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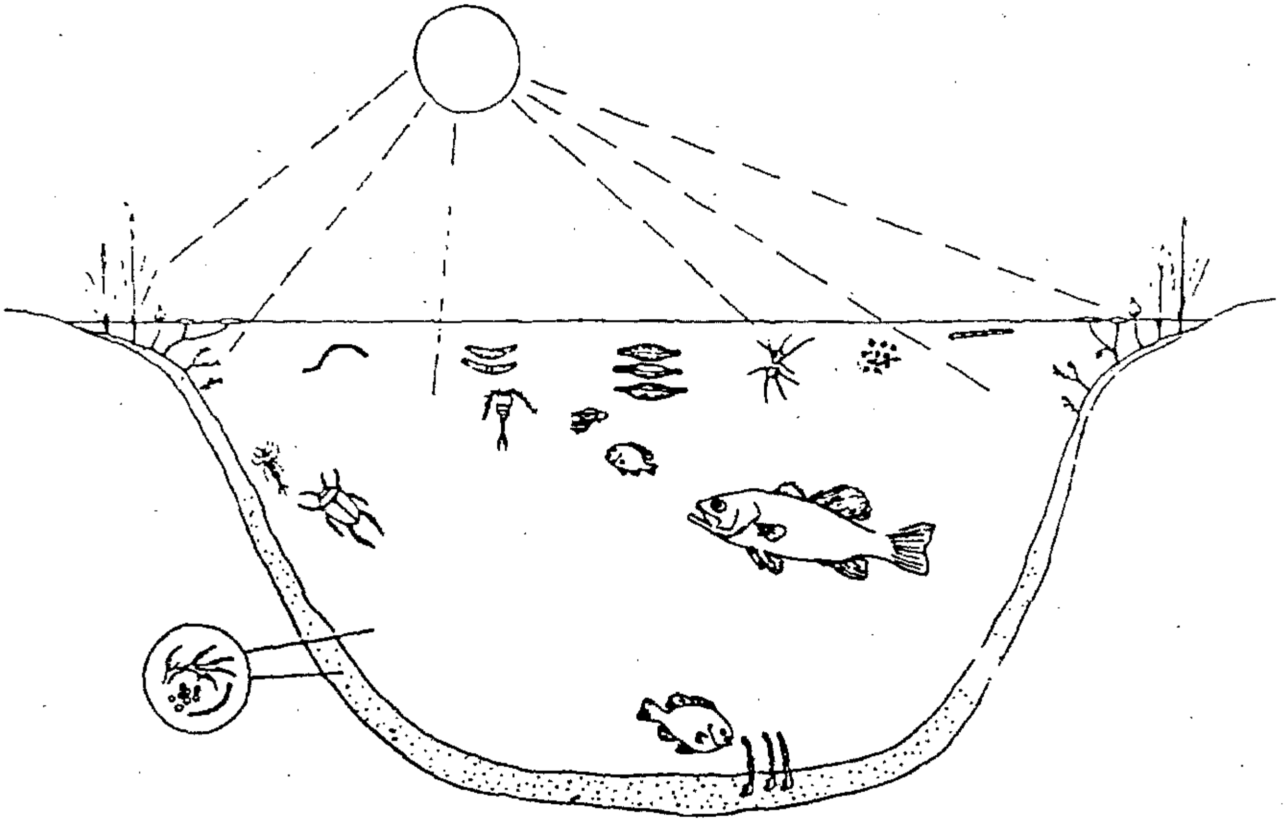
TECHNICAL GUIDANCE MANUAL
FOR THE REGULATIONS PROMULGATED
PURSUANT TO SECTION 301(g)
OF THE
CLEAN WATER ACT OF 1977
40 CFR PART 125 (SUBPART F)

Reserved



Front cover illustration taken from Fundamentals of Ecology, Eugene P. Odum, 1971 (Third Edition)

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IMPORTANT EPA CONTACTS

DIVISION	PHONE #	301(g) RELATED ACTIVITY
PERMITS (Office of Water Enforcement and Permits)	(202) 426-7035	overall review and coordination; use of biomonitoring
CRITERIA & STANDARDS (Office of Water Regulations and Standards)	(202) 245-3042	updates on EPA criteria; review of alternative criteria derivation methods
MONITORING AND DATA SUPPORT (Office of Water Regulations and Standards)	(202) 382-7056	fate models/wasteload allocations/design conditions
CARCINOGEN ASSESSMENT GROUP (CAG) (Office of Research and Development)	(202) 382-7343	carcinogenicity determinations; updates of CAG list
RESEARCH AND DEVELOPMENT (Environmental Criteria and Assessment Office, ECAO-Cin.)	(513) 684-7531	human health risk analyses; criteria updates and Multi-Media documents, and ADI derivations
(Industrial Environmental Research Lab, IERL-Cin.)	(513) 684-4402	bench scale treatment studies

I. Introduction

A. Purpose of this Manual

The purpose of this manual is to assist applicants, States, and EPA Regions in developing section 301(g) variance requests and reviewing completed section 301(g) requests. This manual outlines the roles for each of the parties involved in the variance process and identifies techniques and methods of use in the section 301(g) process. If any of the methodologies or conditions recommended in this manual seem inappropriate to an applicant's situation, the applicant may use alternative methods but must first get approval from EPA (the Director of OWRS and Regional Administrator have separate responsibilities) during the early consultation suggested in the regulations addressing 40 CFR Part 125, Subpart F.*

B. Statutory Background

The Clean Water Act requires achievement of best available technology economically achievable (BAT) effluent limitations for all nonconventional pollutants by July 1, 1984 or not more than three years after EPA establishes the limitations, up to July 1, 1987, whichever is later. Section 301(b)(2)(F).

Section 301(g) of the Clean Water Act (P.L. 95-217) establishes a mechanism whereby a discharger may obtain a modification of the requirements of section 301(b)(2)(F). The discharger can be granted a section 301(g) variance by showing that the modified requirements will meet certain environmental criteria. These

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* The regulation referred to is the proposed regulation which appeared at 49 FR 31462, (8-7-84). If changes are made when the regulation is promulgated, this manual will be modified accordingly.

criteria were specified in the 1977 amendments to the Clean Water Act:

- the variance is not available for pollutants designated as toxic, conventional, or as a thermal component of a discharge.
- the new limitation will not be less than required by best practicable control technology currently available (BPT).
- the new limitation will comply with applicable water quality standards specific to the nonconventional pollutant.
- the modification will not result in any additional requirements on any other point or nonpoint source.
- the modification will not interfere with water quality which assures protection of public drinking water supplies and the protection and propagation of a balanced population of fish, shellfish, and wildlife, and allows recreational activities in and on the water.
- the modification will not result in a discharge of pollutants in quantities which may reasonably be anticipated to pose an unacceptable risk to human health or the environment due to acute toxicity, chronic toxicity (including carcinogenicity, mutagenicity or teratogenicity), bioaccumulation, persistency, or synergistic propensities.

The legislative history of the 1977 Amendments to section 301 of the Clean Water Act (CWA) makes it clear that Congress intended relief from promulgated BAT effluent limitations guidelines where warranted. Congress determined that it was possible that the BAT requirements might result in the application of excessive controls to certain kinds of pollutants. Where sufficient information could be generated on these pollutants to make a judgment concerning their effects on receiving water, appropriate relief from unnecessarily stringent limitations should be provided. Congress envisioned that the Administrator would develop a pollutant-specific waiver without affecting necessary BAT limitations on the remainder of the pollutants in the discharge. The enactment of section 301(g) was the result of an effort to eliminate "treatment for treatment's sake" for nonconventional pollutants.

The legislative history also contains Congress's recognition of the delays encountered with section 316(a) thermal variances and its expectation that the section 301(g) process be as expeditious as possible.

C. Summary of Section 301(g) Variance Process

To make the variance process as efficient and expeditious as possible, EPA recommends relying primarily upon State water quality standards or EPA section 304(a) water quality criteria, together with the methodologies for developing the criteria.

At a minimum, the proposed modified effluent limitation (PMEL) must meet applicable State water quality standards. In those cases where State standards do not individually address a nonconventional pollutant, EPA recommends that a specific criterion number be identified or developed for the pollutant or pollutant parameter in question and that number be met at the edge of the State mixing zone. (See Figure I)

To avoid lengthy studies (i.e., site-specific environmental impact assessments which require extensive resources and time), EPA recommends use of section 304(a) water quality criteria unless relevant criteria do not exist or the EPA Director of the Office of Water Regulations and Standards consents to the development of other criteria, notwithstanding the existence of relevant 304(a) criteria. Therefore, the criteria or applicable water quality standards should be the usual basis of 301(g) variance determinations. Essentially the variance hinges on the applicant's ability to meet State standards or EPA (or other site-specific) water quality criteria for nonconventional pollutants, at the edge of an authorized mixing zone. Compliance with water quality standards or criteria at the edge of the mixing zone would provide EPA with a strong basis for concluding that aquatic life and human health will be protected from acute and chronic toxicity. Additionally, however, all other statutory factors will have to be addressed on a case-by-case basis such as synergism, persistency, etc.

Steps to Gaining a Variance

The following is a summary of the steps required to gain a section 301(g) variance. These steps are discussed in more detail in section II.

1. Identify pollutant as nonconventional.
2. Ensure compliance with BPT or BPJ/BPT.
3. Demonstrate no impact on other point and nonpoint sources.
4. Ensure compliance with applicable State water quality standards, or EPA water quality criteria at edge of State mixing zone if there is no State standard.
5. Demonstrate no impact on water supplies.
6. Demonstrate no impact on recreational activities.

7. Ensure no impact on human health.
8. Demonstrate no synergism/persistency causing adverse impact.

D. Applicant Responsibilities

The primary responsibility of the applicant is to file a completed request which adequately addresses each of the statutory factors. The applicant will be responsible for conducting all tests and making all demonstrations of compliance with the section 301(g) requirements. The burden of proof is on the applicant.

The applicant should work as closely as possible with the State and Regional permitting authority in order to determine an acceptable plan for developing a completed request. The applicant is encouraged to conduct an early consultation with the State and Region to outline the studies and data that will be contained in its completed request. This will help to avoid denial of an application based on incompleteness or misinterpretation of the section 301(g) requirements.

