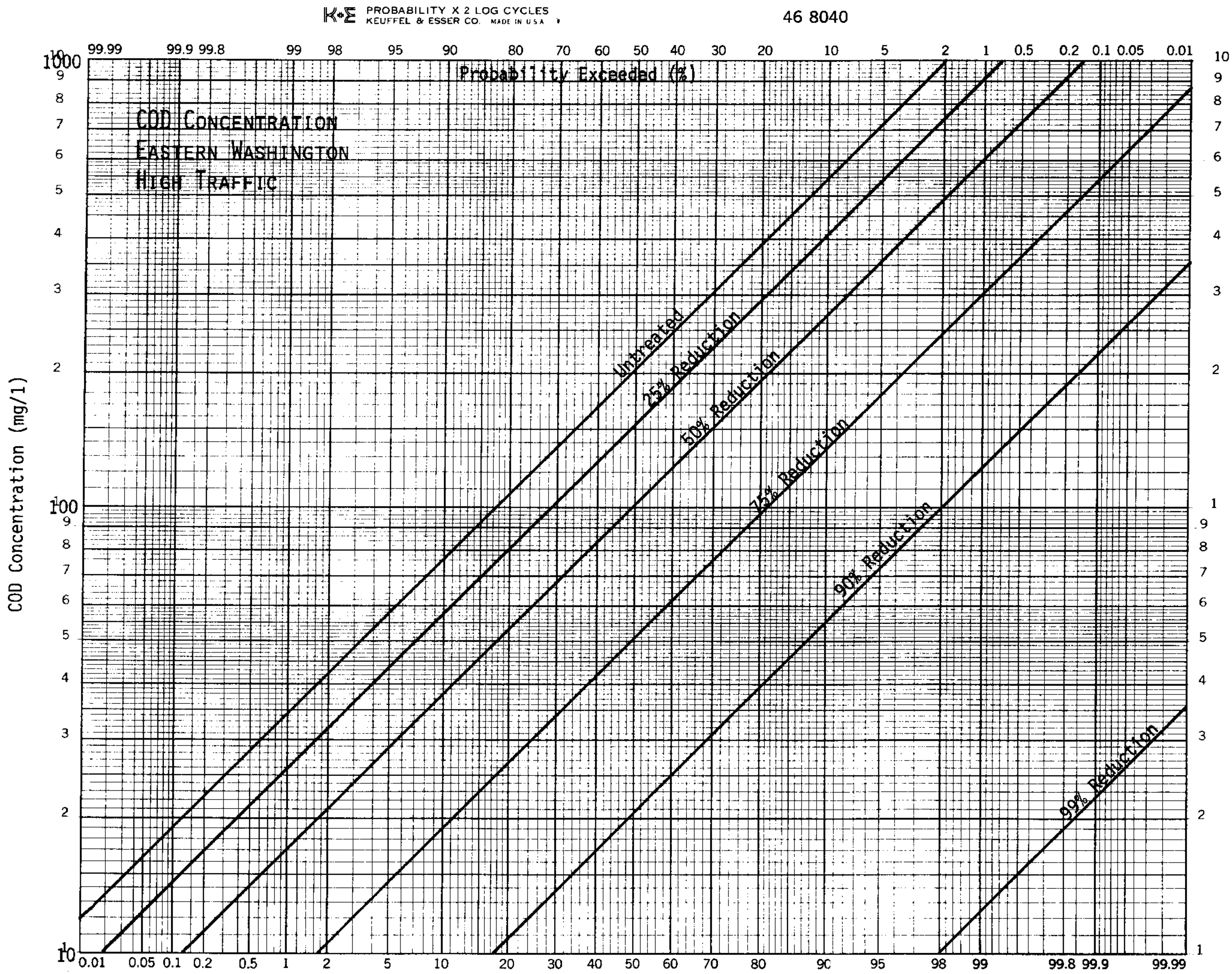
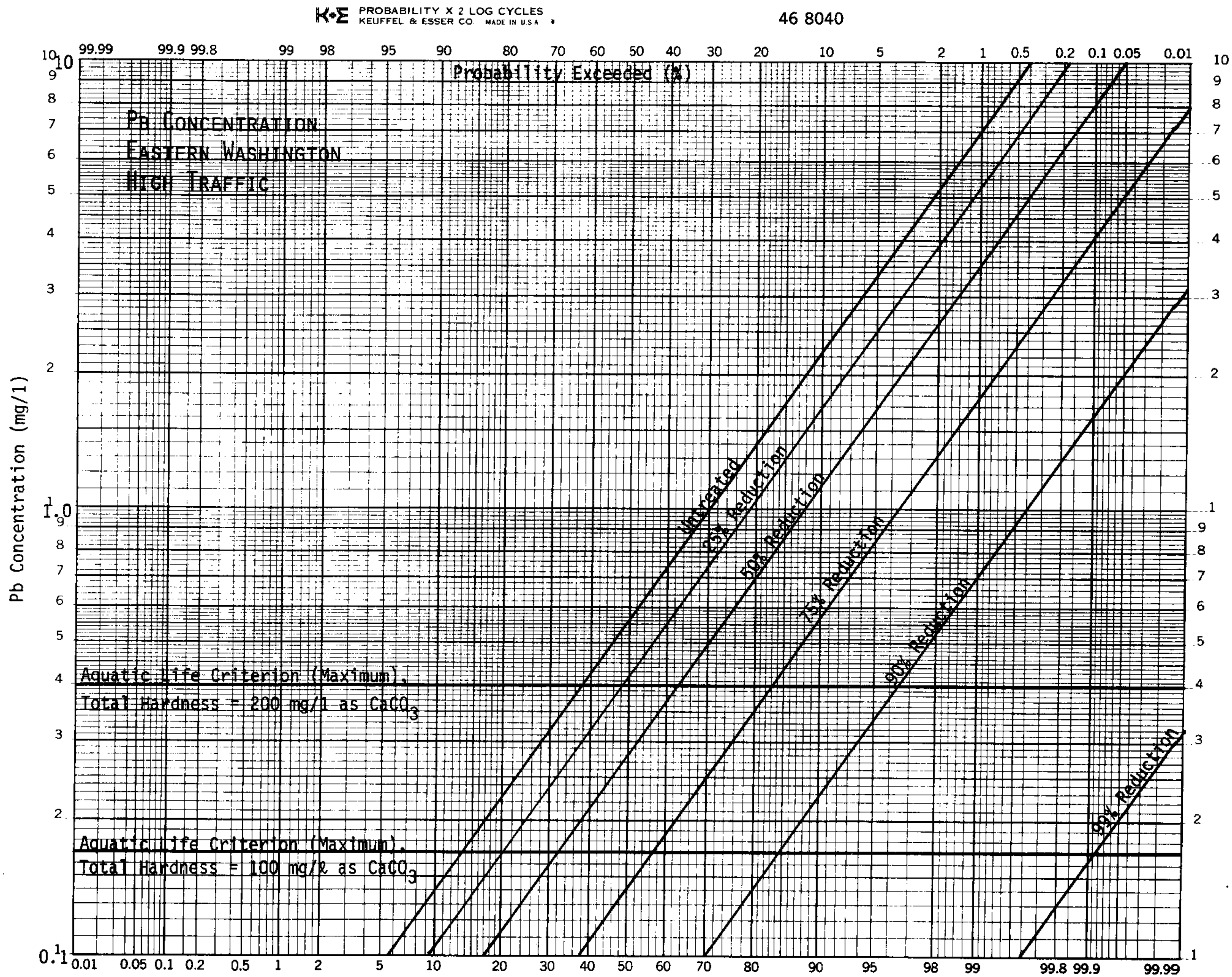
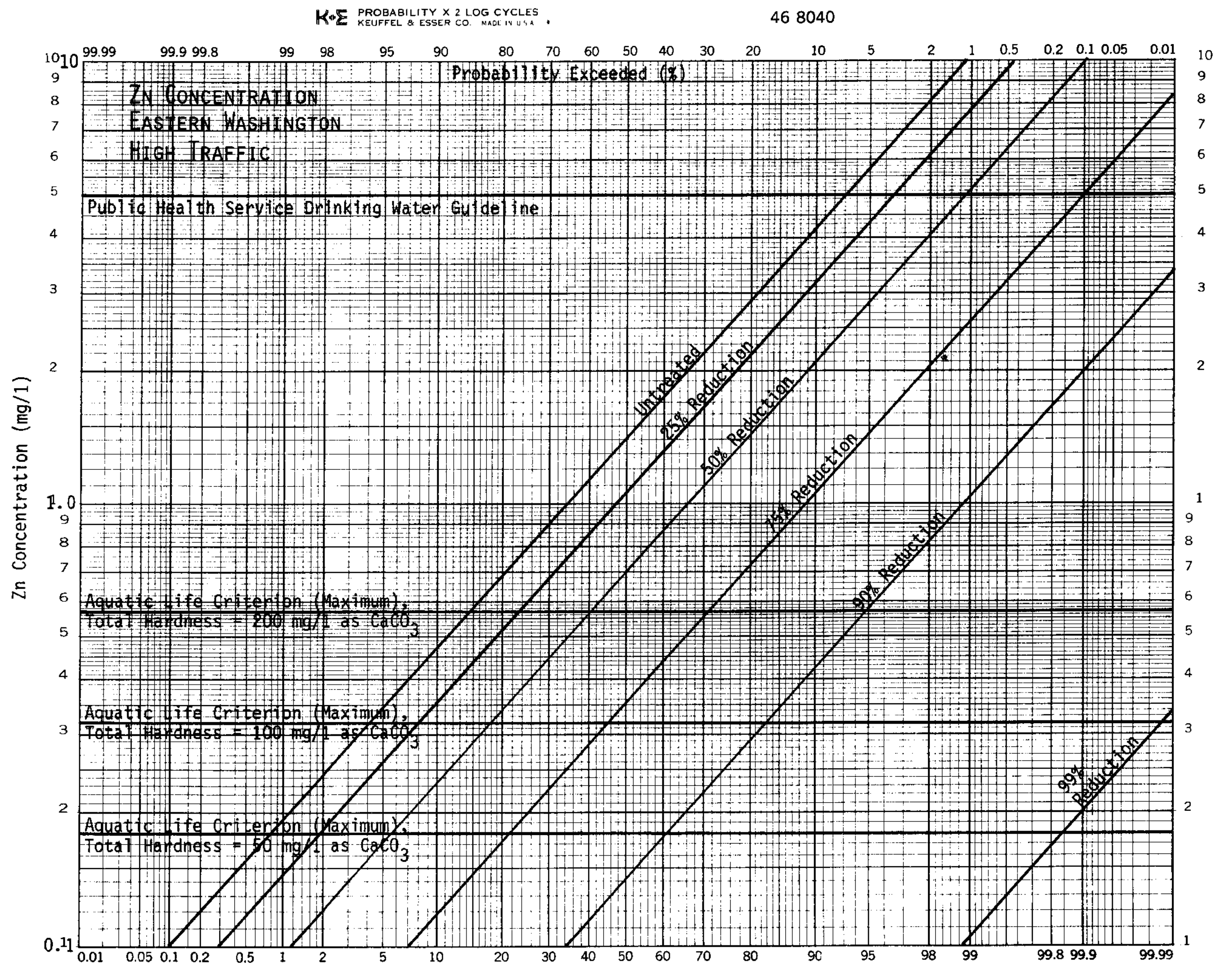