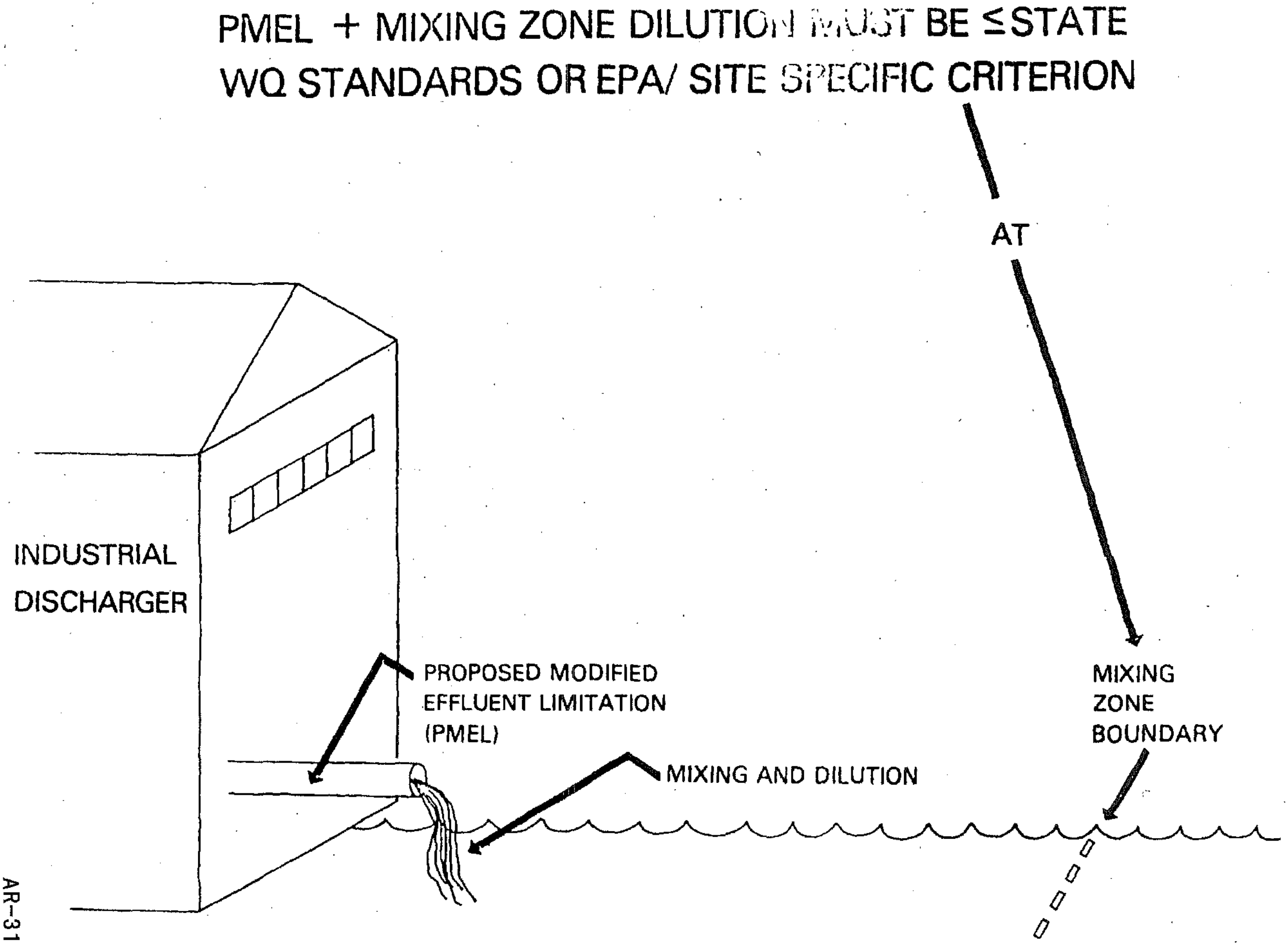
Appendix G is a 301(g) checklist which is designed to help the applicant file an adequate, completed request. The checklist includes all the topics and informational needs which must be addressed by an applicant in order to be considered for a section 301(g) variance. Failure to address these topics adequately will most likely lead to a denial.

E. State Role

A number of aspects will involve the State where the variance request originates. They are:

- State concurrence required.
- State water quality standards must be met.
- State mixing zones must be used.

Figure 1


PMEL + MIXING ZONE DILUTION MUST BE ≤ STATE WQ STANDARDS OR EPA/ SITE SPECIFIC CRITERION
AT
INDUSTRIAL DISCHARGER
PROPOSED MODIFIED EFFLUENT LIMITATION (PMEL)
MIXING AND DILUTION
MIXING ZONE BOUNDARY

- o State Agency responsible for wasteload allocations (other point sources) must make determination about impact of PMEL on other sources.

Section 301(g) authorizes the EPA Administrator to approve section 301(g) variance requests. The Administrator has delegated the final approval authority to the Director of the Office of Water Enforcement and Permits, formerly referred to as the Deputy Assistant Administrator; see 40 CFR 124.62(d). A strong State role in the section 301(g) variance process is nonetheless assured because the statute requires that no modified effluent limitation may be granted unless the State concurs. If a State waives its right to approve or deny the variance, the request will be denied. 40 CFR 124.62 specifies the way in which the State is involved in a section 301(g) determination.

✓ The State Director of an NPDES-approved State may deny or forward to the Regional Administrator with a written concurrence, or submit to the EPA Regional Administrator without recommendation, a completed request for a section 301(g) variance (40 CFR 124.62(b)). In non-NPDES States, the State Director may provide certification of a permit containing a section 301(g) variance and such certification of the permit shall constitute the State's concurrence in the variance. Thus, States may exercise a veto over a proposed modified effluent limitation.

Applicants must meet relevant State water quality standards. If a mixing zone or zone of initial dilution (in marine waters) is defined in the State water quality standards, it will be used in the section 301(g) analysis when comparing concentrations of the discharged nonconventional pollutant to the water quality standard or water quality criteria, (whichever is more appropriate)

The State's mixing zone (defined by its water quality standards) will be used to review water quality effects even when an independent criterion number, not a State water quality standard, is used to define acceptable concentrations of the nonconventional pollutants. If the State has no mixing zone, the State should work with the applicant to derive a site-specific mixing zone for section 301(g) purposes, unless the State prohibits a mixing zone. In that case the proposed modified effluent limitation must be met at the point of discharge (end of pipe).

In addition to the above responsibilities, the section 301(g) regulation requires a State to determine whether the applicant's modified effluent will result in any additional requirements on other point or nonpoint sources. The State must determine whether there are any wasteload allocation/total maximum daily load requirements for the nonconventional pollutant in the area of the discharge and whether the applicant's discharge will prevent compliance with these requirements.

F. EPA Regional Role

Section 301(g) requires the Regional Administrator to deny or approve each 301(g) variance request which is forwarded to the Region by the State. Approved requests will be forwarded to EPA Headquarters for final approval or denial. The Regional Administrator will also be responsible for approving or denying the use of substitute (local) test species in site-specific criteria development. It is recommended that the Regional Administrator consult the State permitting authority before making a decision on a species substitution. It is anticipated that Region and State representatives will work closely together on making a section 301(g) variance decision.

G. Early Consultation

EPA recommends that all applicants hold an early consultation with Federal and State permitting authorities. The applicant can discuss the tentative plan for developing the contents of its completed request either in person, by phone, or correspondence. The early consultation will allow EPA, the State and the applicant to determine what is required to prepare a section 301(g) completed request. The early consultation should help the applicant avoid unnecessary or inadequate testing and could lead to a redirection of the applicant's proposed study.

During the early consultation, the applicant should discuss a plan of study describing the proposed modified effluent limitation, a general description of the data, studies, experiments and other information to be submitted, including any other data and information necessary to assist the Regional Administrator and State Director in determining whether the applicant's plan of study is adequate.

Early consultation is particularly recommended if: (1) the proposed modified effluent limitation is for a pollutant or pollutant parameter for which the State has not adopted a numerical standard and the applicant does not plan to use a published EPA numerical criterion or none is available; (2) the proposed modified effluent limitation is for a pollutant or pollutant parameter which is suspected of being a carcinogen (Applicants may determine whether the nonconventional pollutant has been evaluated by the Carcinogen Assessment Group (CAG) of EPA, and whether it is suspected of being a carcinogen, by calling CAG at (202) 382-7315); (3) the applicant has reason to believe that the pollutant or pollutant parameter for which the variance is requested will contribute to synergistic or additive effects in the effluent or receiving water; and/or, (4) the applicant plans to request an extension for filing a completed request as provided in 40 CFR 122.21(n)(2).

II. Determining Factors in a Section 301(g) Variance

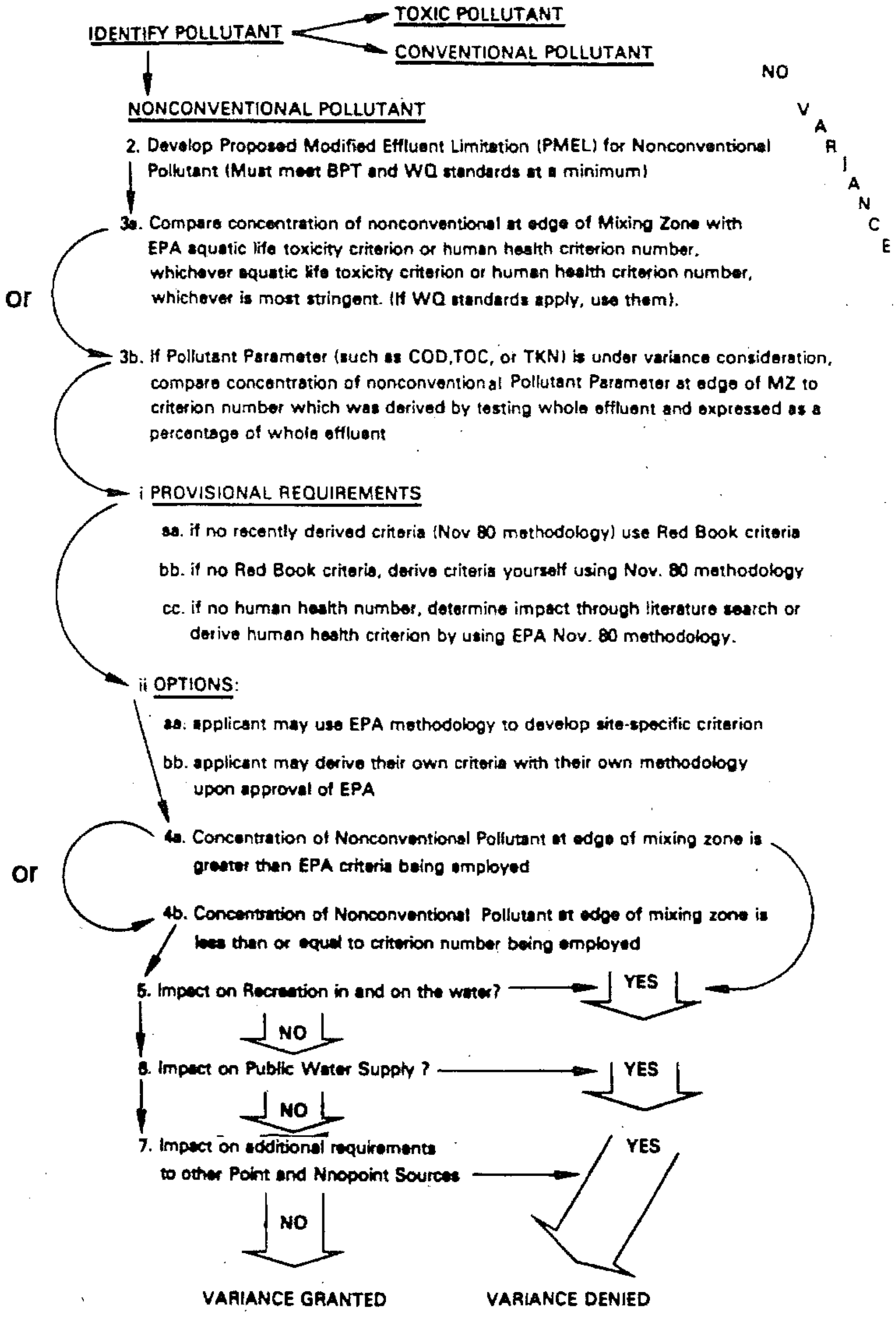
The following paragraphs discuss the factors that need to be addressed in order to be considered for a section 301(g) variance. Many of the sections provide EPA recommendations on how they should be addressed; however, an applicant may present its own methods and suggestions to the EPA Region and Headquarters. If an applicant believes there is a better way of addressing an issue under section 301(g), the applicant should discuss the option with EPA during the early consultation period before proceeding. Section 125.53(b) discusses the recommended time periods when early consultations should be held.

A. Pollutant Check

The first step an applicant must take is to identify the nonconventional pollutant for which a variance is sought (See Figure II). Toxic pollutants found on the section 307(a) list of toxic pollutants and conventional pollutants listed under section 304(a)(4) are ineligible for a variance under section 301(g). See Appendix A or 40 CFR 401.15 and 401.16. However, delisted pollutants, those pollutants removed from the 307(a) list of toxic pollutants through EPA administrative action, are eligible for section 301(g) variances. (Official delistings will be publicly noticed in the Federal Register.)

Figure II

301(g) DECISION LOGIC



IDENTIFY POLLUTANT

TOXIC POLLUTANT

CONVENTIONAL POLLUTANT

NO VARIANCE

NONCONVENTIONAL POLLUTANT

2. Develop Proposed Modified Effluent Limitation (PMEL) for Nonconventional Pollutant (Must meet BPT and WQ standards at a minimum)

3a. Compare concentration of nonconventional at edge of Mixing Zone with EPA aquatic life toxicity criterion or human health criterion number, whichever aquatic life toxicity criterion or human health criterion number, whichever is most stringent. (If WQ standards apply, use them).

or

3b. If Pollutant Parameter (such as COD,TOC, or TKN) is under variance consideration, compare concentration of nonconventional Pollutant Parameter at edge of MZ to criterion number which was derived by testing whole effluent and expressed as a percentage of whole effluent

i PROVISIONAL REQUIREMENTS

aa. if no recently derived criteria (Nov 80 methodology) use Red Book criteria

bb. if no Red Book criteria, derive criteria yourself using Nov. 80 methodology

cc. if no human health number, determine impact through literature search or derive human health criterion by using EPA Nov. 80 methodology.

ii OPTIONS:

aa. applicant may use EPA methodology to develop site-specific criterion

bb. applicant may derive their own criteria with their own methodology upon approval of EPA

4a. Concentration of Nonconventional Pollutant at edge of mixing zone is greater than EPA criteria being employed

or

4b. Concentration of Nonconventional Pollutant at edge of mixing zone is less than or equal to criterion number being employed

5. Impact on Recreation in and on the water? → YES

NO

6. Impact on Public Water Supply ? → YES

NO

7. Impact on additional requirements to other Point and Nnopoint Sources → YES

NO

VARIANCE GRANTED

VARIANCE DENIED

Pollutant parameters such as COD, surfactants, TOC, total phenols, etc. are also eligible for a section 301(g) variance as long as none of the constituents is found on the toxic or conventional pollutant lists (or if found on these lists, the pollutants must be properly limited by BAT or BCT). Analytical methods such as GC/MS are suggested to validate that no toxic pollutants make up the pollutant parameter.

B. Compliance with BPT Limitations

The owner/operator of a point source must demonstrate that the proposed modified effluent limitation (PMEL) will, at a minimum, be as stringent as BPT for the nonconventional pollutant in question. If an applicant requests a variance from a BAT guideline when there is no BPT guideline for that specific industrial subcategory, the permitting authority must determine a BPT/BPJ (best professional judgment) limit for that pollutant which will serve as a minimum requirement.

C. Compliance with State Water Quality Standards

At a minimum, the PMEL must meet the State water quality standard for the nonconventional pollutant. If an applicant does not know the State water quality standard which controls its nonconventional pollutant, it should contact its State permitting or water quality authority. EPA recommends that a section 301(g) applicant determine impact on aquatic life and human health by first reviewing water quality standards which address these concerns (i.e., fishable/swimmable, drinking water standards). If the State water quality standards for a nonconventional pollutant address aquatic life and human health concerns, the applicant can determine whether the PMEL would violate those standards by measuring the nonconventional pollutant concentration at the edge of the mixing zone. A violation would mean an immediate denial of the variance.

D. Other Point and Nonpoint Sources

The owner/operator of a point source must demonstrate that the modified effluent limitation will not result in any additional requirements on any other point and nonpoint sources.

The section 301(g) regulation requires that a section 301(g) applicant obtain a determination from the State or other interstate agency(s) having authority to establish wasteload allocations (WLAs) and total maximum daily loads (TMDLs) indicating whether the applicant's discharge will result in any additional treatment, pollution control, or other requirements on any other point or nonpoint sources. The applicant should contact the State water quality or permitting authority and ask them to provide a written determination. The determination should be attached to the variance request if it is forwarded to the EPA Regional Office and/or EPA Headquarters. The State determination must include a rationale for its conclusion.

If wasteload allocations have not been established in the locale of the section 301(g) variance applicant, EPA recommends that the applicant identify other point sources in the vicinity of the modified effluent limitation and determine whether the increased nonconventional pollutant load expected in the receiving stream if a variance is granted would affect any other source's treatment requirements. The applicant may accomplish this by conferring with the State permitting agency or with the point sources most likely to be affected. If the modified effluent limitation under section 301(g) resulted in additional requirements on these dischargers, the 301(g) variance would be denied. Failure to show evidence of no effect on other point sources will result in a denial of the variance.

With regard to receiving waters where WLAs and TMDLs are absent, the section 301(g) regulation requires that once a section 301(g) variance has been granted, the State must establish numerical water quality standards for the nonconventional pollutant and WLAs and TMDLs for the section 301(g) source and the other dischargers in the vicinity. This must be done within the 5 year permit term for the section 301(g) permittee and before the permit containing the section 301(g) variance is reissued. The rationale for this requirement is that many of the factors considered in a section 301(g) review are also considered in the development of water quality standards (under section 303(c) of the Clean Water Act). Accordingly, it follows that the resulting data from a section 301(g) variance should be applied to the development of site-specific water quality standards and wasteload allocations and total maximum daily loads. Since States must by law review their water quality standards every 3 years, this requirement should not impose any undue extra administrative burden on them. EPA has a number of draft documents which may assist a State in developing WLAs and TMDLs. They are listed in Appendix H.

E. Maintenance of Water Quality

Section 301(g) requires an applicant to assure protection of water quality which will protect the following:

1. Public water supply
2. Recreational Activities
3. Balanced Population of Shellfish, Fish, Wildlife
4. Human Health Considerations

1. Public Water Supply

The applicant must demonstrate that the modified effluent limitation will not adversely affect any public water supplies that are in the vicinity of the point of discharge. The modified effluent limitation must not prevent a planned or existing public water supply from being used, or from continuing to be used, as a public water supply, or have the effect of requiring any public water supply to provide additional treatment.

The applicant should contact the State permitting authority to determine whether there are or will be public water supplies in the area and then contact the public water supplies in the vicinity of the discharge to determine if the PMEL would affect their operation. If they are affected, a section 301(g) variance request would be denied. The applicant should also determine from the permitting authority whether State or local drinking water standards would be violated by the PMEL. If standards would be violated, the request would be denied.

2. Recreational Activities

The applicant must demonstrate that the PMEL will not adversely affect recreational activities beyond the mixing zone boundary. If a recreational use is affected, a section 301(g) variance request would be denied. The section 301(g) regulation requires that the PMEL not interfere with recreational activities beyond the mixing zone boundary (or zone of initial dilution, whichever is applicable), including without limitation swimming, diving, boating, fishing and picnicking and sports activities along shorelines, river banks, lake shores and beaches.

The section 301(g) regulation also requires that there are no Federal, State, or local restrictions on recreational activities within the vicinity of the applicant's outfall due to the PMEL, unless such restrictions are routinely imposed around industrial discharges.

The applicant should take an inventory of recreational activities in the area of the discharge and determine if the section 301(g) variance would affect these activities. For example, does the PMEL, after dilution in the mixing zone, exceed human health related standards or criteria? Human health criteria protect humans from both body contact and the consumption of water, fish or shellfish containing harmful levels of pollutants. An aquatic life criterion is a good measure of the potential impact to a fish population associated with a specific recreational use such as trout fishing.

3. Balanced Population of Shellfish, Fish and Wildlife

Section 301(g) requires the applicant to demonstrate that a section 301(g) variance will not interfere with the attainment or maintenance of water quality which shall assure protection and propagation of a balanced population of fish, shellfish and wildlife. At the same time, the statute requires that human health and the environment be protected from acute and chronic toxicity, persistency, bioaccumulation and synergistic propensities.

(Chronic toxicity, according to section 301(g), includes carcinogenicity, teratogenicity, and mutagenicity.)

Applicants are urged to use State water quality standards in making a section 301(g) variance demonstration, if those standards address the required aquatic life and human health concerns with respect to the specific pollutant or pollutant parameter. Using these standards would considerably simplify the demonstration. Such standards are usually described as "fishable/swimmable," "drinking water," or "aquatic life" standards. State standards protecting designated uses such as "industrial" or "agricultural" are not acceptable to demonstrate compliance with section 301(g). If the State has water quality standards which protect aquatic life and human health on other water bodies in the State, these can be used in a section 301(g) assessment.

If State standards are inadequate to protect aquatic life and human health, or are not available with respect to the specific pollutant or pollutant parameter, EPA recommends use of the section 304(a) criteria to evaluate the environmental impact of the PMEL. These criteria address several of the objectives which underlie the section 301(g) statutory criteria (including acute and chronic toxicity and bioaccumulation). The criteria, designed to protect aquatic life and human health uses, consist of numerical concentrations of specific pollutants. They are based on data and scientific judgments on the relationships between pollutant concentrations and environmental and human health effects. When using a section 304(a) criterion number, the most recent EPA criterion document should be consulted and the most stringent criterion should be chosen (i.e., the latest criteria for ammonia and chlorine are presented at 49 FR 4551, February 7, 1984). For latest updates on criteria development, please contact the Criteria and Standards Division at EPA (202) 245-3042.

Most State water quality standards and EPA water quality criteria do not cover persistence and synergistic propensities. The applicant must be address these factors separately. See Section IV (Special Considerations) for discussions of ways for applicants to address synergistic propensities, and persistence.

An applicant, with EPA approval, may develop modified criteria if it feels it is necessary to reflect site-specific water quality characteristics or if it thinks the EPA criteria are inappropriate. EPA's guidance document entitled "Water Quality Standards Handbook," December 1983, specifically outlines guidelines for deriving site-specific water quality criteria for the protection of aquatic life and its uses. For more information, refer to section III-C.

Use of Biomonitoring

Meeting a water quality standard or water quality criterion is a good indication that water quality is being maintained. However, the additional use of some kind of biological monitoring (whole effluent bioassays or instream surveys) can serve as a good tool to further verify that a balanced population of aquatic life is being maintained over time.

EPA recommends that permit writers (State and EPA) incorporate biomonitoring requirements into section 301(g) permits once a variance is granted to verify that the variance, once in place, will not result in an impact to the aquatic community in the receiving stream. Biomonitoring also will help to further account for synergistic effects (and other combined impacts of effluent and receiving water) in and around the effluent. Refer to EPA's draft biomonitoring guidance manual (A Technical Support Document for Water Quality-Based Toxics Control, May 1984) to determine appropriate biomonitoring techniques for the 301(g) applicant.

4. Human Health Considerations

If State water quality standards or EPA water quality criteria do not include consideration of human health (such as a drinking water standard or a human health criterion), the applicant should use the most stringent aquatic life toxicity criterion number as a baseline requirement and also demonstrate that human health is not being affected. EPA does not expect every applicant to perform the scientific studies necessary to develop specific human health criteria numbers when those numbers are unavailable. Instead, the applicant should retrieve and analyze relevant literature and data to determine whether the nonconventional pollutant (at the discharge level) is known to be acutely or chronically toxic to humans. If the pollutant will cause acute or chronic toxicity at the discharge level, the variance will be denied.

With regard to chronic toxicity, the applicant should first determine whether the pollutant is a known or suspected carcinogen, teratogen, or mutagen. The applicant can do this a number of ways. First, EPA criteria or Multi-Media documents, while they may not have a human health number, usually contain some information on mutagenicity, teratogenicity, and carcinogenicity; applicants should review these documents for this information. (See section III-A.) The applicant should secondly determine whether an acceptable daily intake (ADI) is available for a particular chemical. ADIs represent a level of intake of a particular chemical that is expected not to elicit any chronic toxicity. Applicants may call the Environmental Criteria and Assessment Office in Cincinnati (ECAO-Cin.) at (513) 684-7531 to determine whether an ADI for a certain nonconventional pollutant is available. If not, ECAO can provide guidelines for their determination.

To determine mutagenicity, an applicant may follow EPA's proposed guidelines for determining mutagenicity found at 47 FR 53200, Pesticides Registration: Proposed data requirements, November 24, 1982.