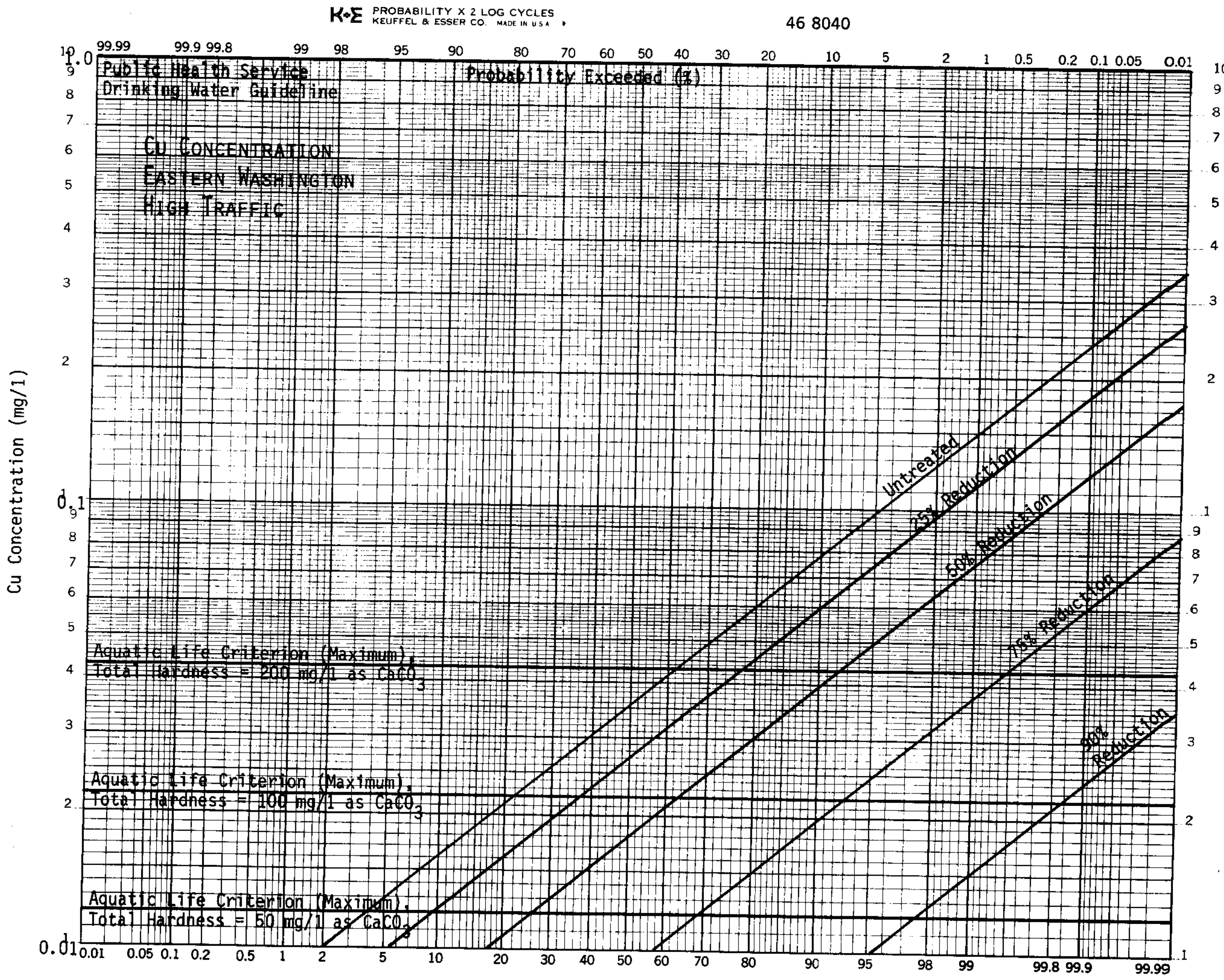
Figure 6. Concentration - Probability Distributions for Eastern Washington; High Traffic Volume (Continued next 6 pages)

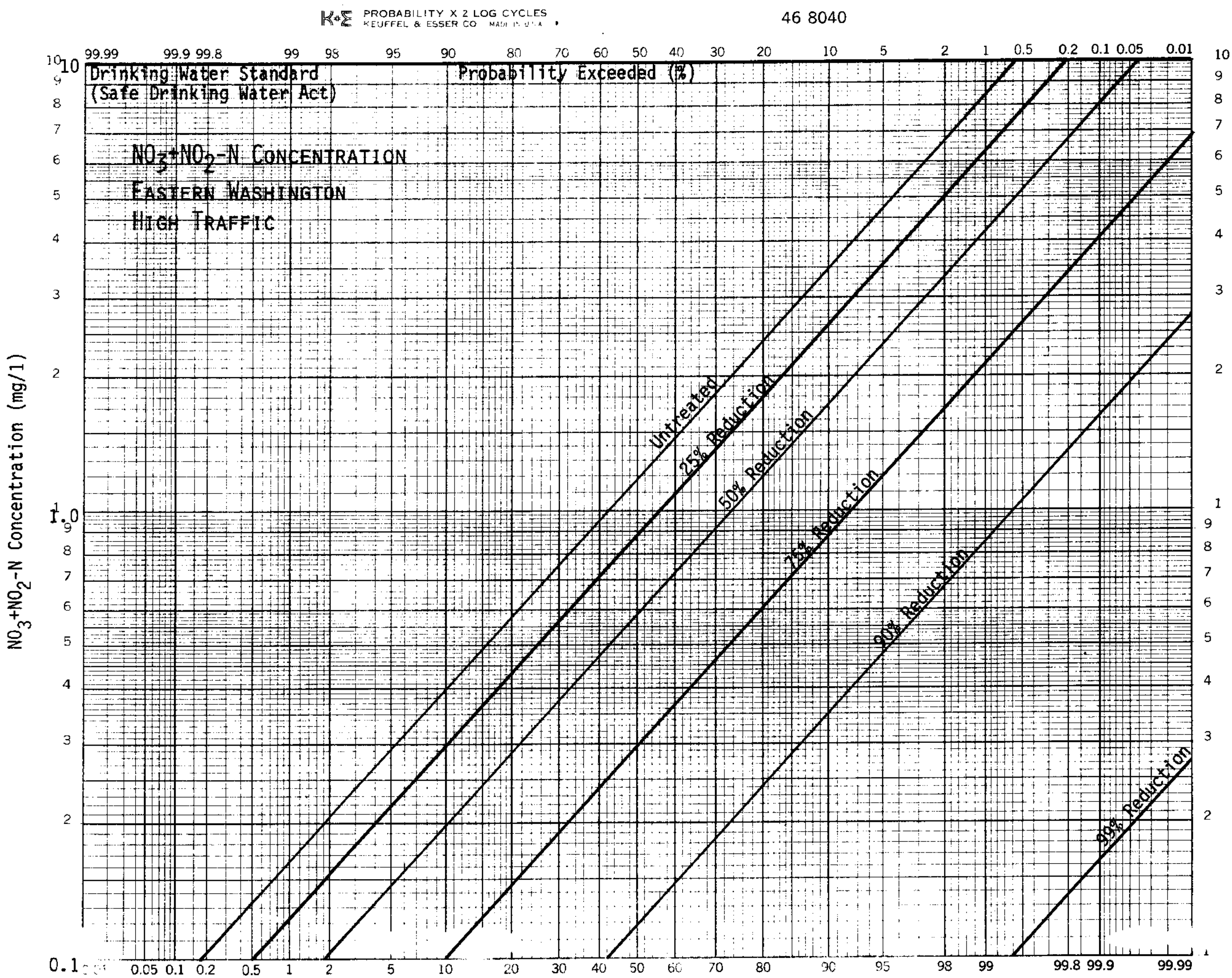

K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
COD CONCENTRATION
EASTERN WASHINGTON
HIGH TRAFFIC
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
COD Concentration (mg/1)



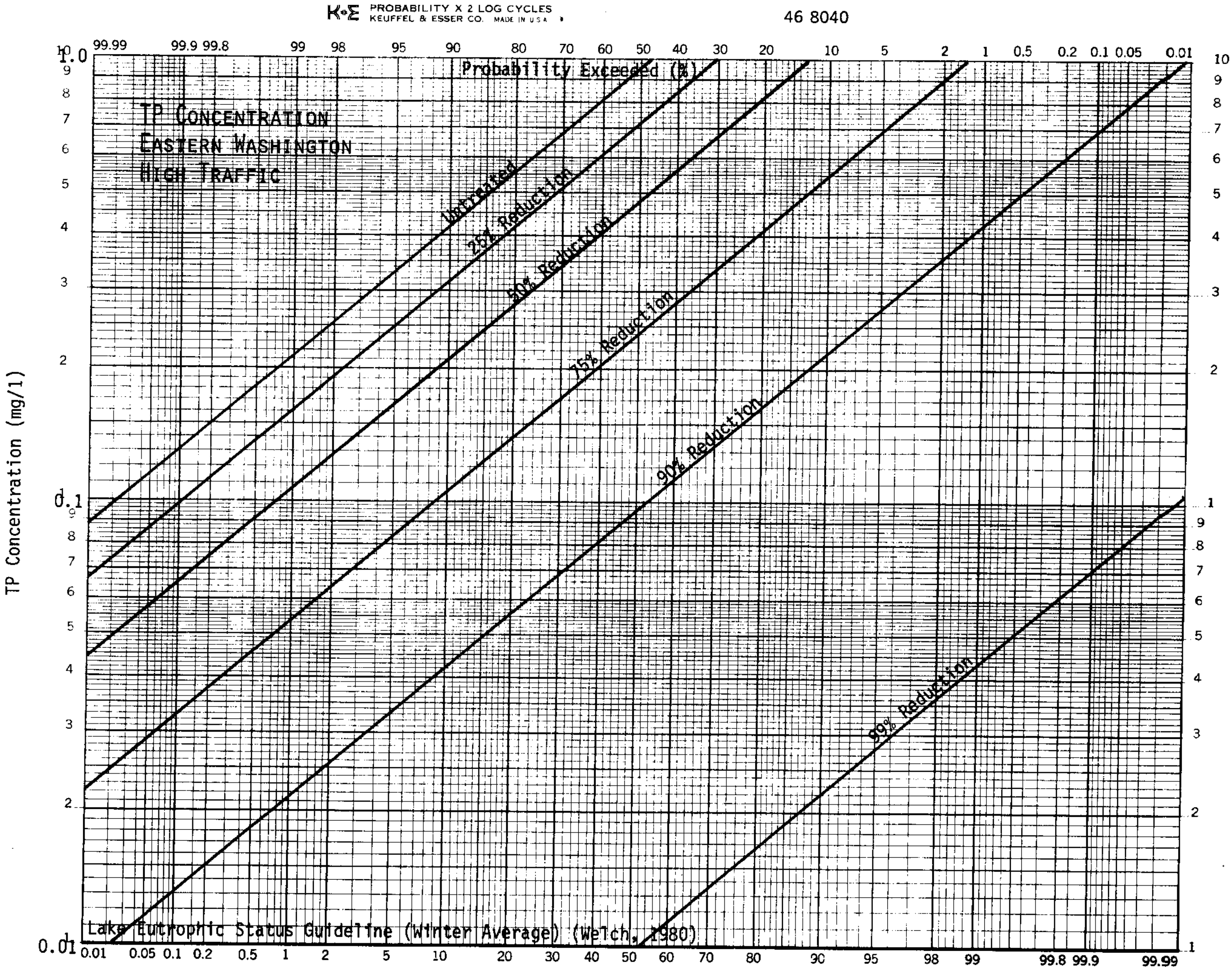
K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
Pb CONCENTRATION
EASTERN WASHINGTON
HIGH TRAFFIC
Pb Concentration (mg/l)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
Aquatic Life Criterion (Maximum),
Total Hardness = 200 mg/l as CaCO3
Aquatic Life Criterion (Maximum),
Total Hardness = 100 mg/l as CaCO3


K+E PROBABILITY X 2 LOG CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
ZN CONCENTRATION
EASTERN WASHINGTON
HIGH TRAFFIC
Public Health Service Drinking Water Guideline
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
Aquatic Life Criterion (Maximum),
Total Hardness = 200 mg/l as CaCO3
Aquatic Life Criterion (Maximum),
Total Hardness = 100 mg/l as CaCO3
Aquatic Life Criterion (Maximum),
Total Hardness = 50 mg/l as CaCO3
Zn Concentration (mg/l)


K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
Public Health Service
Drinking Water Guideline
Cu Concentration
Eastern Washington
High Traffic
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
Aquatic Life Criterion (Maximum),
Total Hardness = 200 mg/1 as $CaCO_3$
Aquatic Life Criterion (Maximum),
Total Hardness = 100 mg/1 as $CaCO_3$
Aquatic Life Criterion (Maximum),
Total Hardness = 50 mg/1 as $CaCO_3$
Cu Concentration (mg/1)
1.0
0.1
0.01



K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO.
46 8040
Drinking Water Standard
(Safe Drinking Water Act)
Probability Exceeded (%)
NO_3+NO_2-N CONCENTRATION
EASTERN WASHINGTON
HIGH TRAFFIC
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
NO_3+NO_2-N Concentration (mg/l)


K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
TP CONCENTRATION
EASTERN WASHINGTON
HIGH TRAFFIC
Probability Exceeded (%)
TP Concentration (mg/l)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
Lake Eutrophic Status Guideline (Winter Average) (Welch, 1980)

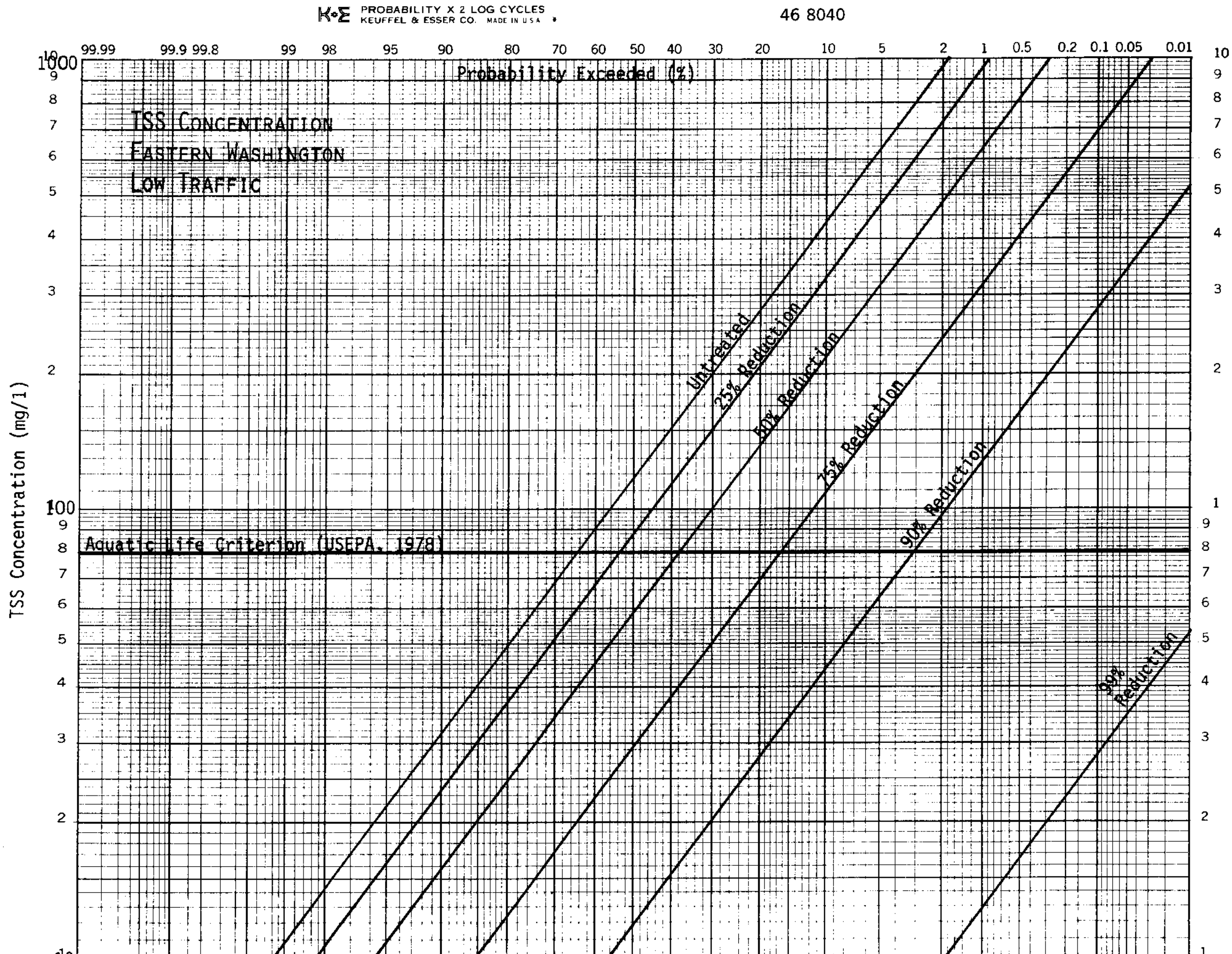
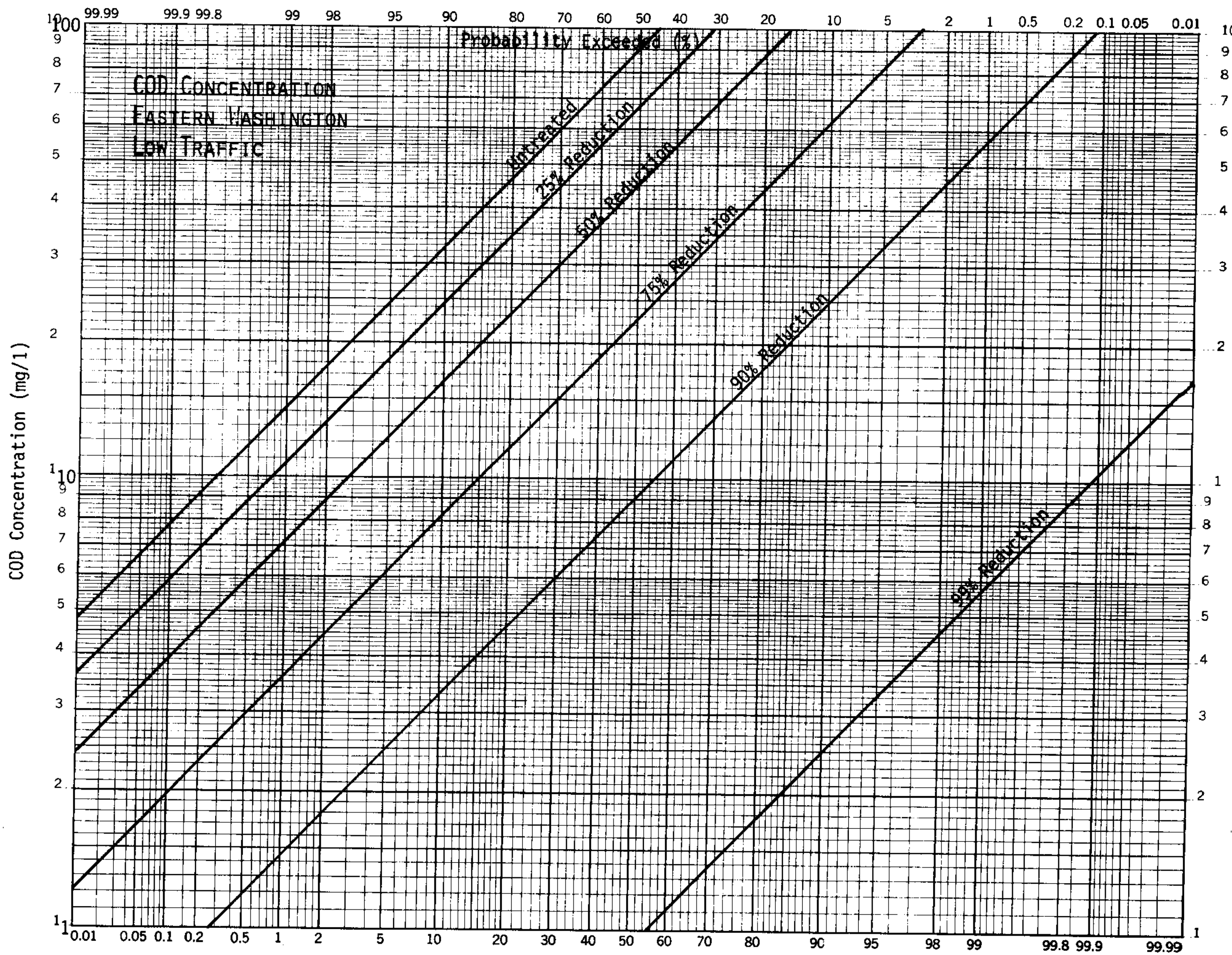
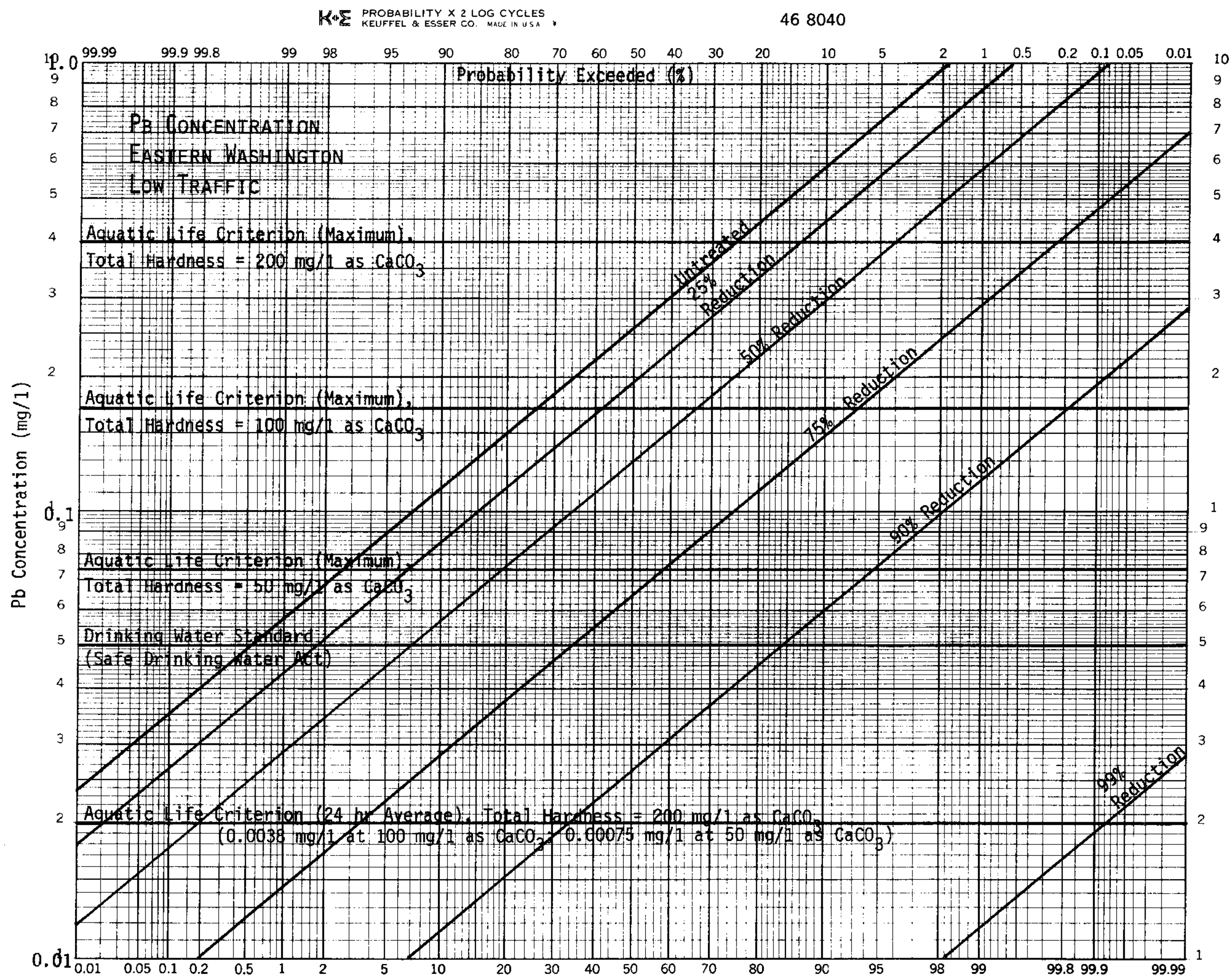
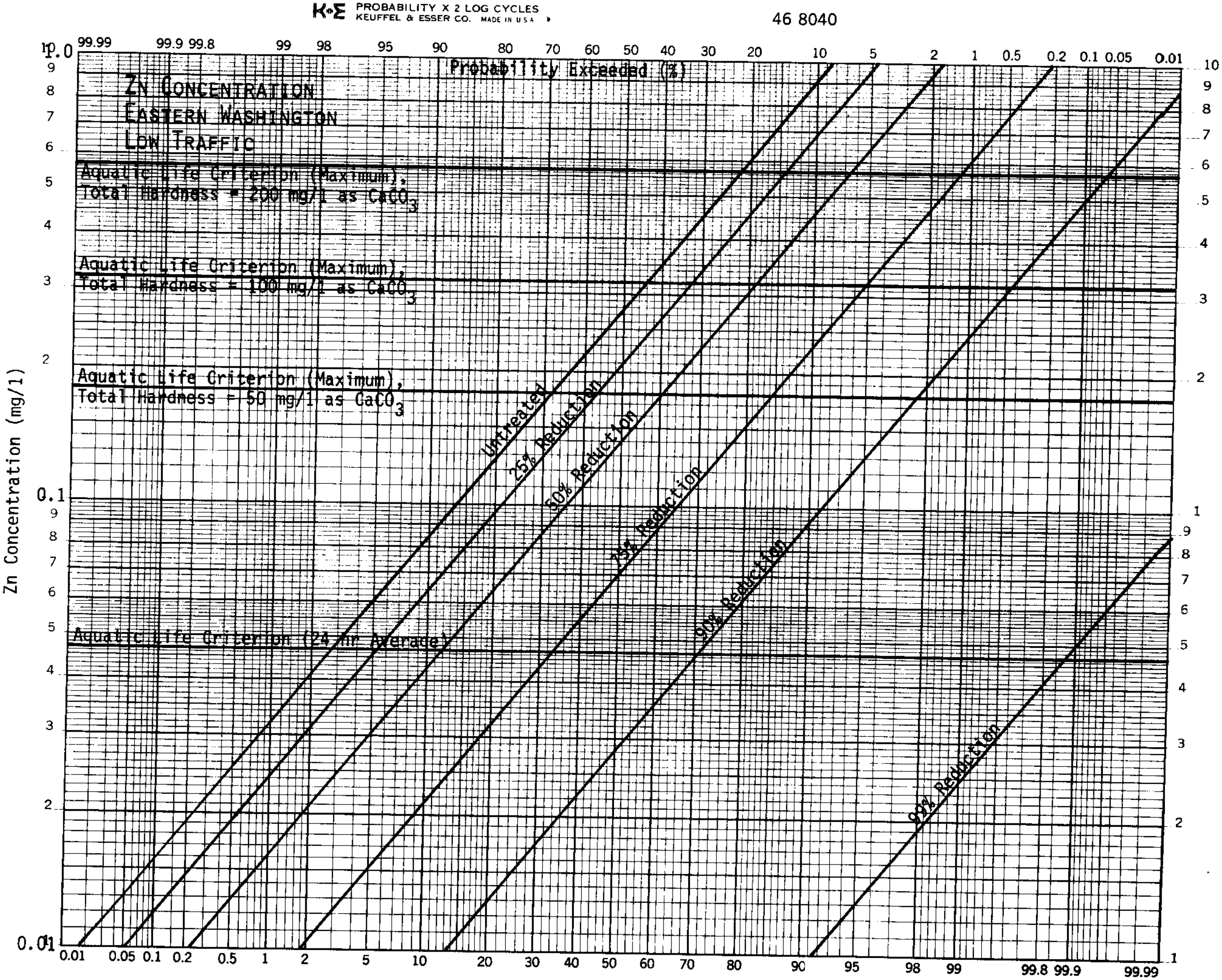