To examine carcinogenicity, besides reviewing the data in the criteria documents and other literature sources, the applicant is urged to see if the nonconventional pollutant is on EPA's Carcinogen Assessment Group (CAG) list of potential and known carcinogens. Call CAG at (202) 382-7343 to determine which pollutants are on the list and which ones have been added or deleted. If the pollutant is on the CAG list, the applicant should determine the level at which carcinogenic activity occurs and which route of exposure is prominent (oral, inhalation) and compare this to the section 301(g) variance conditions. If response data on carcinogenicity exists, then low risk concentrations (e.g., levels which give one in 100,000 excess risk) should be estimated.

The applicant also can use the November 28, 1980 criterion derivation methodology to determine human health criteria (see Appendix C at 45 FR 79347). This methodology, however, is very detailed and costly. It is a matter of discretion on the applicant's part whether to use this methodology. If the methodology is used, there is greater assurance that an adequate assessment of potential human health impacts has been made for the nonconventional pollutant.

An approach to addressing one aspect of human health impact is to determine the bioconcentration factor (BCF) of the pollutant. A bioconcentration factor relates the concentration of a chemical in water to the concentration in aquatic organisms. Since accumulation of pollutants is generally assumed to be potentially hazardous it is desirable that a material show a low BCF. According to Stern and Walker, 1978, a BCF of a 100 may not indicate a substance is hazardous if clearance of the pollutant is rapid, but a BCF above 100 and certainly above 1000 indicates a great potential for danger. Accordingly, EPA recommends that if a nonconventional pollutant has a BCF greater than 100, more information should be obtained on this pollutant with regard to chronic toxicity and effects such as carcinogenicity, mutagenicity, teratogenicity. The November 1980 criterion derivation methodology (45 FR 79341) provides guidelines for deriving an acceptable bioconcentration factor. In addition, if no measured value of BCF is available, BCF may be estimated from the octanol-water partition coefficient, K_{OW} by use of the following regression equation (Veith et al., 1980): $\text{Log BCF} = (0.76 \text{ Log } K_{OW}) - 0.23$. Since the bioconcentration factor alone is not conclusive evidence of an impact to human health, other significant data should be reviewed to make a complete human health risk assessment.

III. EPA Water Quality Criteria

A. Existing EPA Water Quality Criteria for Nonconventional Pollutants

EPA recommends an applicant review the following sources to determine which water quality criteria to apply in a section 301(g) variance assessment:

1. The most recently published ambient water quality criterion document (or Federal Register notice) for the nonconventional pollutant;

2. The Red Book, Quality Criteria for Water, 1976, if no criterion document exists published since 1976.

3. A Multi-Media Document (If no criterion document or Red Book number exists for the nonconventional pollutant)

The following is a discussion of each of these sources of water quality information.

EPA Water Quality Documents

An EPA water quality criterion document is a publication which presents the most recent toxicological data on a pollutant and provides the derivation of aquatic life and human health criteria numbers based on those data and EPA approved methodologies. There are, presently, criteria documents for 65 toxic pollutants or pollutant classes.

Criteria documents for two important nonconventional pollutants, ammonia and chlorine, are presently being published for public comment. (Proposed criteria for ammonia and chlorine can be found at 49 FR 4551, Feb. 7, 1984. See Appendix B.) These documents will present the aquatic life criteria as 3 different numerical criteria:

a. a 30 day average
b. a maximum concentration
c. a 96-hour range

There are, in addition, two human health criteria numbers. The more stringent of these numbers is designed to protect human health from the toxic properties of a pollutant if ingested from drinking water or contaminated aquatic organisms. The other criterion protects human health from the toxic properties of a pollutant if ingestion of contaminated organisms alone occurs. Each human health criterion number also incorporates data on mutagenicity, carcinogenicity and teratogenicity.

Red Book Criteria

When there are no recently published water quality criteria, EPA recommends the applicant review the Red Book for applicable water quality criteria. If the Red Book offers more than one criterion number for the nonconventional pollutant, the applicant should use the most stringent number.

Multi-Media Documents

If an applicable State water quality standard or EPA water quality criterion (including a Red Book criterion) has not been developed for a nonconventional pollutant, the applicant requesting a variance should generate a number or examine EPA's Multi-Media Documents for pertinent aquatic life and human health data. Multi-Media Documents address the aquatic life and human health toxicity of nonconventional pollutants in different environmental media - air, water, soil. These documents will not include EPA recommended criteria numbers or safe exposure levels but will provide a great deal of scientific data which may be helpful in making a section 301(g) variance determination. These documents will offer results from studies, lowest effect levels, and no-effect levels for the following nonconventional pollutants:

1. Acetone
2. Dibenzofurans
3. Methoxychlor
4. Chlorophenoxy herbicides
5. Malathion
6. Parathion
7. Mirex
8. Kepone
9. Iron
10. Barium

EPA encourages section 301(g) applicants to refer to these documents and use data where applicable to address aquatic life and human health impacts of these nonconventional pollutants. These documents will be available from EPA during 1984. Information on the documents and the studies contained in the documents can be obtained by calling EPA's Environmental Criteria and Assessment Office in Cincinnati at (513) 684-7531.

B. Application of Criteria in Section 301(g) Determinations

In determining whether a variance request is justified, the instream water quality that would result from a discharge controlled by the PMEL (after dilution in a State mixing zone) should be compared with the most stringent water quality criterion (human health or aquatic life toxicity) for the pollutant. If the PMEL will not result in poorer water quality than that described by the State water quality standards, or water quality criterion and the results of any tests required for synergism or persistency (see Section IV-C), the PMEL is acceptable for the purposes of section 301(g) provided all other statutory requirements are met.

C. Procedures Where There Are No Existing Criteria/Standards or Applicant Wishes to Modify Criteria

When there are no existing water quality standards or water quality criteria available for the nonconventional pollutant, it is recommended that the applicant derive a water quality criterion on its own. In these cases the applicant is urged to use EPA's methodology for developing criteria numbers (45 FR 79341 Appendix B - Guidelines for Deriving Water Quality Criteria for the Protection of Aquatic Life and Its Use, Nov. 1980), unless the Office of Water Regulations and Standards (OWRS) approves another method. (A summary of EPA's criterion derivation methodology is provided in Appendix B.) EPA has made revisions to the Nov. 1980 methodology. These can be found at 49 FR 4551 (See Appendix B).

In any case where an applicant does not agree with EPA's criteria or methodology, the applicant may generate its own criterion number, using its own methodology, provided that the alternative methodology for deriving criteria is scientifically valid and will generate criteria that protect fishable/swimmable uses. The Director of OWRS will make determinations. Where the applicant wishes to substitute local biota into the EPA methodology, the applicant should first have the selection of biota approved by the Regional Administrator. See Section I-G on early consultation. The Regional Administrator should consult the State to determine which species are accurate representatives of local biota before approving the substituted selection. It should be noted that the applicant must protect against human health effects.

IV. Special Considerations

A. Pollutant Parameters (COD, TOC, TKN, Total phenols)

EPA recommends that section 301(g) applicants seeking a variance from a pollutant parameter such as COD, TOC, TKN or total phenols, use one of two procedures:

- o EPA's criterion derivation methodology, or
- o Bench scale treatments.

1. Criterion Derivation Methodology for Aquatic Life

To determine whether a pollutant parameter may qualify for a section 301(g) variance using the EPA criterion derivation methodology, the applicant must follow the acute and chronic toxicity tests requirements prescribed in the EPA methodology and conduct the tests with whole effluent. For example, if an applicant is deriving a criterion number for a nonconventional pollutant parameter such as chemical oxygen demand (COD), acute and chronic toxicity tests must be run on the whole effluent of which COD is a component. The toxicity tests are conducted with increasingly diluted samples of the whole effluent rather than diluted concentrations of a single pollutant. The resulting criterion number is expressed as a percent of the whole effluent - a diluted fraction of the 100% whole effluent. For example, if acute bioassays are conducted, the whole effluent should be assayed and the percentage of the whole effluent which caused 50% mortality (LC50) should be identified. After conducting several acute and chronic bioassays, the resulting criterion number might be, for example, 20% of the whole effluent. The applicant would have to prove that there is sufficient dilution within the mixing zone to meet the 20% whole effluent concentration at the mixing zone edge or, if dilution is insufficient in the mixing zone, the applicant would have to reduce the level of the pollutant parameter in the effluent and re-measure the whole effluent toxicity. The permit writer must assure that any reduction of a pollutant parameter concentration in the applicant's effluent is achieved by treatment, not by increased in-plant flows. Given the new whole effluent criterion number, the applicant would re-evaluate the whole effluent concentration at the edge of the mixing zone. (See Figures III and IV.) See Appendix B, especially sections IV - VII. Where the EPA criterion derivation methodology calls for bioassay results such as LC50 or EC50 values, the applicant should use the percent effluent which resulted in the LC50 or EC50 when deriving final acute/chronic values.

Because toxic and conventional pollutants are ineligible for a variance, the section 301(g) regulation requires an applicant to identify those constituents of the whole effluent which are conventional or on the section 307(a)(1) toxic pollutant list. A GC/MS screen for toxics is recommended. If toxics are present, they must be controlled by BAT or discharged at levels equivalent to BAT treatment.

The applicant is also required to make a human health impact assessment to ensure that the nonconventional pollutant parameter and none of its constituents will cause human health impact. EPA recommends a literature search on the pollutant parameter or development of a human health criterion using the November 1980

CRITERION DERIVATION FOR AQUATIC LIFE

PMEL & DILUTION → Must Meet Criteria at Edge of Mixing Zone

Figure III

TO DERIVE CRITERION FOR SINGLE POLLUTANT (e.g. Iron)	8 ACUTE BIOASSAYS + 8 LC 50s	3 CHRONIC TESTS 3 EC50's	+ RESIDUE + BIOACCUMULATION TESTS →	EPA CRITERION NUMBER X mg/l IRON
TO DERIVE CRITERION FOR POLLUTANT PARAMETER (Such as COD)	8 BIOASSAYS WITH WHOLE EFFLUENTS LC50s EXPRESSED AS % EFFLUENT e.g. 25% EFFLUENT CAUSES 50% MORTALITY	3 CHRONIC TESTS WITH WHOLE EFFLUENT EC5o EXPRESSED AS % EFFLUENT e.g. 25% EFFLUENT CAUSES 50% MORTALITY	→	EPA CRITERION EXPRESSES AS PERCENT WHOLE EFFLUENT