Figure 7. Concentration - Probability Distributions for Eastern Washington; Low Traffic Volume (Continued next 6 pages)

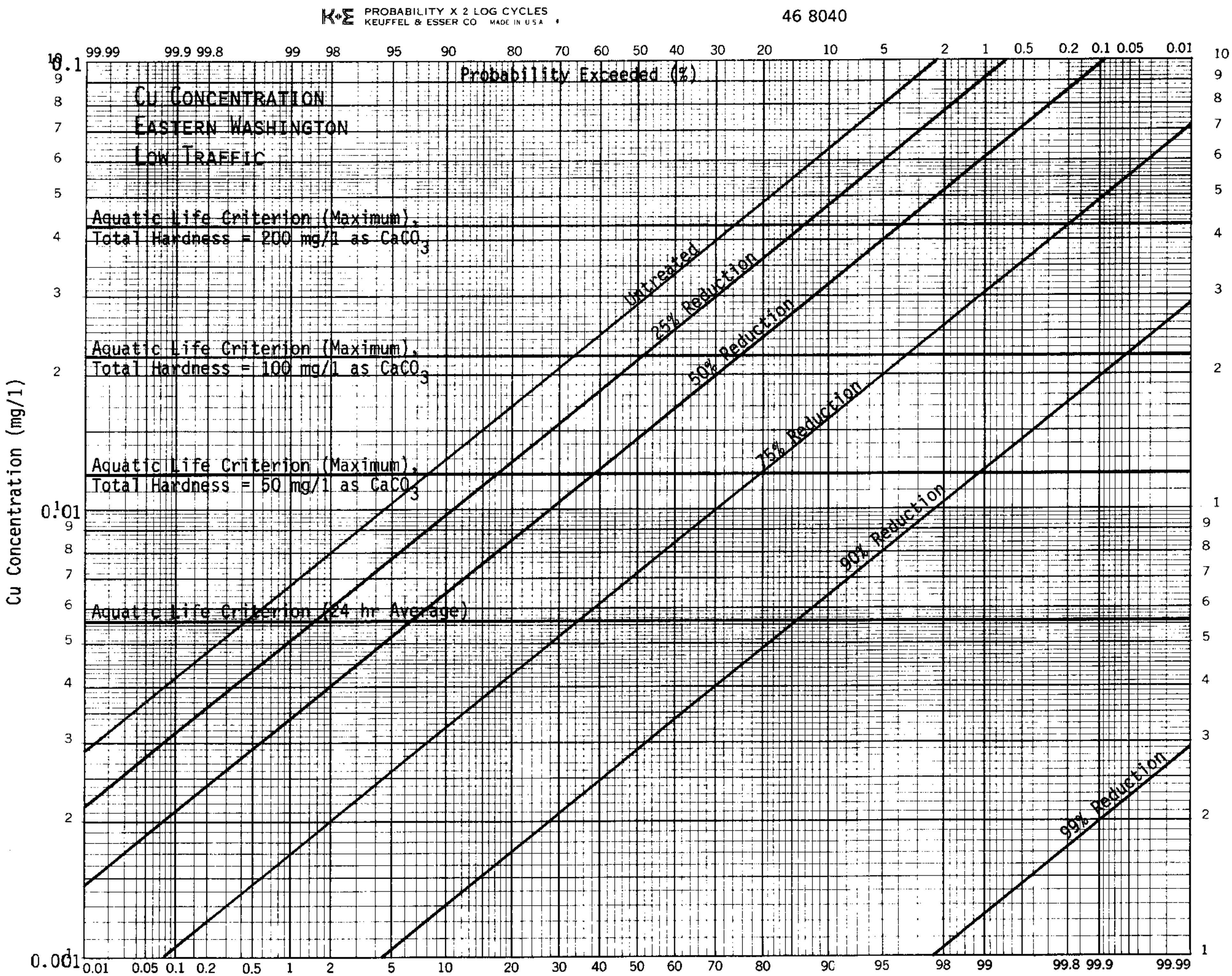
46 8040

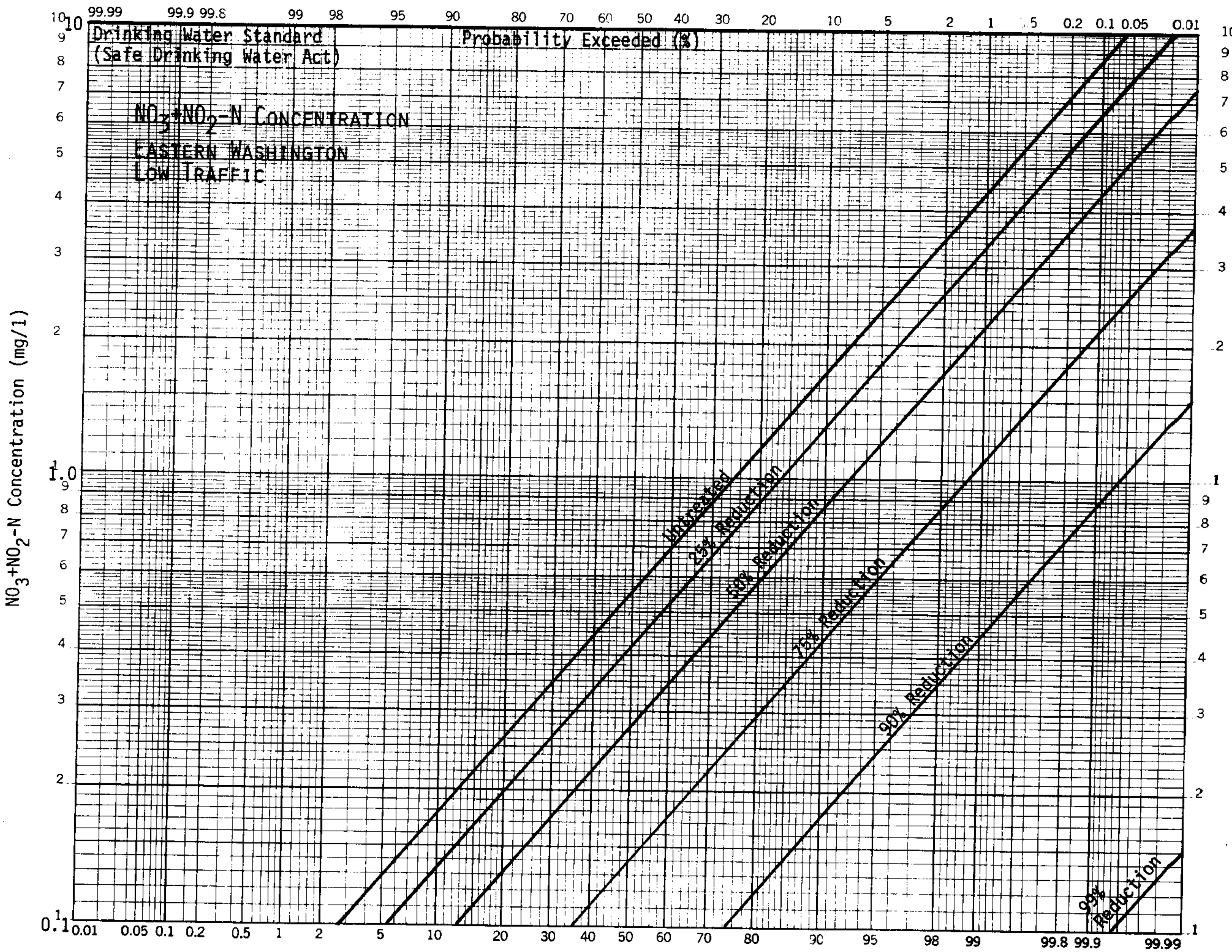

Probability Exceeded (%)
COD Concentration
Eastern Washington
Low Traffic
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
COD Concentration (mg/l)

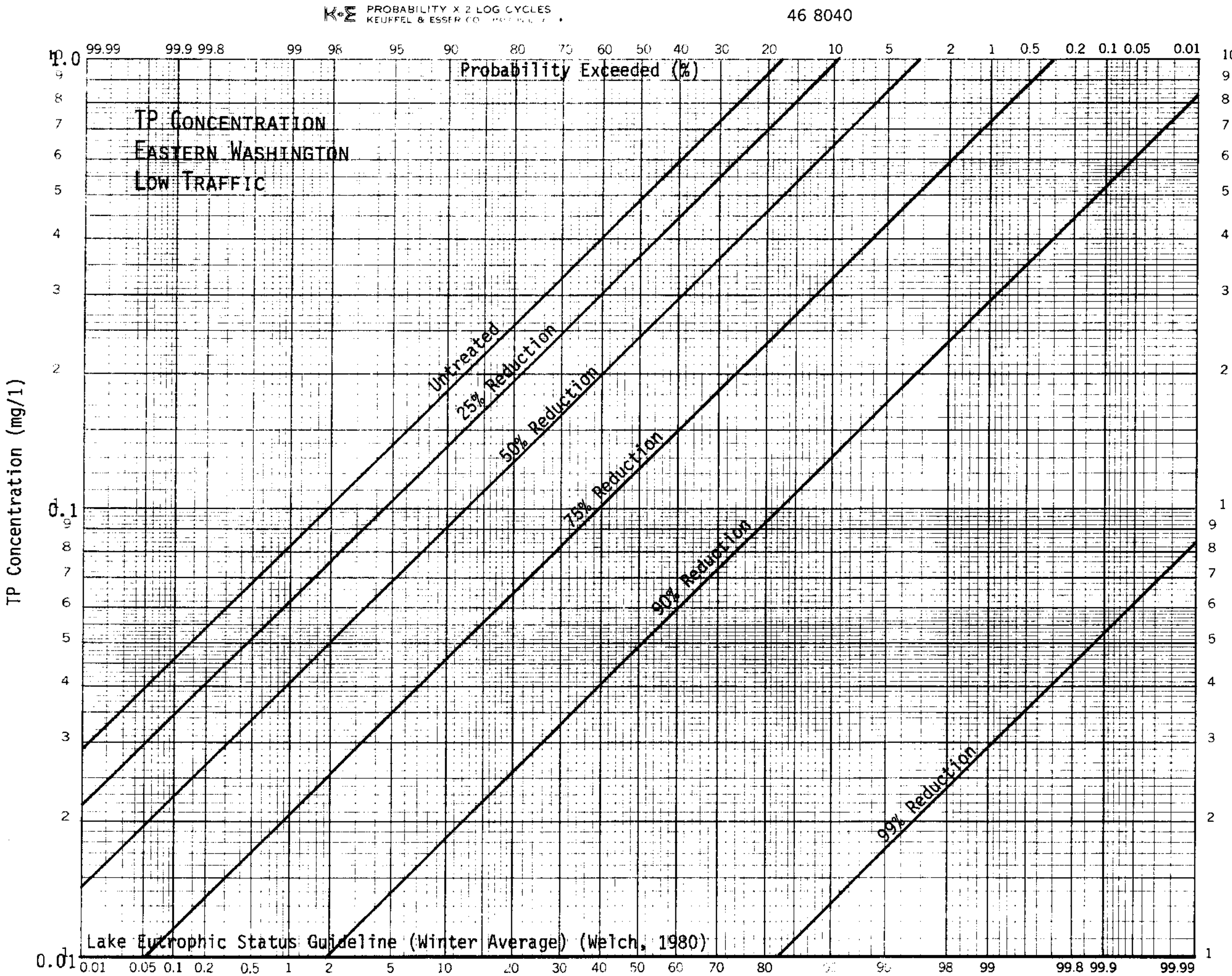

K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Probability Exceeded (%)
Pb CONCENTRATION
EASTERN WASHINGTON
LOW TRAFFIC
Aquatic Life Criterion (Maximum),
Total Hardness = 200 mg/l as $CaCO_3$
Aquatic Life Criterion (Maximum),
Total Hardness = 100 mg/l as $CaCO_3$
Aquatic Life Criterion (Maximum),
Total Hardness = 50 mg/l as $CaCO_3$
Drinking Water Standard
(Safe Drinking Water Act)
Aquatic Life Criterion (24 hr Average), Total Hardness = 200 mg/l as $CaCO_3$
(0.0038 mg/l at 100 mg/l as $CaCO_3$; 0.00075 mg/l at 50 mg/l as $CaCO_3$)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
Pb Concentration (mg/l)
1.0
0.1
0.01



K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8040
Zn Concentration
Eastern Washington
Low Traffic
Probability Exceeded (%)
Zn Concentration (mg/l)
Aquatic Life Criterion (Maximum), Total Hardness = 200 mg/l as $CaCO_3$
Aquatic Life Criterion (Maximum), Total Hardness = 100 mg/l as $CaCO_3$
Aquatic Life Criterion (Maximum), Total Hardness = 50 mg/l as $CaCO_3$
Aquatic Life Criterion (24 hr Average)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction


K+E PROBABILITY X 2 LOG CYCLES KEUFFEL & ESSER CO MADE IN U.S.A.
46 8040
Probability Exceeded (%)
Cu Concentration
Eastern Washington
Low Traffic
Aquatic Life Criterion (Maximum), Total Hardness = 200 mg/l as CaCO3
Aquatic Life Criterion (Maximum), Total Hardness = 100 mg/l as CaCO3
Aquatic Life Criterion (Maximum), Total Hardness = 50 mg/l as CaCO3
Aquatic Life Criterion (24 hr Average)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
Cu Concentration (mg/l)
0.1
0.01
0.001


Drinking Water Standard
(Safe Drinking Water Act)
Probability Exceeded (%)
NO3+NO2-N CONCENTRATION
EASTERN WASHINGTON
LOW TRAFFIC
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
NO3+NO2-N Concentration (mg/1)
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
10 9 8 7 6 5 4 3 2 1.0 9 8 7 6 5 4 3 2 0.1


K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO.
46 8040
Probability Exceeded (%)
TP CONCENTRATION
EASTERN WASHINGTON
LOW TRAFFIC
TP Concentration (mg/1)
Untreated
25% Reduction
50% Reduction
75% Reduction
90% Reduction
99% Reduction
Lake Eutrophic Status Guideline (Winter Average) (Welch, 1980)
1.0
0.1
0.01

<u>Level III</u>

Note: The purpose of Level III analysis is to reconsider cases identified by Level II analysis which may cause significant environmental impacts. It is recommended that these cases be reviewed using the more comprehensive and exact methods outlined and that mitigation measures be considered in more detail if the Level III analysis confirms the likelihood of significant impacts. Conduct a Level III assessment only for the specific problem(s) (quantity, loading or individual storm) identified by Level II analysis as potentially significant.

1.) Runoff quantity assessment (if receiving water is a stream):

   a.) Where Level II analysis has indicated a runoff quantity increase exceeding that permitted under the regulations existing at the location in question, design or redesign detention facilities, using customary departmental procedures. Repeat the assessment as in Level II, step 1, with the revised detention facilities.

2.) Monthly pollutant loading assessment:

   a.) For the month experiencing the greatest number of hr of precipitation, estimate the hours during which the roadway is expected to be wet as equal to the hours of recorded precipitation, using data in Appendix C for the location closest to the proposed construction site (see footnote associated with Level II, step 2.a.

   b.) Estimate the total vehicles passing during storms for the month in question (VDS/mo) as follows:

$$\text{VDS/mo} = \text{ADT}\left(\frac{\text{wet hr/mo}}{\text{24 hr/day}}\right)$$

   c.) Estimate highway runoff TSS loading for the month in question according to:

$$\text{TSS (lb/highway-mi/mo)} = (K)\left(\frac{\text{VDS/mo}}{1000}\right)(C)$$

   where: K and C are as defined in Level II, step 2.c.

   d.) Express highway loadings (L_H) for TSS in kg/mo for the month in question by multiplying by the number of highway-mi.

e.) If a mitigation device such as a detention basin is provided, reduce the TSS loading according to the solids removal capability of the device. If highway runoff is discharged to receiving water via a vegetated drainage course, multiply the estimated TSS loading by the appropriate fraction, as follows (after Wang, 1981). Interpolate as necessary.

Length of Vegetated Drainage Course (ft)	Fraction of Pollutant Remaining
< 30	1
31- 60	0.50
61- 90	0.40
91-120	0.30
121-150	0.26
151-180	0.23
≥ 180	0.20

Use the modified TSS loading in further calculations.

f.) Estimate annual highway loadings of other pollutants from:

$$\text{Loading (lb/yr)} = (K_p)(\text{TSS Loading})$$

where: K_p = ratio of pollutant P to TSS (Table 2)
TSS Loading is estimate from step 2.d. or 2.e.

g.) If the receiving water is a stream and if a comprehensive water quality record exists for the stream, proceed to step 2.h. Otherwise, go to step 2.i.

h.) Estimate the mean monthly loading for the month in question of each pollutant transported by the stream prior to the presence of the highway (L_S, lb/mo) according to:

$$L_{\overline{S}} = 1965\ \overline{Q}_S \overline{C}_S$$

where: $\overline{Q}_S$ and $\overline{C}_S$ are average quantities for the month in question (otherwise as in Level II, step 2.h.)
Go to step 2.p.

i.) Determine annual areal loading (lb/acre/yr) of each contaminant for each land use in the receiving water basin from local data, if they exist, or Table 4. Where a range is given, use the lower value if a conservative estimate of highway

Table 4: Storm Runoff Pollutant Loadings for Specific Land Use Categories

Land Use	Loading (lb/acre/yr)							
	TSS	COD	Pb	Zn	Cu	NO_3+NO_2-N	TKN	TP
Central Business District	964	955	6.3	2.7	1.9	4.0	13	2.5
Other Commercial	750	906	2.7	2.9	N/A	0.6	13	2.4
Industrial	50	56	1.8 - 6.3	3.1 - 11	0.3 - 1.0	0.4	2 - 13	0.8 - 3.6
Single-Family Residential	15	25	0.1	0.2	0.03	0.3	1 - 5	0.2 - 1.3
Multiple-Family Residential	390	297	0.6	0.3	0.3	3.4	3 - 4	1.2 - 1.4
Cropland	402	N/A	0.004 - 0.005	0.03 - 0.07	0.01 - 0.05	7.0	1.5	0.3
Pasture	306	N/A	0.003 - 0.013	0.02 - 0.15	0.02 - 0.04	0.3	0.6	0.06
Forested	76	N/A	0.01 - 0.03	0.01 - 0.03	0.02 - 0.03	0.5	2.6	0.08
Open	6	1.8	N/A	N/A	N/A	0.3	1.5	0.06

Notes: (1) Means given where available; otherwise ranges are reported. See Note 1 in Table 3 for references.

(2) N/A -- Not available.

contribution to total loading is desired; otherwise, use the midpoint of the range.

j.) Approximate the proportion of each annual areal loading delivered during the month in question according to:

$$\text{lb/acre/mo} = \left(\frac{\text{hr precipitation during the month}}{\text{annual hr precipitation}}\right)(\text{lb/acre/yr})$$

k.) Determine the areas (in acres) in Central Business District, Other Commercial, Industrial, Single-Family Residential, Multiple-Family Residential, Cropland, Pasture, Forested and Open land uses in the watershed draining to the highway runoff discharge point located farthest downstream. If it is projected by the planning agency for the location that development will modify land uses substantially in coming years, conduct the analysis for both present and ultimate land uses.

l.) Multiply loadings in lb/acre/mo by the respective areas to obtain loadings for the month in question for each land use (L_{L_i}). Then sum over all land uses for each pollutant (ΣL_{L_i}).

m.) If the receiving water is a stream, proceed to step 2.n. If the receiving water is a lake or wetland, go to step 2.q.

n.) Estimate point source loadings (L_p) of each pollutant as follows:

$$L_p \text{ (lb/mo)} = 1965\ Q_p C_p$$

where: Q_p and C_p are monthly quantities for the month in question (otherwise as in Level II, step 2.m.)

o.) Estimate total stream loadings prior to highway presence (L_S) as:

$$L_S = \Sigma L_{L_i} + L_p$$

p.) Express the impact on stream pollutant loadings in terms of the estimated increase due to highway runoff (L_H) as a percentage of the original stream loading (L_S). If in the judgment of the impact analyst the evidence accumulated through Level II and III analyses indicates the impact may be excessive, mitigation should be further considered. An individual storm event loading assessment procedure is included (Level III, step 3) to aid in designing pollution control facilities. If the stream eventually discharges to a lake or wetland, also evaluate the impact on that water body according to steps 2.q. and 2.r. Otherwise, go to step 3 (if necessary) or step 4.

q.) If the immediate or eventual receiving water is a lake or wetland, estimate total loadings for the month in question prior to the highway presence (L_{La}) as equal to ΣL_{Li} plus any point source loading (1965 Q_pC_p). Express and evaluate the impact on wetland pollutant loadings as in step 2.p.

r.) If the immediate or eventual receiving water is a lake, conduct a special analysis to assess the potential impact of phosphorus loading on trophic state as follows:

(1) Convert L_H and L_{La} to kg/mo by dividing by 2.2 lb/kg.