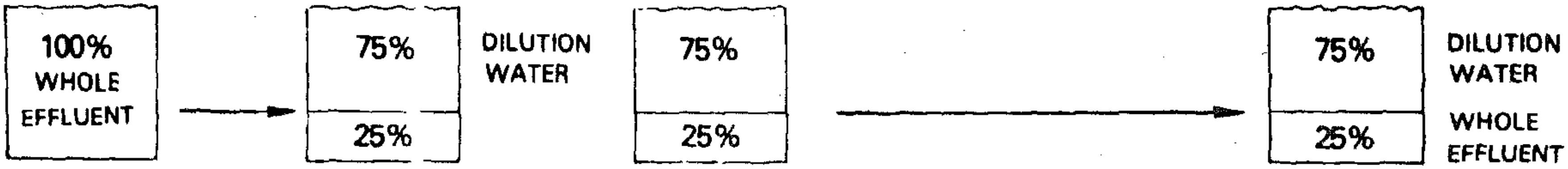


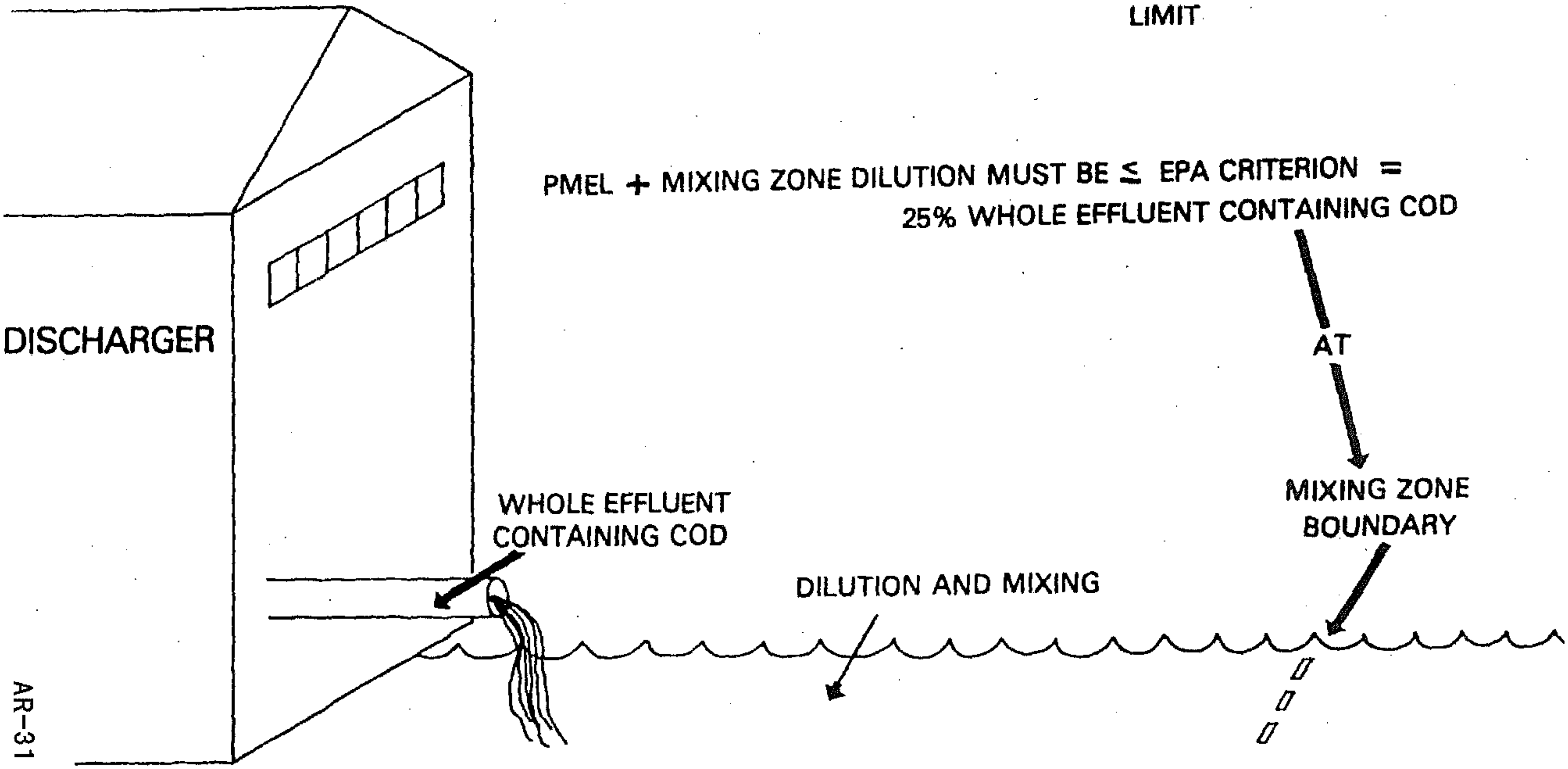
Figure IV

POLLUTANT PARAMETER

COD Chemical
Oxygen
Demand

ASSUMPTIONS

1. DIFFICULT TO SEPARATE COD FROM WHOLE EFFLUENT
2. EXAMINING WHOLE EFFLUENT RATHER THAN COD EFFLUENT LIMIT



PMEL + MIXING ZONE DILUTION MUST BE ≤ EPA CRITERION = 25% WHOLE EFFLUENT CONTAINING COD human health criterion derivation methodology (Appendix C at 45 FR 79347), if applicable. It is recommended that each component of the pollutant parameter be evaluated with regard to human health impact. See the section II - E(4) above on addressing human health impacts.

Note: In many cases a pollutant parameter such as COD will have variable constituents from day to day. Accordingly, the applicant must assess the variability of its COD or other pollutant parameters so that the section 301(g) variance request is based on COD representative of applicant's effluent. The applicant should list the pollutants that are in detectable quantities comprising the COD, the percentage of these pollutants in the COD, and the expected variability of these components.

2. Bench Scale Treatment Technologies

Bench Scale Treatment Technologies (Appendix C) are small (i.e., "bench") scale treatment strategies designed to simulate an effluent where only one pollutant or pollutant fraction is removed from the whole effluent by the proposed BAT and BPT treatment technologies. Using these methods, an applicant can compare the measured toxicity or effect attributed to a whole effluent with and without a pollutant parameter controlled at BPT and BAT levels. If an applicant can be demonstrate that the existence of the pollutant parameter treated to BPT in the whole effluent does not contribute to a significant increase in acute or chronic toxicity or synergistic effects, that no section 307(a) pollutants are present, and that all other section 301(g) factors are met, then the effect of the pollutant parameter at the edge of the mixing zone and downstream can be disregarded and the section 301(g) variance may be granted.

Before using a bench scale treatment procedure, the applicant should outline, during the early consultation, the specific toxicity testing or biological effects testing which will be used to prove no significant impact due to the pollutant parameter. The applicant must also demonstrate that if a section 307(a) toxic pollutant is part of the whole effluent that the toxic pollutant does not affect the toxicity evaluation of the nonconventional pollutant at PMEL concentrations. If section 307(a) toxic pollutants are part of the whole effluent, toxicity associated with the toxic component must be isolated from any discussion or measurements of toxicity of the whole effluent containing the nonconventional component treated. The concern is for "masked effects" where the toxic treated at BAT will mask the toxicity effects of the nonconventional pollutant treated at BPT.

The applicant must also obtain approval of any toxicity test employed from the State permitting authority and the EPA Regional Office. The type and number of tests must be chosen carefully in order to protect a balanced population of shellfish, fish and wildlife. EPA recommends discussion of these tests during the early consultation.

Human health impact of the pollutant parameter must also be addressed by the applicant. If bench scale treatment procedures are employed, the applicant must specify which human health effect test methods will be used after the bench scale treatment simulates the appropriate effluent quality. Human health risk assessment methods must be approved by EPA Cincinnati and Headquarters.

3. Downstream Effects

Because the nature of many pollutant parameters is not well understood, applicants should demonstrate that pollutant parameters such as nutrients and oxygen demanding materials will not cause downstream effects which violate State water quality standards. There is concern that many pollutant parameters may not cause impacts immediately beyond the mixing zone but further downstream, beyond the immediate vicinity of the discharge. Pollutants should be examined for latent fate and effects in all cases.

Mixing Zones/Dilution and Fate Models

1. Mixing Zone Determination

In most cases, the impact of a PMEL will be judged at the edge of the State mixing zone. If the State's mixing zone provision is not specific with regard to physical dimensions, a mixing zone may be determined on a case-by-case basis by the State permitting authority and the applicant. If the State forbids use of a mixing zone boundary as part of its water quality standards, the applicant will be required to meet the criterion number (or applicable State water quality standard) at the point of discharge. (Appendix D is a listing of mixing zone dimensions by State.)

In some cases a State may not have a mixing zone policy but may have other parameters in its water quality standards designed to determine water quality and the fate of pollutant discharges after initial mixing. For example, in Pennsylvania wasteload allocations and other water quality analyses are conducted assuming complete mixing at the point of discharge. Dynamic models are also used to evaluate the behavior of non-conservative substances such as toxic organics and pesticides which may mix and recombine with other compounds and substrates in a number of ways. For the purposes of section 301(g) determinations, State water quality standard programs which rely upon predictive models and wasteload allocations in place of mixing zones should apply their models to the 301(g) determination. In some cases, a mixing zone will not serve as a purposeful boundary when the activity of a non-conventional pollutant takes place far beyond the mixing zone boundary. For example, acute toxicity may occur if an ammonia discharge enters a highly alkaline downstream area with increased temperature and reduced dissolved oxygen content.

If the State has no mixing zone policy or boundary but does have approved mixing and dilution predictive models, those should be used in the applicant's section 301(g) completed request. EPA guidance on mixing zones is available in the Water Quality Standards Handbook, November 1983. Copies of the Handbook can be obtained from EPA's Criteria and Standards Division. Call (202) 245-3042.

2. Marine Discharges

When an applicant applies for a section 301(g) variance for an ocean discharge containing nonconventional pollutants, the applicant should determine whether the State has an estuarine or marine mixing zone as part of its water quality standards. If there is none, the applicant should apply the zone of initial dilution (ZID) referenced in the section 301(h) regulation and technical support document which was developed for marine municipal waste discharges. See Appendix E.

3. Water Quality Models

In order to demonstrate that a 301(g) waiver will result in compliance with water quality standards and will not impact other point and nonpoint source discharges, predictive water quality modeling should be performed using either dilution analysis or fate and transport models. Dilution analyses using mixing zone models are adequate for evaluating the impact of wastewater discharges only when the following conditions are met: (1) the pollutant of interest exerts its maximum effect immediately after discharge and (2) either the substance is conservative or an isolated discharge situation exists in which there is a single discharger or a discharger located beyond interaction with other dischargers. Pollutant kinetics and the travel time of the discharge will determine whether these conditions will occur. Fate and transport models are, therefore, required whenever: 1) a pollutant exerts delayed water quality impacts or 2) slow degradation rates relative to travel time and/or scour and resuspension of sorbed pollutants result in an upstream discharge affecting downstream dischargers.

When dilution analyses are appropriate, the 301(g) waiver applicant is encouraged to use an EPA-approved mixing zone model (Appendix F). These models predict the concentration of a pollutant at a specified distance after a specified time of dispersal. If the applicant chooses an EPA model, the computer model must be identified and the printout containing the data and results must also be submitted with the completed request. All computations must be based on sampling data representative of critical conditions. The critical flow chosen for model predictions should be approved by the State and EPA Region before costly computer resources are expended.

The applicant may also use predictive mixing zone models but first must gain approval from the EPA Regional Administrator and State permitting authority. In any case, the applicant should provide a diagram showing the boundary of the mixing zone, the point of discharge, and the pollutant concentration isopleths generated in the mixing zone.

When fate and tranport modeling is required, the 301(g) waiver applicant is encouraged to use an EPA-approved farfield model. If phytoplankton effects on dissolved oxygen are significant in a receiving water and a 301(g) waiver would result in increased ammonia and phosphorus discharges, it is recommended that these pollutants be predicted with one of the following fate and transport models:

Model	Receiving Water Application
Qual II	rivers
Receiv II	rivers and estuaries
WASP	rivers, estuaries, lakes
CLEAN	lakes
LAKECO	lakes
WQRRS	lakes
DEM	estuaries
MIT-DNM	estuaries
EXPLORE-I	estuaries

If a 301(g) waiver would result in increased discharge of nonconventional pesticides or metals which reach downstream discharges or exert delayed water-quality impacts, the following fate and transport models should be considered for use:

Model	Receiving Water Application
EXAMS, MEXAMS	rivers, estuaries, lakes
TOXIWASP	rivers, estuaries, lakes
CTAP	rivers, estuaries, lakes
WASTOX	rivers, estuaries, lakes
SERATRA	rivers
MICHRIV	rivers
HSPF	rivers
FETRA	rivers and estuaries
SLSA	rivers and lakes

These models are described in the guidance documents listed in Appendix H. For further information, contact the Wasteload Allocation Section of the Office of Water Regulations and Standards at (202) 382-7056.