(2) Estimate annual loadings from the monthly loadings found previously by proportion (for both L_H and $\Sigma L_{L_i} + L_B$):

$$\text{Kg/yr} = \left(\frac{\text{annual hr precipitation}}{\text{hr precipitation during the month}}\right)(\text{Kg/mo})$$

(3) Carry out steps (2) to (4) under Level II, step 2.q.

(4) If the highway loading addition does not move the status point near or into a higher trophic category, declare minimal impact on lake eutrophication and analyze impacts associated with maintenance or special problem areas (Section IV). If a substantial impact on trophic state appears likely, mitigation should be further considered (see step 3).

3.) Individual storm event loading assessment:

Note: The available data are not sufficient at this point to support a Level III individual storm event concentration assessment. The following loading assessment procedure is included to provide a basis for the design of detention and other mitigation devices. A specific probability of occurrence may be selected as a design basis and the associated loading used to select and design facilities.

a.) Select a probability on which to base design (for example, the control device should be designed for the loading exceeded in only ten percent of the storms).

b.) For the design probability, location, and traffic level, determine the design TSS loading (lb/highway-mi) by referring to Figure 8 or 9 (for definition of traffic levels, see footnote associated with Level II, step 3.f.).

c.) Multiply by highway-mi to obtain total mass loading.

d.) Calculate the design loadings of other pollutants by multiplying by the ratios from Table 2.

e.) Using the estimated loadings and design storm and customary departmental procedures, design the control device.

f.) With the control device included in the analysis, repeat the portion of the assessment which indicated an unacceptable water quality impact (Level II, step 3 for pollutant concentrations or Level III, step 2 for pollutant loadings) to insure that the impact will be reduced to an acceptable level.

4.) Analyze impacts associated with the particular maintenance practices anticipated or any special problem areas (see Section IV).

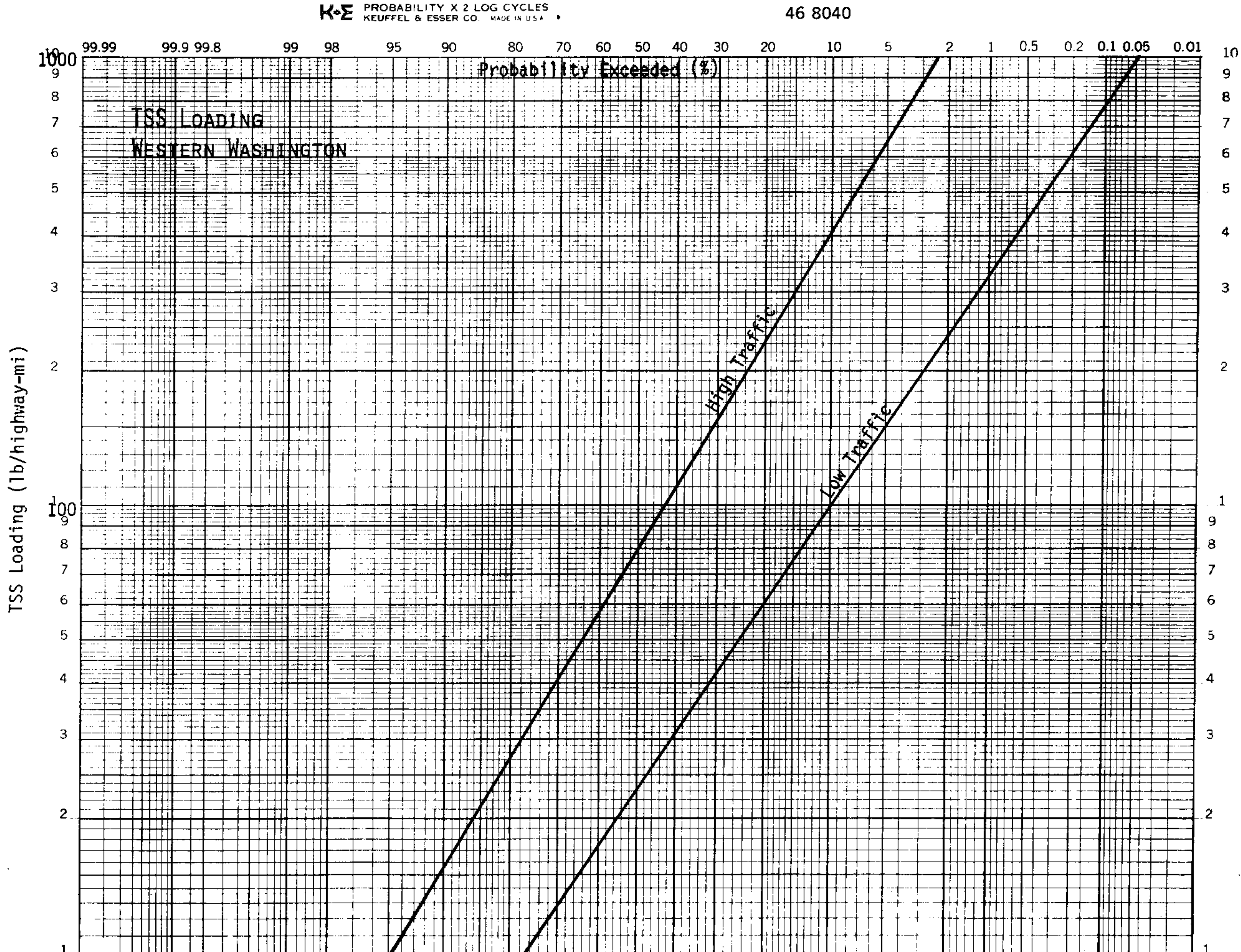


Figure 8. TSS Loading - Probability Distribution for Western Washington

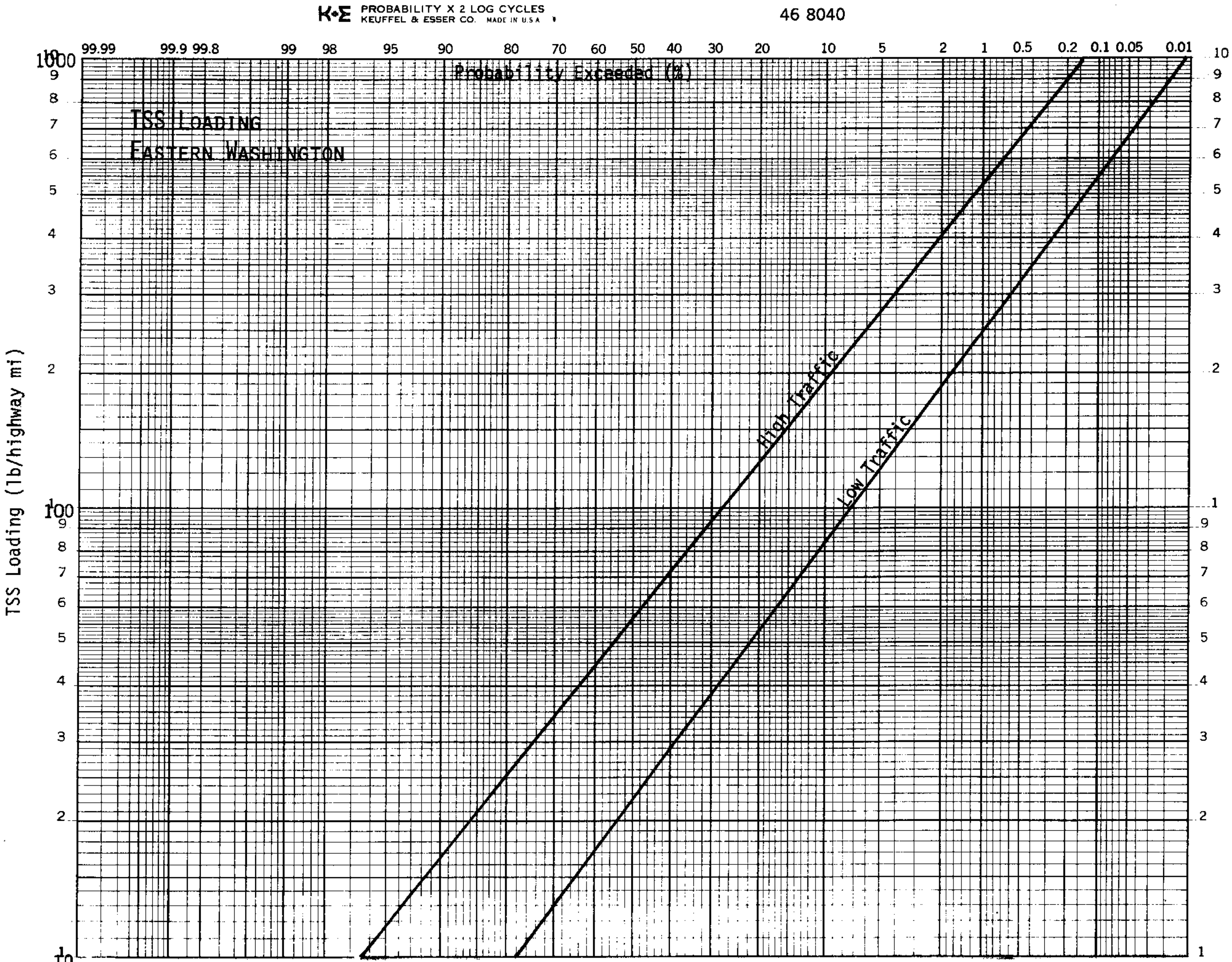


Figure 9. TSS Loading Probability Distributions for Eastern Washington

IV. ASSESSMENT OF IMPACTS ASSOCIATED WITH MAINTENANCE PRACTICES AND SPECIAL PROBLEMS

This section covers impact assessment under highway operating conditions which may differ from time-to-time or district-to-district within Washington State or which are somewhat out of the ordinary. In projects where they apply, these conditions must be evaluated in addition to the general case detailed in the preceding section and their expected impacts added to those previously estimated.

Sanding

Sand applied to the roadway for winter operations is biologically and chemically stable. The total amount applied may eventually contribute to the solids loading on the receiving water. Smaller particles can be transported by the runoff water as part of the suspended solids, and larger particles can be pulverized by traffic and then suspended in the runoff. The following factors reduce the fraction of applied sand entering the drainage system:

1.) Larger particle sizes and/or denser particles (if removed from the traffic lanes before pulverized).
2.) A period between application and the first extensive runoff, during which traffic-generated winds can remove particles from the highway.
3.) Plowing which throws sand particles to the side before melting and runoff occur.
4.) Sweeping which cleans the shoulder and avoids any chance of accumulated material in the larger size fractions being carried along with runoff from a heavy storm.

One approach to sanding impact assessment is to estimate a typical winter's usage (lb/yr) from the expected number of storms and prevailing lane-mile application rates and assume the entire quantity drains from the highway as TSS. If runoff discharges via a vegetated drainage course or other mitigation measures are provided, modify the loading as described in Section III. Then add the sanding TSS load to that from normal operations, as estimated by Level II or III methods. This total loading should then be evaluated in the context of TSS loads from all land uses, also as outlined in Section III.

Another approach would be to estimate the reduction in runoff loading likely to result from selection of particle size and density, plowing, and sweeping. Only the remaining sanding load would then be added to that from normal operations. Estimating the reduction due to the various factors would be difficult and subject to judgment but would be warranted when the sand characteristics and maintenance procedures are well-established. With plowing, it is likely that most of the sand will be removed prior to runoff. Therefore, when regular plowing is anticipated, the sanding contribution to TSS loading can be considered small and neglected. When sweeping is anticipated, it may be possible for maintenance personnel to estimate the quantity recovered by sweeping according to records on the number of truck loads removed. The TSS loading in runoff would then be estimated as the difference between application and removal.