C. Synergistic Propensities

The section 301(g) regulation requires an applicant to demonstrate that synergistic propensities will not cause an impact to human health or aquatic life. According to Casarett and Bruce, 1980, a synergistic effect is a situation in which the combined effect of two chemicals is much greater than the sum of the effect of each agent alone. For example, both tetrachloride and ethanol are hepatotoxic agents, but together they produce much more liver injury than the mathematical sum of their individual effects on the liver would suggest. For the purposes of section 301(g), EPA recommends a broad assessment under the heading of Synergistic Propensities. In addressing synergism, an applicant should include an assessment of the combined effects of two or more pollutants, an assessment of effects produced by combining pollutants and different physical factors, and an assessment of the potential for pollutants to combine chemically and form a more toxic substance. To make such an assessment the applicant must identify the pollutants and the physical conditions in the effluent and the receiving waters which may combine to cause greater toxicity or impact than may be commonly suspected from the individual nonconventional pollutants alone.

To address this aspect a section 301(g) applicant should be review the literature to determine whether its effluent or the effluent and the receiving water will contain dangerous combinations of pollutants. An applicant could also conduct toxicity tests with each of the chemicals in its effluent and compare the sum of the toxicities with the toxicity of the whole effluent. To accomplish this, the applicant may apply biomonitoring techniques, where applicable, to determine whether synergism is occurring in an applicant's effluent. These techniques could include conducting acute and chronic bioassays on the whole effluent and separate fractions of the whole effluent to determine whether the nonconventional component of the effluent, when combined with the toxic or conventional fractions, exhibits synergistic qualities. (See Walsh and Garnas, 1983) In cases where effluents are highly complex, this may be impractical and the applicant may have to rely upon a literature search.

With regard to pollutants and physical parameters in the receiving stream, the applicant should be aware of combinations of varying temperature, pH, and dissolved oxygen levels which could increase the toxicity of the effluent and the receiving stream. For example, the toxicity of ammonia is very much dependent upon pH and temperature. As alkalinity increases, the concentration of highly toxic un-ionized ammonia also increases.

Another area of concern is the possibility of two pollutants combining to form a more toxic substance. For example, when ammonia and chlorine are in the same effluent or receiving waters, they may combine to form more toxic and persistent chlorinated amines. Another dangerous combination of pollutants may be total phenols and chlorine. If the nonconventional portion of total phenols combines with chlorine, the result may be highly toxic chlorinated phenols.

EPA strongly urges applicants to describe their plan to determine whether synergism is occurring in their effluent during the early consultation.

D. Persistency

The section 301(g) regulation requires the applicant to demonstrate whether the nonconventional pollutant will impact human health or aquatic life due to persistency. The applicant should determine the fate of the nonconventional pollutant with regard to its chemical structure and concentration in the environment. The applicant should determine whether the pollutant or pollutant concentration will be altered (and to what degree) by such chemical or physical reactions as volatilization, photolysis, adsorption, absorption, oxidation, hydrolysis, etc. This can be accomplished through a review of the literature or direct measurements. Direct analytical methods must be cited if used. EPA has prepared a draft document which outlines different methods for assessing the fate of a pollutant. The document entitled "Chemical Fate Test Guidelines" is available from NTIS at (703) 487-4650 or the EPA Office of Toxic Substances library at headquarters, referenced as USEPA 560/6-82-003.

Another way to assess persistency is to analyze the chemical structure and properties of the pollutant. The octanol-water partition coefficient, the degree of halogenation, the molecular weight of the compound can help correlate the biological activity of structurally related compounds to the physical parameters of the chemicals.

E. Indicator Pollutants

An applicant can receive consideration for a section 301(g) variance only under very specific conditions. 40 CFR 125.3(g) of the Environmental Permit Regulations states that if a pollutant is being used as an indicator for a toxic or conventional pollutant it cannot be considered for a section 301(g) variance. However, a nonconventional pollutant may be considered for a section 301(g) variance if its role as an indicator can be eliminated. To do so, either: (1) the nonconventional pollutant being used (or proposed for use) as an indicator must be replaced by another indicator or (2) individual permit limits must be placed on the toxic or conventional pollutants for which the indicator is being used.

F. Total Phenols

In keeping with the NPDES Litigation settlement of June 7, 1982, EPA recognizes that total phenols may be considered for section 301(g) variance requests as long as certain conditions are met. Because total phenols (as tested by 4AAP) is a pollutant parameter, it would be subject to the requirements of section 125.54(e)(2) of the section 301(g) regulations. Therefore, the applicant must demonstrate that the total phenols in its effluent do not include toxic phenolics, that those toxic phenolics present are at BAT concentrations or that the toxic phenolics are directly controlled by BAT effluent limitations.

G. Design Conditions

While EPA realizes it cannot impose standard design conditions on all tests and demonstrations provided as evidence for a variance, it is still important that 301(g) applicants strive toward a high degree of consistency in their approaches. The applicant should establish critical design conditions during early consultations with State and EPA officials. In some cases, State water quality standards will specify low flow conditions (e.g., 7Q10). Under such circumstances, the applicant must use the State-specified low flow conditions. Appendix H has a list of design condition documents prepared by the Wasteload Allocation Section of the Office of Water Regulations and Standards. These guidance documents outline procedures for determining the critical temperature, pH, and flow conditions that should be used in steady state mixing zone or fate and transport modeling of streams and rivers. Future documents will be prepared on appropriate design conditions for steady state lake and estuary modeling.

In the absence of EPA guidance on lake and estuary design conditions, the applicant should consider water quality modeling in the waterbodies during periods of minimum dilution. The river inflow to lakes and estuaries could be set at the design conditions recommended for streams and rivers. Lake modeling could then be performed at periods of low water levels as well as spring and fall overturns. Estuarine modeling could be performed at slack tides during periods of maximum stratification and/or minimum dilution.

Mixing zone modeling of marine discharges should follow the guidelines developed for 301(h) waivers. The 301(h) program requires that the zone of initial dilution be determined for periods of critical minimum dilution. These periods are defined as a function of maximum vertical density stratification, minimum initial density differences, maximum waste flow rate, and minimum currents.

IV. EPA Section 301(g) Checklist

EPA has provided prospective section 301(g) applicants and State and Regional Officials with a checklist of factors EPA recommends the applicant and all reviewers (State, Regional officials) address when preparing or reviewing a section 301(g) completed request. This checklist (Appendix G) spans several areas that might affect the granting or denial of a variance. All of these subjects do not have to be addressed with an extraordinary amount of supporting data, but the more completely and concisely they can be addressed, the greater the chance an application will not be rejected due to lack of information or incompleteness.

It is strongly recommended that both the applicant and the State and Regional representatives hold an early consultation and determine what is expected from each applicant before a completed request is filed. The checklist may serve as an agenda for an early consultation and may be used as an outline for preparation of the completed request.

References

Casarett, L.J. and Bruce, M.C., "Origin and Scope of Toxicology," Toxicology: The Basic Science of Poisons, John Doull, C.D. Klaasen, and M.O. Amdur, Eds., Macmillan Publishing Co., Inc., 1980, pp.3-10.

Stern, A.M. and Walker, C.R., "Hazard Assessment of Toxic Substances: Environmental Fate Testing of Organic Chemicals and Ecological Effects Testing," Estimating the Hazard of Chemical Substances to Aquatic Life, ASTM STP 657, John Cairns, Jr., K.L. Dickson, and A.W. Maki, Eds., American Society for Testing and Materials, 1978, pp. 81-131.

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Walsh, G.E. and Garnas, R.L., "Determination of Bioactivity of Chemical Fraction of Liquid Wastes Using Freshwater and Saltwater Algae and Crutaceans". Environmental Science and Technology. March 1983, pp. 180-183.

APPENDIX A

POLLUTANT CHECK

1. Pollutants listed under section 304(a)(4)

A. Conventional pollutants (Not eligible for a 301(g) variance)

The following comprise the list of conventional pollutants designated at40 CFR401.16 pursuant to section 304(a)(4) of the Act.

1. Biochemical oxygen demand (BOD)
2. Total suspended solids (TSS) (nonfilterable)
3. pH
4. Fecal coliform
5. Oil and grease

(44 FR 44501, July 30, 1979)

B. Toxic Pollutants (Not eligible for a 301(g) variance)

The following comprise the list of toxic pollutants designated pursuant to section 307(a)(1) of the Clean Water Act.

1. Acenaphthene
2. Acrolein
3. Acrylonitrile
4. Aldrin/Dieldrin
5. Antimony and compounds*
6. Arsenic and compounds
7. Asbestos
8. Benzene
9. Benzidine
10. Beryllium and compounds
11. Cadmuim and compounds
12. Carbon tetrachloride
13. Chlordane (technical mixture and metabolites)
14. Chlorinated benzenes (other than dichlorobenzenes)
15. Chlorinated ethanes (including 1,2-dichloroethane, 1,1,1-trichloroethane, and hexachloroethane)
16. Chrioalkyl ethers (chloroethyl and mixed ethers)
17. Chlorinated naphthalene
18. Chlorinated phenols (other than those listed elsewhere; includes trichlorophenols and chlorinated cresols)
19. Chloroform
20. 2-chlorophenol
21. Chromium and compounds
22. Copper and compounds
23. Cyanides
24. DDT and metabolites
25. Dichlorobenzenes (1,2-, 1,3-, and 1,4-dichlorobenzenes)
26. Dichlorobenzidene
27. Dichloroethylenes (1,1-, and 1,2-dichloroethylene)
28. 2,4-dichlorophenol
29. Dichloropropane and dichloropropene
30. 2,4-dimethylphenol
31. Dinitrotoluene
32. Diphenylhydrazine
33. Endosulfan
34. Endrin and metabolites
35. Ethylbenzene
36. Fluoranthene
37. Haloethers (others than those listed elsewhere; includes chlorophenylphenyl ethers, bromophenylphenyl ether, bis(dichloroisopropyl) ether, bis-*(chloroethoxy) methane and polychlorinated diphenyl* ethers).
38. Halomethanes (other than those listed elsewhere; includes methylene chloride, methylchloride, methylbromide bromoform, dichlorobromomethane)

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* The term "compounds" shall include organic and inorganic compounds.

39. Heptachlor and metabolites
40. Hexachlorobutadiene
41. Hexachlorocyclohexane
42. Hexachlorocyclopentadiene
43. Isophorone
44. Lead and compounds
45. Mercury and compounds
46. Naphthalene
47. Nickel and compounds
48. Nitrobenzene
49. Nitrophenols (including 2,4-dinitrophenol, dinitrocresol)
50. Nitrosamines
51. Pentachlorophenol
52. Phenol
53. Phthalate esters
54. Polychlorinated biphenyls (PCBs)
55. Polyaromatic hydrocarbons (including benzanthracenes, benzopyrenes, benzofluoranthene, chrysenes, dibenzoanthracenes, and indenopyrenes)
56. Selenium and compounds
57. Silver and compounds
58. 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)
59. Tetrachloroethylene
60. Thallium and compounds
61. Toluene
62. Toxaphene
63. Trichloroethylene
64. Vinyl chloride
65. Zinc and compounds

[44 FR 44502, July 30, 1979, as amended at 46 FR 2266, Jan.8, 1981; 46 FR 10724, Feb 4, 1981]

C. MAJOR NONCONVENTIONAL POLLUTANTS

The following nonconventional pollutants are common to a great number of industrial dischargers and as such are expected to be limited by effluent guidelines for some industrial subcategories.

Aluminum

Ammonia

Barium

Chemical Oxygen Demand (COD)

Chlorine

Fluorines

Iron

Manganese

Pesticides (all those considered nonconventional in the Pesticides Guideline and not listed as toxic)

Total Phenols (4AAP)

APPENDIX B

The following appendix contains the two sets of guidelines for deriving water quality criteria as presented by EPA on November 28, 1980 in the Federal Register (45 FR 79341). The first set of guidelines (Appendix B) is intended for deriving water quality criteria which protect aquatic life and its uses. The second set of guidelines (Appendix C) on page 79347 is intended for making human health assessments about a particular pollutant. Both sets of guidelines offer methodologies for deriving water quality criteria. These guidelines should be applied in a 301(g) assessment if there are no existing EPA water quality criteria or State water quality standards for the nonconventional pollutant in question.