The research demonstrated that the ratios of other pollutants to TSS associated with sanding were equal to those reported in Table 2 at the high traffic sites. With lower traffic, pollutant deposition failed to saturate the solids due to sanding, and the ratios were substantially lower on a cumulative basis (Asplund, 1980). It is thus recommended that the loadings of other pollutants be established according to the procedures given in Section III when ADT is projected to exceed 10,000. With lower traffic, the assessment should reflect the elevated TSS loading due to sanding but should not augment the loadings of other pollutants in proportion to the TSS resulting from sanding.

Deicing

Deicing salts have a number of potential environmental impacts, including degradation of drinking water supplies, stress on the aquatic ecosystem created by chlorides and anti-caking ingredients, density stratification of lakes, damage to roadside vegetation and corrosive damage to metals. Because of these effects, avoiding the use of salt is recommended whenever possible. WSDOT has followed this policy in recent years. Sand-salt mixtures are still used and vary considerably within the state. In District 1, for instance these mixtures contain 20-25 percent salt (WSDOT, 1982). On the other hand, many roads do not receive any salt.

The deicing material most frequently used in Washington State is sodium chloride. The average total application rate in recent winters on the Spokane viaduct has been 12.89 tons/lane-mi, whereas an average of 43.46 tons/lane-mi had been used in 1980-81 and previous winters on I-90 at Snoqualmie Pass (Wieman, personal communication). During the 1981-82 winter pelletized urea and isopropyl alcohol were used as deicing agents on I-90 in the Snoqualmie Pass area (WSDOT, 1982). Oxidation products of urea, principally ammonia and nitrate, could create water quality impacts.

Road salt purchased by WSDOT is treated by the supplier with sodium ferrocyanide at 200 ppm by weight to prevent caking (Forman, personal communication).

For the evaluation of water quality impacts where winter maintenance will employ salt, the EPA (1978) Draft Guidelines require the following:

> ...data on chloride concentrations in surface and groundwaters with analysis of the seasonal variation in levels. If data are available, the trends in chloride levels should be presented and correlated to trends in quantities of deicing salt used in the drainage basin. Sodium and chloride data on municipal and well water supplies in the vicinity of the proposed highway should be presented in the EIS if the maintenance program includes plans for significant salt application. The EIS should also summarize or include by reference the results of any published study on the salinity of the impacted receiving waters or the water quality effects of highway deicing in the drainage basin. Finally, the EIS should describe the extent to which the plans for highway deicing conform to state and local non-point source regulations and regional or local water quality plans.

As soluble but chemically and biologically stable compounds, sodium chloride and sodium ferrocyanide quantities must be regarded as likely to enter the runoff. Some would probably be sprayed from the highway by passing traffic, but the amount removed in this way is unpredictable.

No modeling of deicing salt runoff was undertaken during this project. The U.S. Geological Survey (Frost et al., 1981), in cooperation with the Massachusetts Department of Public Works, conducted a five-year investigation to develop methods of estimating annual mean and maximum chloride and sodium concentrations and loadings in streams receiving highway runoff. The data were analyzed using multiple and simple linear regression techniques. Table 5 summarizes the resulting relationships.

The estimates can be used to express deicing impacts and, when it appears necessary, to guide mitigation strategy. Specific chloride and sodium criteria have not been promulgated for public water supplies and aquatic life. It has been recommended (U.S. Environmental Protection Agency, 1973) that

Table 5: Regression Equations for Estimating Chloride and Sodium Concentrations and Loadings (from Frost et al., 1981)

$$MEAN\_CL = -0.94 + 1.22 \times \frac{SALT\_APP}{ANAVFLOW} + 0.06\ SLOPE$$

R = 0.91 SE 3.3 mg/L

$$MAX\_CL = 26.1 + 2.1 \times \frac{SALT\_APP}{ANAVFLOW} - 3.2 \times STORAGE$$

R = 0.76 SE = 12 mg/L

$$CL\_LOAD = -37.8 + 50.0\ STORAGE + 0.816\ SALT\_APP$$

R = 0.93 SE = 90 tons

$$MEAN\_NA = 5.13 + 0.483 \times CONCSALT$$

R = 0.90 SE = 1.9 mg/L

$$MAX\_NA = 11.0 + 1.02 \times CONCSALT$$

R = 0.90 SE = 4.0 mg/L

$$NA\_LOAD = -36.4 + 14.9\ STORAGE + 1.02\ SALT\_APP$$

R = 0.98 SE = 26 tons

where:

R	Multiple correlation coefficient.
SE	Standard error of estimate.
MEAN_CL	Annual average of daily mean chloride concentrations (mg/L).
MAX_CL	Annual maximum of daily mean chloride concentrations (mg/L).
CL_LOAD (tons/day)	Annual sum of daily values of chloride concentrations (mg/L) x discharge (ft^3/s) x 0.0027.
MEAN_NA	Annual average of daily mean sodium concentrations (mg/L).
MAX_NA	Annual maximum of daily mean sodium concentrations (mg/L).
NA_LOAD (tons/day)	Annual sum of daily values of sodium concentration (mg/L) x discharge (ft^3/s) x 0.0027.
SALT_APP	Annual sum of tons of NaCl applied to roadways in the basin.
SLOPE	Slope of main channel, in feet per mile, between points 10 percent and 85 percent along the stream from discharge point to the topographic divide.
STORAGE	Area of lakes and ponds expressed as a percentage of the drainage area plus 0.5 percent.
ANAVFLOW	Annual mean rate of water discharge (ft^3/s); flood with recurrence interval 2.33yr
CONCSALT	SALT_APP divided by ANAVFLOW.

chloride in drinking water not exceed 250 mg/1 on the basis of taste considerations. McKee and Wolf (1963) reported that 95 percent of U.S. waters sustaining good fish life had less than 170 mg/1 of chloride. Natural salinity is generally relatively low in Washington State waters, and aquatic life is adapted to such conditions. Thus, a large increase in chloride due to deicing salt runoff would be of special concern in ecologically sensitive waters of the state. The U.S. Environmental Protection Agency (1973) reported that individuals on sodium-restricted diets are permitted no more than 20 mg/1 of sodium in drinking water but recommended no limit for public water supplies.

Pesticides

The application of pesticides to roadside vegetation must be selective because of their potential to adversely impact receiving water biota and beneficial uses and the possible destruction of vegetation which is capable of treating runoff water. Pesticides can impact aquatic life through acute toxicity and chronic effects resulting from bioaccumulation. The persistence of pesticides in the environment varies because of differing volatilities and rates of degradation.

The impact analyst should work closely with maintenance personnel to determine pesticide treatments anticipated at the site in question. The assessment should report pesticide types, quantities and application frequencies and provide data on LC_{50}'s and U.S. Department of Agriculture toxicity ratings if available. The assessment should also evaluate the potential for transport to receiving water. It should be kept in mind and pointed out if applicable that the organic compounds in question are effectively adsorbed by solids. Thus, vegetated drainage courses can remove pesticides, along with solids, as runoff passes through, unless a particular herbicide would destroy or prevent grass growth.

Highway Sections on Woodwaste Fill

As part of the WSDOT/UW research an extensive literature review, laboratory column studies and field observations on woodwaste fills were completed to establish the water quality impacts of this construction technique. Vause (1980) reported the details of these efforts, and Vause et al. (1980) summarized the findings.

The data indicated that pollutants were released by physical leaching of wood extracts and that microbial fermentation was of secondary importance. The ultimate pollutant releases measured were:

BOD -- 30 $\pm$ 8 lb/ton dry solids

COD -- 80 $\pm$ 20 lb/ton dry solids

TOC -- 20 $\pm$ 5 lb/ton dry solids

It was found that pollutants were released exponentially with time and that discharges were negligible after one year of soaking. The above values may thus be used as an approximation of maximum annual loadings for the first year after construction. Loadings to receiving waters would be reduced by any dilution or removal in the drainage system prior to entrance into the water body.

The total annual (or monthly for Level III) COD loading estimated from these results should be added to that computed for general operations and evaluated as indicated in Section III.

Pollutant concentrations were also determined during the research. Peak measured concentrations were:

	Leachate Underdrain Outfall	Seep
BOD (mg/1)	670	1590
COD (mg/1)	1830*	4220

*2920 in laboratory column simulating intermittent rainfall infiltration.

Underdrain BOD concentrations required approximately 180 days to decline to relatively stable low concentrations, while seep (slowly leaching) concentrations required about 100 days longer. Except in the intermittent rainfall experiment, outfall COD concentrations reached low, rather stable values in 60 to 180 days. As with BOD, seep COD concentrations required about 280 days to reach a low level. TSS concentrations were uniformly low, approximately 15 mg/1.

Receiving stream, lake, or wetland concentrations during the leaching period can be estimated according to a mass balance procedure in order to assess the leachate impact and, if necessary, guide the development of a mitigation strategy. The equations to make this estimate are:

Stream -- $C_S' = \dfrac{QC + \overline{Q}_S\overline{C}_S}{Q + \overline{Q}_S}$

where: All quantities are as defined in Level II, step 3, except Q and C apply to woodwaste fill leachate rather than highway runoff

Lake or wetland -- $\overline{C}_{La} = \overline{C}_{in} + (\overline{C}_o - \overline{C}_{in})e^{-(\overline{Q}_{in}/V)t}$

where: $\overline{C}_{La}$ = mean equilibrium lake or wetland pollutant concentration (mg/l)

$\overline{C}_{in}$ = mean inflow pollutant concentration (mg/l)

$\overline{C}_{in} = (QC + \Sigma\,\overline{Q}_S\overline{C}_S\ /(Q + \Sigma\overline{Q}_S)$

(Σ indicates summation of all tributary inflows)

$\overline{C}_o$ = mean lake or wetland pollutant concentration prior to discharge of woodwaste fill leachate (mg/l)

e = base of natural logarithms

$\overline{Q}_{in}$ = mean total surface inflow of water (any volume/unit time units consistent with volume units)

V = lake or wetland water volume (any consistent volume units)

t = time of leachate discharge (any consistent time units)

Note: The equation given is the solution of a differential equation for mixed reactor with flushing, $d\overline{C}_{La}/dt = \overline{Q}_{in}\ V(\overline{C}_{in} - \overline{C}_L)$, with an initial condition $\overline{C}_L = \overline{C}_o$ at $t = 0$.

Several steps may be taken to reduce water quality impacts of woodwaste fills. First, pre-soaking of the woodwaste prior to placement or the use of old, weathered material would reduce leachate pollution. Secondly, the fill should be designed to reduce the entrance of water which would become contaminated leachate. Further, discharge of leachate in high volumes of dilution water would reduce its environmental impact. Finally, leachate could be treated.

Accidental Spills

The assessment should develop projections of the number, types and volumes of spills, working from records on similar highways. It should further outline a hazardous spill management plan that will minimize accident-related water impacts. An important element of this plan should be consideration of the construction of holding basins where ecologically sensitive waters are proximate to the highway. The impact analyst should consult Eagen (1980) and Andrews et al. (1981) for data helpful in developing projections and a more complete discussion of spill management.

Involvement with Groundwater

A key recommendation arising from the WSDOT/UW research is drainage of highway runoff over vegetated drainage courses whenever possible. Studies have shown (Wang, 1981) that pollutants captured in such channels in Western Washington soils and vegetation are effectively held in the upper soil horizons. There is less assurance that treatment of the runoff and soil retention would be as complete with the more meager vegetation and more porous soils of Eastern Washington. There surface receiving waters are scarce, and most storm runoff is directed off the pavement where it percolates through the soil. Extensive aquifers underlie Eastern Washington and are the source of most potable water.

The federal Safe Drinking Water Act requires additional specific information when federally funded construction is to occur in an area overlying an EPA-designated sole-source aquifer (when the aquifer serves as the sole or principal drinking water source for the area). The Spokane Valley and Whidbey and Camano Islands have been so designated in Washington State. The environmental impact statement documenting a project in such a region must contain the information noted in Table 6, in addition to that assembled for general assessment purposes, as listed in Table 1. Table 7 stipulates the analysis that must be conducted in this case (U.S. Environmental Protection Agency, 1977).

In conducting this analysis, loading estimates can be made according to the procedures previously outlined for surface receiving waters. Much as before, these loadings should be assessed in the context of those from all land uses in the recharge area. With present knowledge, it is not possible to predict at all accurately the proportion of the total loadings which actually enters groundwater. It can be said that the soils should act like a sand filter and remove the majority of the solids and the pollutants associated with them, unless the water table is very close to the surface. Removal of

Table 6: Outline of Specific Information Required for Groundwater Impact Evaluations in Sole-Source Aquifer Regions (U.S. Environmental Protection Agency, 1977).

Geologic Characteristics

- Location and extent of aquifer recharge and streamflow source zones in relation to project site (maps and description)
- Dimensions of aquifer (area, thickness, and variations)
- Hydraulic boundaries, including discontinuities, location, and extent of horizontal and vertical confining materials, and perched water tables
- Description of water-bearing formations (consolidated or unconsolidated, general proportions of clay, silt, sand, and gravel)
- Permeability of aquifer materials in project area

Hydrologic Characteristics

- Average annual precipitation and average annual recharge estimates
- Depth to water table in project area (especially where excavations will be required), including seasonal variations, if significant
- Magnitude and direction of hydraulic gradient in sufficient detail to estimate general direction of ground-water movement at project site and adjacent areas

Physiographic Characteristics

- Topography of project area
- Drainage patterns, including location of perennial and/or ephemeral streams relative to project site

Soil Characteristics

- Soil types (SCS maps or unpublished data) in project area
- Soil classifications (textural characteristics, particularly silt and clay content)
- Infiltration and transmission capacity of soils in the project area (e.g., SCS hydrologic soil groups)

Land Use/Cultural Characteristics

- Location of major producing and known abandoned wells in the project area, and effects on hydraulic gradient
- Land uses, including type, development densities, and vegetative cover at project site and in project area
- Local and regional land use plans and regulations affecting development in project area or entire aquifer recharge zone

Project Characteristics

- Type, alignment, and size of improvement (number of lanes, corridor dimensions, and impervious surface area)
- Location and magnitude of excavation and fill areas
- Expected traffic volume and mix
- Description of highway drainage facilities and provisions
- Probable maintenance practices with respect to storage and use of deicing chemicals, petroleum products, pesticides, and other chemicals

dissolved substances, NO_3+NO_2-N being of most concern, would not be expected to be nearly as effective. Measured concentrations in highway runoff have remained below the 10 mg/l drinking water standard for NO_3-N, however (Asplund, 1980; Chui, 1981). Thus, even if untreated by the soil, nitrate in Washington State highway runoff should not endanger aquifers. Should a situation arise in which highway runoff would be drained over thin, porous soils in the recharge area of an EPA-designated sole-source aquifer, it would be possible to gain insurance by engineering a channel containing more adsorbent soils and more profuse vegetation than naturally present.

Table 7: Outline of Impact Analyses Required for Projects in Sole-Source Aquifer Regions (U.S. Environmental Protection Agency, 1977).

- Estimation of effect on ground-water recharge and ground-water levels caused by highway construction; estimation methodology is described in DOT's Notebook 4 (U.S. Department of Transportation, 1975).

- Existing chloride concentrations in ground-water and estimation of contributions due to application of deicing chemicals in aquifer recharge zone (cumulative effects over time in combination with other possible chloride sources must be considered).

- Description of quantity, quality, and fate of stormwater runoff from highway right-of-way, particularly if significant ground-water recharge is likely.

- Description of probable future land uses along the highway corridor and estimation of potential for adverse ground-water quality impacts (special attention should be given to effects of possible development over critical aquifer areas such as highly permeable recharge zones).

- Description of proposed maintenance practices involving pesticides and other potentially hazardous chemicals; application rates and frequency, and restrictions on use in sensitive areas should be specified.

- Description of responsibilities and methods for handling accidental spills, including reporting, remedial actions, and monitoring.

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APPENDICES

APPENDIX A

SOURCES OF WASHINGTON STATE ENVIRONMENTAL DATA FOR IMPACT ASSESSMENT

Federal Agencies

U.S. Geological Survey
1201 Pacific Avenue
Suite 600
Tacoma, WA 98402

(stream gaging records, stream and lake water quality data)

Tel. 206-593-6510

U.S. Geological Survey 7-day low flow studies:

1. Cummans, J.E. and E.G. Nassar, "Low-Flow Characteristics of Streams in the Grays Harbor Drainages, Washington," 1975.

2. Hidaka, F.T., "Low Flows and Temperatures of Streams in the Seattle-Tacoma Urban Complex and Adjacent Areas, Washington," 1972.

3. LaFrance, "Low-Flow Characteristics of Selected Streams in Northeast Washington." 1975.

4. Nassar, E.G., "Low-Flow Characteristics of Streams in the Pacific Slope Basins and Lower Columbia River Basin, Washington," 1973.

5. Cummans, J.E., "Low-Flow Characteristics of Streams on the Kitsap Peninsula and Selected Adjacent Islands," Open-File Report 76-704, 1977.

6. Haushild, W.L., "Low-Flow Characteristics of Streams on the Olympic Peninsula," Open-File Report 77-812, 1978.

7. Collins, M.R. and F.T. Hidaka, "Low-Flow Characteristics of Streams in the Willapa Bay Drainages, Washington," 1974.

U.S. Environmental Protection Agency (general information)
1200 Sixth Avenue
Seattle, WA 98101
Water programs tel. 206-442-1014

U.S. Army Corps of Engineers (hydrologic and water quality data)
Seattle District Office
P.O. Box C3755
Seattle, WA 98124
Water Quality tel. 206-764-3586

Portland District Office
P.O. Box 2946
Portland, OR 97208
Hydrology tel. 503-221-6470

Walla Walla District Office
Building 602
City-County Airport
Walla Walla, WA 99362
tel. 509-525-5308

National Oceanic and Atmospheric Administration (meteorological data)
Environmental Data and Information Service
7600 Sand Point Way N.E.
Seattle, WA 98115
tel. 206-527-6241

<u>State Agencies</u>

Department of Ecology

National Pollutant Discharge Elimination System permit records (point source data) --
Lloyd Taylor
PV-11
Olympia, WA 98504
tel. 206-459-6039
SCAN 585-6039

Surface water quality data (headquarters)
Allen Moore
PV-11
Olympia, WA 98504
tel. 206-459-6063
SCAN 585-6063

Surface water quality data (regional) --
Southwest Regional Office
7272 Clean Water Lane
Olympia, WA 98504
tel. 206-753-2353
SCAN 243-2353

Northwest Regional Office
4350 150th Avenue N.E.
Redmond, WA 98052
tel. 206-885-1900
SCAN 241-2610

Eastern Regional Office
East 103 Indiana
Spokane, WA 99207 tel. 509-456-2926 SCAN 545-2926

Central Regional Office
3601 West Washington
Yakima, WA 98903 tel. 509-575-2991 SCAN 558-2491

Local Agencies

Municipality of Metropolitan Seattle (King County)
821 Second Avenue
Seattle, WA 98104

Surface water and nonpoint source data --
Janet Condon tel. 206-447-6370
Sewage treatment plant data --
West Point Plant (Gordon Gabrielson) tel. 206-447-6801
Renton Plant (Bill Burwell) tel. 206-226-3680

Snohomish County Metropolitan Municipal Corporation
c/o Office of Community Planning
County Administration Building
Everett, WA 98102 Water Quality (Steve Rice)
tel. 206-259-9313

Local municipal wastewater utilities
(for point source data)

APPENDIX B
FLOOD PROBABILITY ANALYSIS

Reference: Linsley et al. (1975).

1.) For the entire gaging record, find the mean ($\overline{q}$) and standard deviation (σ_q) of the annual maximum discharges.

2.) Select K for the design storm recurrence interval and gaging record length from the table below. Use linear interpolation between table entries where necessary.

Values of K for the Extreme-Value (Type 1) Distribution

Return Period, Years	Probability	Record Length, Years 20	30	40	50	100	200	∞
1.58	0.63	-0.492	-0.482	-0.476	-0.473	-0.464	-0.459	-0.450
2.00	0.50	-0.147	-0.152	-0.155	-0.156	-0.160	-0.162	-0.164
2.33	0.43	0.052	0.038	0.031	0.026	0.016	0.010	0.001
5	0.20	0.919	0.866	0.838	0.820	0.779	0.755	0.719
10	0.10	1.62	1.54	1.50	1.47	1.40	1.36	1.30
20	0.05	2.30	2.19	2.13	2.09	2.00	1.94	1.87
50	0.02	3.18	3.03	2.94	2.89	2.77	2.70	2.59
100	0.01	3.84	3.65	3.55	3.49	3.35	3.27	3.14
200	0.005	4.49	4.28	4.16	4.08	3.93	3.83	3.68
400	0.0025	5.15	4.91	4.78	4.56	4.51	4.40	4.23

3.) Compute streamflow for the design condition (q) according to:

$$q = \overline{q} + K\sigma_q$$

APPENDIX C
AGGREGATED HOURLY PRECIPITATION DATA[1]

Location	Hr/yr	Data for Month with Maximum Hr Precipitation (2)	
		Month	Hr in Month
Aberdeen	1973	December	297
Blaine	979	December	143
Castle Rock	1257	December	179
Clearwater	1833	December	269
Colville	537	January/November	79/65
Cougar	1758	December	267
Coulee Dam	363	December/November	55/46
Darrington	1601	January	223
Dayton	652	December	105
Diablo Dam	1375	December/November	225/190
Easton	1220	December/November	203/170
Electron	1569	December	202
Glenwood	835	January/November	138/125
Lind	300	December/November	42/37
Mazama	584	December/November	111/99
Methow	363	January/November	60/42
Mud Mtn. Dam	1251	December	165
Naches	286	January/November	44/42
Oroville	384	December/November	51/46
Palmer	1683	December	224
Port Angeles	624	December and January	92
Pullman	620	December/November	92/78
Rainier-Ohanapecosh	1398	November	204

Republic	496	January/November	62/54
Seattle (City)	911	January	139
Silverton	2109	December	287
Snoqualmie Pass	1864	December/March	253/226
Spokane	558	December/November	90/72
Stampede Pass	1976	December/March	282/230
Walla Walla	454	January/November	66/56
Wenatchee	322	December/November	54/47
Yakima	269	January/November	48/34
Portland (use for Southwest Washington)	997	January	174

Notes: (1) Source: Pacific Northwest River Basin Commission, 1968.
(2) Where data are given for two months, the first quantity represents the month with the maximum hr precipitation in the average year and the second represents the month outside of the anticipated period of an extended freeze (December-February). If it is expected that temperatures will remain consistently below freezing in the month with the maximum hr in most years, the second quantity should be used in the assessment.
(3) For locations other than those given, the quantities can be estimated according to the following regression equations:

$$Hr/yr = 20.7\ P + 158 \qquad r^2 = 0.990$$

$$hr/mo = 18.1\ P' + 34 \qquad r^2 = 0.970$$

Where: P = mean annual precipitation (inches)
P' = mean precipitation in month with most hr precipitation (inches)

APPENDIX D
UNIT CONVERSIONS

Multiply -------------->	By ---------------->	To Get
To Get <-------------	By <----------------	Divide
grams (g)	2.2×10^{-3}	pounds (lb)
hectares (ha)	2.47	acres (ac)
kilograms (kg)	2.2	pounds (lb)
kilograms/hectare (kg/ha)	0.89	pounds/acre (lb/ac)
liters (l)	0.035	cubic feet (ft^3)
liters (l)	0.264	gallons (gal.)
meters (m)	3.28	feet (ft)
milligrams (mg)	2.2×10^{-6}	pounds (lb)
acre (ac)	43,560	square feet (ft^2)
mile (mi)	5,280	feet (ft)
square mile (mi^2)	640	acre (ac)
ton	2,000	pound (lb)
day	86,400	second (sec)
hour (hr)	3,600	second (sec)
year (yr)	8,760	hour (hr)