Appendix B—Guidelines for Deriving Water Quality Criteria for the Protection of Aquatic Life and Its Uses

Introduction

This version of the Guidelines provides clarifications, additional details, and technical and editorial changes in the last version published in the Federal Register [44 FR 15970 (March 15, 1979)]. This version incorporates changes resulting from comments on previous versions and from experience gained during U.S. EPA's use of the previous versions. Future versions of the Guidelines will incorporate new ideas and data as their usefulness is demonstrated.

Criteria may be expressed in several forms. The numerical form is commonly used, but descriptive and procedural forms can be used if numerical criteria are not possible or desirable. The purpose of these Guidelines is to describe an objective, internally consistent and appropriate way of deriving numerical water quality criteria for the protection of the uses of, as well as the presence of, aquatic organisms.

A numerical criterion might be thought of as an estimate of the highest concentration of a substance in water which does not present a significant risk to the aquatic organisms in the water and their uses. Thus the Guidelines are intended to derive criteria which will protect aquatic communities by protecting most of the species and their uses most of the time, but not necessarily all of the species all of the time. Aquatic communities can tolerate some stress and occasional adverse effects on a few species, and so total protection of all of the species all of the time is not necessary. Rather, the Guidelines attempt to provide a reasonable and adequate amount of protection with only a small possibility of considerable overprotection or underprotection. Within these constraints, it seems appropriate to err on the side of overprotection.

The numerical aquatic life criteria derived using the Guidelines are expressed as two numbers, rather than the traditional one number, so that the criteria can more accurately reflect toxicological and practical realities. The combination of both a maximum value and a 24-hour average value is designed to provide adequate protection of aquatic life and its uses from acute and chronic toxicity to animals, toxicity to plants and bioconcentration by aquatic organisms without being as restrictive as a one-number criterion would have to be to provide the same amout of protection. The only way to assure the same degree of protection with a one-number criterion would be to use the 24-hour average as a concentration that is not to be exceeded at any time in any place.

The two-number criterion is intended to identify an average pollutant concentration which will produce a water qualtiy generally suited to the maintenance of aquatic life and its uses while restricting the extent and duration of excursions over the average so that the total exposure will not cause unacceptable adverse effects. Merely specifying an average value over a time period is insufficient, unless the period of time is rather short, because of concentration higher than the average value can kill or cause substantial damage in short periods. Furthermore, for some substances the effect of intermittent high exposures is cumulative. It is therefore necessary to place an upper limit on pollutant concentrations to which aquatic organisms might be exposed, especially when the maximum value is not much higher than the average value. For some substances the maximum may be so much higher than the 24-hour average that in any real-world situation the maximum will never be reached if the 24-hour average is achieved. In such cases the 24-hour average will be limiting and the maximum will have no practical significance, except to indicate that elevated concentrations are acceptable as long as the 24-hour average is achieved.

These Guidelines have been developed on the assumption that the results of laboratory tests are generally useful for predicting what will happen in field situations. The resulting criteria are meant to apply to most bodies of water in the United States, except for the Great Salt Lake. All aquatic organisms and their common uses are meant to be considered, but not necessarily protected, if relevant data are available, with at least one specific exception. This exception is the accumulation of residues of organic compounds in the siscowet subspecies of lake trout which occurs in Lake Superior and contains up to 67% fat in the fillets (Thurston, C.E., 1962, Physical Characteristics and Chemical Composition of Two Subspecies of Lake Trout, J. Fish. Res. Bd. Canada 19:39–44). Neither siscowet nor organisms in the Great Salt Lake are intentionally protected by these Guidelines because both may be too atypical.

With appropriate modifications these Guidelines can be used to derive criteria for any specified geographical area, body of water (such as the Great Salt Lake), or group of similar bodies of water. Thus with appropriate modifications the Guidelines can be used to derive national, state, or local criteria if adequate information is available concerning the effects of the substance of concern on appropriate species and their uses. However, the basic concepts described in the Guidelines should be modified only when sound scientific evidence indicates that a criterion produced using the Guidelines would probably significantly overprotect or underprotect the presence or uses of aquatic life.

Criteria produced by these Guidelines are not enforceable numbers. They may be used in developing enforceable numbers, such as water quality standards and effluent standards. However, the development of standards may take into account additional factors such as social, legal, economic, and hydrological considerations, the environmental and analytical chemistry of the substance, the extrapolation from laboratory data to field situations, and the relationship between the species for which data are available and the species which are to be protected.

Because fresh water and salt water (including both estuarine and marine waters) have basically different chemical compositions and because freshwater and saltwater species rarely inhabit the same water simultaneously, separate criteria should be derived for these two kinds of waters. However, for some substances sufficient data may not be available to allow derivation of one or both of these criteria using the Guidelines.

These Guidelines are meant to be used after a decision is made that a criterion is needed for a substance. The Guidelines do not address the rationale for making that decision. If the potential for adverse effects on aquatic life and its uses are part of the basis for deciding whether or not a criterion is needed for a substance, these Guidelines may be helpful in the collection and interpretation of relevant data.

I. Define the Substance for Which the Criterion Is To Be Derived

A. Each separate chemical which would not ionize significantly in most natural bodies of water should usually be considered a separate substance, except possibly for structurally similar organic compounds that only differ in the number and location of atoms of a specific halogen, and only exist in large quantities as commercial mixtures of the various compounds, and apparently have similar chemical, biological, and toxicological properties.

B. For chemicals, which would ionize significantly in most natural bodies of water, such as inorganic salts, organic acids and phenols, all forms that would be in chemical equilibrium should usually be considered one substance. For metals, each different valence and each different covalently bonded organometallic compound should usually be considered a separate substance.

C. The definition of the substance may also need to take into account the analytical chemistry and fate of the substance.

II. Collect and Review Available Data

A. Collect all available data on the substance concerning (1) toxicity to, and bioaccumulation by, aquatic animals and plants, (2) FDA action levels, and (3) chronic feeding studies with wildlife.

B. Discard all data that are not available in hard copy (publication, manuscript, letter, memorandum, etc.) with enough supporting information to indicate that acceptable test procedures were used and that the results are reliable. Do not assume that all published data are acceptable.

C. Discard questionable data. For example, discard data from tests for which no control treatment existed, in which too many organisms in the control treatment died or showed signs of stress or disease, or in which distilled or deionized water was used as the dilution water for aquatic organisms. Discard data on formulated mixtures and emulsifiable concentrates of the substance of concern, but not necessarily data on technical grade material.

D. Do not use data obtained using:

1. Brine shrimp, because they usually only occur naturally in water with salinity greater than 35 g/kg.

2. Species that do not have reproducing wild populations resident in—but not necessarily native to—North America. Resident North American species of fishes are defined as those listed in "A List of Common and Scientific Names of Fishes from the United States and Canada", 3rd ed., Special Publication No. 6, American Fisheries Society, Washington, D.C., 1970. Data obtained with non-resident species can be used to indicate relationships and possible problem areas, but cannot be used in the derivation of criteria.

3. Organisms that were previously exposed to significant concentrations of the test material or other pollutants.

III. Minimum Data Base

A. A minimum amount of data should be available to help ensure that each of the four major kinds of possible adverse effects receives some consideration. Results of acute and chronic toxicity tests with a reasonable number and variety of aquatic animals are necessary so that data available for tested species can be considered a useful indication of the sensitivities of the numerous untested species. The requirements concerning toxicity to aquatic plants are less stringent because procedures for conducting tests with plants are not as well developed and the interpretation of the results is more questionable. Data concerning bioconcentration by aquatic organisms can only be used if other relevant data are available.

B. To derive a criterion for freshwater aquatic life, the following should be available:

1. Acute tests (see Section IV) with freshwater animals in at least eight different families provided that of the eight species:

—at least one is a salmonid fish
—at least one is a non-salmonid fish
—at least one is a planktonic crustacean
—at least one is a benthic crustacean
—at least one is a benthic insect
—at least one of the benthic species is a detritivore

2. Acute-chronic ratios (see Section VI) for at least three species of aquatic animals provided that of the three species:

—at least one is a fish
—at least one is an invertebrate
—at least one is a freshwater species (the other two may be saltwater species)

3. At least one test with a freshwater alga or a chronic test with a freshwater vascular plant (see Section VIII). If plants are among the aquatic organisms that are most sensitive to the substance, tests with more than one species should be available.

4. At least one acceptable bioconcentration factor determined with an aquatic animal species, if a maximum permissible tissue concentration is available (see Section IX).

C. To derive a criterion for saltwater aquatic life, the following should be available:

1. Acute tests (see Section IV) with saltwater animals in at least eight different families provided that of the eight species:

—at least two different fish families are included
—at least five different invertebrate families are included
—either the Mysidae or Penaeidae family or both are included
—at least one of the invertebrate families is in a phylum other than Arthropoda

2. Acute-chronic ratios (see Section VI) for at least three species of aquatic animals provided that of the three species:

—at least one is a fish
—at least one is an invertebrate
—at least one is a saltwater species (the other two may be freshwater species)

3. At least one test with a saltwater alga or a chronic test with a saltwater vascular plant (see Section VIII). If plants are among the aquatic organisms most sensitive to the substance, tests with more than one species should be available.

4. At least one acceptable bioconcentration factor determined with an aquatic animal species, if a maximum permissible tissue concentration is available (see Section IX).

D. If all the requirements of the minimum data base are met, a criterion can usually be derived, except in special cases. For example, a criterion might not be possible if the acute-chronic ratios vary greatly with no apparent pattern. Also, if a criterion is to be related to a water quality characteristic, (see Sections V and VII), more data will be necessary.

Similarly, if the minimum data requirements are not satisfied, generally a criterion should not be derived, except in special cases. One such special case would be when less than the minimum amount of acute and chronic data are available, but the available data clearly indicate that the Final Residue Value would be substantially lower then either the Final Chronic Value or the Final Plant Value.

IV. Final Acute Value

A. Appropriate measures of the acute (short-term) toxicity of the substance to various species of aquatic animals are used to calculate the Final Acute Value. If acute values are available for fewer than twenty species, the Final Acute Value probably should be lower than the lowest value. On the other hand, if acute values are available for more than twenty species, the Final Acute Value probably should be higher than the lowest value, unless the most sensitive species is an important one. Although the procedure used to calculate the Final Acute Value has some limitations, it apparently is the best of the procedures currently available.

B. Acute toxicity tests should be conducted using procedures such as those described in:

ASTM Standard E 729–80, Practice for Conducting Acute Toxicity Tests with Fishes, Macroinvertebrates, and Amphibians. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM Standard E 724–80, Practice for Conducting Static Acute Toxicity Tests with Larvae of Four Species of Bivalve Molluscs. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

C. Results of acute tests in which food was added to the test solutions should not be used, because this may unnecessarily affect the results of the test.

D. Results of acute tests conducted with embryos should not be used (but see Section IV.E.2), because this is often an insensitive life stage.

E. Acute values should be based on endpoints and lengths of exposure appropriate to the life stage of the species tested. Therefore, only the following kinds of data on acute toxicity to aquatic animals should be used:

1. 48-hr EC50 values based on immobilization and 48-hr LC50 values for first-instar (less than 24 hours old) daphnids and other cladocerans, and second- or third-instar midge larvae.

2. 48- to 96-hr EC50 values based on incomplete shell development and 48- to 96-hr LC50 values for embryos and larvae of barnacles, bivalve molluscs (clams, mussels, oysters, and scallops), sea urchins, lobsters, crabs, shrimps, and abalones.

3. 96-hr EC50 values based on decreased shell deposition for oysters.

4. 96-hr EC50 values on immobilization or loss of equilibrium or both and 96-hr LC50 values for aquatic animals, except for cladocerans, midges, and animals whose behavior or physiology allows them to avoid

exposure to toxicant or for whom the acute adverse effect of the exposure cannot be adequately measured. Such freshwater and saltwater animals include air-breathing molluscs, unionid clams, operculate snails, and bivalve molluscs, except for some species that cannot "close up" and thus prevent exposure to toxicant, such as the bay scallop (*Argopecten irradians*).

F. For the use of LC50 or EC50 values for durations shorter and longer than those listed above, see Section X.

G. If the acute toxicity of the substance to aquatic animals has been shown to be related to a water quality characteristic such as hardness for freshwater organisms or salinity for saltwater organisms, a Final Acute Equation should be derived based on that water quality characteristic. Go to Section V.

H. If the acute toxicity of the substance has not been adequately shown to be related to a water quality characteristic, for each species for which at least one acute value is available, calculate the geometric mean of the results of all flow-through tests in which the toxicant concentrations were measured. For a species for which no such result is available, calculate the geometric mean of all available acute values, i.e., results of flow-through tests in which the toxicant concentrations were not measured and results of static and renewal tests based on initial total toxicant concentrations.

Note.—The geometric mean of N numbers is obtained by taking the N^{th} root of the product of N numbers. Alternatively, the geometric mean can be calculated by adding the logarithms of the N numbers, dividing the sum by N, and taking the antilog of the quotient. The geometric mean of two numbers can also be calculated as the square root of the product of the two numbers. The geometric mean of one number is that number. Either natural (base e) or common (base 10) logarithms can be used to calculate geometric means as long as they are used consistently within each set of data, i.e., the antilog used must match the logarithm used.

I. Count the number = N of species for which a species mean acute value is available.

J. Order the species mean acute values from low to high. Take the common logarithms of the N values (log mean values).

K. The intervals (cell widths) for the lower cumulative proportion calculations are 0.11 common log units apart, starting from the lowest log value. The value of 0.11 is an estimate of average precision and was calculated from replicate species acute values.

L. Starting with the lowest log mean value, separate the N values into intervals (or cells) calculated in Step IV. K.

M. Calculate cumulative proportions for each non-empty interval by summing the number of values in the present and all lower intervals and dividing by N. These calculations only need to be done for the first three non-empty intervals (or cells).

N. Calculate the arithmetic mean of the log mean values for each of the three intervals.

O. Using the two interval mean acute values and cumulative proportions closest to 0.05, linearly extrapolate or interpolate to the 0.05 log concentration. The Final Acute Value is the antilog of the 0.05 concentration.

In other words, where

Prop(1) and conc(1) are the cumulative proportion and mean log value for the lowest non-empty interval.
Prop(2) and conc(2) are the cumulative proportion and mean log value for the second lowest non-empty interval.
A = Slope of the cumulative proportions
B = The 0.05 log value

Then:

$A = [0.05 - \text{Prop}(1)]/[\text{Prop}(2) - \text{Prop}(1)]$
$B = \text{conc}(1) + A\,[\text{conc}(2) - \text{conc}(1)]$
$\text{Final Acute Value} = 10^{B}$

P. If for an important species, such as a recreationally or commercially important species, the geometric mean of the acute values from flow-through tests in which the toxicant concentrations were measured is lower than the Final Acute Value, then that geometric mean should be used as the Final Acute Value.

Q. Go to Section VI.

V. Final Acute Equation

A. When enough data are available to show that acute toxicity to two or more species is similarly affected by a water quality characteristic, this effect can be taken into account as described below. Pooled regression analysis should produce similar results, although data available for individual species would be weighted differently.

B. For each species for which comparable acute toxicity values are available at two or more different values of a water quality characteristic which apparently affects toxicity, perform a least squares regression of the natural logarithms of the acute toxicity values on the natural logarithms of the values of the water quality characteristic. (Natural logarithms [logarithms to the base e, denoted as ln] are used herein merely because they are easier to use on some hand calculators and computers than common logarithms [logarithms to the base 10]. Consistent use of either will produce the same result.) No transformation or a different transformation may be used if it fits the data better, but appropriate changes will be necessary throughout this section.

C. Determine whether or not each acute slope is meaningful, taking into account the range and number of values of the water quality characteristic tested. For example, a slope based on four data points may be of limited value if it is based only on data for a narrow range of values of the water quality characteristic. On the other hand, a slope based on only two data points may be meaningful if it is consistent with other information and if the two points cover a broad enough range of the water quality characteristic. If meaningful slopes are not available for at least two species or if the available slopes are not similar, return to Section IV. H., using the results of tests conducted under conditions and in water similar to those commonly used for toxicity tests with the species

D. Calculate the mean acute slope (V) as the arithmetic average of all the meaningful acute slopes for individual species.

E. For each species calculate the geometric mean (W) of the acute toxicity values and the geometric mean (X) of the related values of the water quality characteristic.

F. For each species calculate the logarithmic intercept (Y) using the equation: $Y = \ln W - V(\ln X)$.

G. For each species calculate the species mean acute intercept as the antilog of Y.

H. Obtain the Final Acute Intercept by using the procedure described in Section IV. I–O, except insert "Intercept" for "Value".

I. If for an important species, such as a recreationally or commercially important species, the intercept calculated only from results of flow-through tests in which the toxicant concentrations were measured is lower than the Final Acute Intercept, then that intercept should be used as the Final Acute Intercept.

J. The Final Acute Equation is written as $e^{(V[\ln(\text{water quality characteristic})]+\ln Z)}$, where V = mean acute slope and Z = Final Acute Intercept.

VI. Final Chronic Value

A. The Final Chronic Value can be calculated in the same manner as the Final Acute Value or by dividing the Final Acute Value by the Final Acute-Chronic Ratio, depending on the data available. In some cases it will not be possible to calculate a Final Chronic Value.

B. Use only the results of flow-through (except renewal is acceptable for daphnids) chronic tests in which the concentrations of toxicant in the test solutions were measured.

C. Do not use the results of any chronic test in which survival, growth, or reproduction among the controls was unacceptably low.

D. Chronic values should be based on endpoints and lengths of exposure appropriate to the species. Therefore, only the results of the following kinds of chronic toxicity tests should be used:

1. Life-cycle toxicity tests consisting of exposures of each of several groups of individuals of a species to a different concentration of the toxicant throughout a life cycle. To ensure that all life stages and life processes are exposed, the test should begin with embryos or newly hatched young less than 48 hours old (less than 24 hours old for daphnids), continue through maturation and reproduction, and with fish should end not less than 24 days (90 days for salmonids) after the hatching of the next generation. For fish, data should be obtained and analyzed on survival and growth of adults and young, maturation of males and females, embryos spawned per female, embryo viability (salmonids only) and hatchability. For daphnids, data should be obtained and analyzed on survival and young per female.

2. Partial life-cycle toxicity tests consisting of exposures of each of several groups of individuals of a species of fish to a different concentration of the toxicant through most portions of a life cycle. Partial life-cycle tests are conducted with fish species that require more than a year to reach sexual maturity, so that the test can be completed in less than 15 months, but still expose all major life stages to the toxicant. Exposure to the toxicant begins with immature juveniles at least 2 months prior to active gonad development, continues through maturation and reproduction, and ends not less than 24 days (90 days for salmonids) after the hatching of the next generation. Data should be obtained and analyzed on survival and growth of adults and young, maturation of males and females, embryos spawned per female, embryo viability (salmonids only) and hatchability.

3. Early-life-stage toxicity tests consisting of 28- to 32-days (60 days post-hatch for salmonids) exposures of the early life stages of a species of fish from shortly after fertilization through embryonic, larval, and early juvenile development. Data should be obtained and analyzed on survival and growth.

E. Do not use the results of an early-life-stage test if results of a life-cycle or partial life-cycle test with the same species are available.

F. A chronic value is obtained by calculating the geometric mean of the lower and upper chronic limits from a chronic test. A lower chronic limit is the highest tested concentration (1) in an acceptable chronic test, (2) which did not cause the occurrence (which was statistically significantly different from the control at $p=0.05$) of a specified adverse effect, and (3) below which no tested concentration caused such an occurrence. An upper chronic limit is the lowest tested concentration (1) in an acceptable chronic test, (2) which did cause the occurrence (which was statistically significantly different from the control at $p=0.05$) of a specified adverse effect and (3) above which all tested concentrations caused such an occurrence.

Note.—Various authors have used a variety of terms and definitions to interpret the results of chronic tests, so reported results should be reviewed carefully.

G. If the chronic toxicity of the substance to aquatic animals has been adequately shown to be related to a water quality characteristic such as hardness for freshwater organisms or salinity for saltwater organisms, a Final Chronic Equation should be derived based on that water quality characteristic. Go to Section VII.

H. If chronic values are available for eight species as described in Section III. B.1 or III. C.1, a species mean chronic value should be calculated for each species for which at least one chronic value is available by calculating the geometric mean of all the chronic values for the species. The Final Chronic Value should then be obtained using the procedures described in Section IV. I–O. Then go to Section VI. M.

I. For each chronic value for which at least one appropriate acute value is available, calculate an acute-chronic ratio, using for the numerator the arithmetic average of the results of all standard flow-through acute tests in which the concentrations were measured and which are from the same study as the chronic test. If such an acute test is not available, use for the numerator the results of a standard acute test performed at the same laboratory with the same species, toxicant and dilution water. If no such acute test is available, use the species mean acute value for the numerator.

Note.—If the acute toxicity or chronic toxicity or both of the substance have been adequately shown to be related to a water quality characteristic, the numerator and the denominator must be based on tests performed in the same water.

J. For each species, calculate the species mean acute-chronic ratio as the geometric mean of all the acute-chronic ratios available for that species.

K. For some substances the species mean acute-chronic ratio seems to be the same for all species, but for other substances the ratio seems to increase as the species mean acute value increases. Thus the Final Acute-Chronic Ratio can be obtained in two ways, depending on the data available.

1. If no major trend is apparent and the acute-chronic ratios for a number of species are within a factor of ten, the final Acute-Chronic Ratio should be calculated as the geometric mean of all the species mean acute-chronic ratios available for both freshwater and saltwater species.

2. If the species mean acute-chronic ratio seems to increase as the species mean acute value increases, the value of the acute-chronic ratio for species whose acute values are close to the Final Acute Value should be chosen as the Final Acute-Chronic Ratio.

L. Calculate the Final Chronic Value by dividing the Final Acute Value by the Final Acute-Chronic Ratio.

M. If the species mean chronic value of an important species, such as a commercially or recreationally important species, is lower than the Final Chronic Value, then that species mean chronic value should be used as the Final Chronic Value.

N. Go to Section VIII.

VII. Final Chronic Equation

A. For each species for which comparable chronic toxicity values are available at two or more different values of a water quality characteristic which apparently affects chronic toxicity, perform a least squares regression of the natural logarithms of the chronic toxicity values on the natural logarithms of the water quality characteristic values. No transformation or a different transformation may be used if it fits the data better, but appropriate changes will be necessary throughout this section. It is probably preferable, but not necessary, to use the same transformation that was used with the acute values in Section V.

B. Determine whether or not each chronic slope is meaningful, taking into account the range and number of values of the water quality characteristic tested. For example, a slope based on four data points may be of limited value if it is based only on data for a narrow range of values of the water quality characteristic. On the other hand, a slope based on only two data points may be meaningful if it is consistent with other information and if the two points cover a broad enough range of the water quality characteristic. If a meaningful chronic slope is not available for at least one species, return to Section VI. H.

C. Calculate the mean chronic slope (L) as the arithmetic average of all the meaningful chronic slopes for individual species.

D. For each species calculate the geometric mean (M) of the toxicity values and the geometric mean (P) of the related values of the water quality characteristic.

E. For each species calculate the logarithmic intercept (Q) using the equation: $Q = \ln M - L(\ln P)$.

F. For each species calculate a species mean chronic intercept as the antilog of Q.

G. Obtain the Final Chronic Intercept by using the procedure described in Section IV. I–O, except insert "Intercept" for "Value".

H. If the species mean chronic intercept of an important species, such as a commercially or recreationally important species, is lower than the Final Chronic Intercept, then that species mean chronic intercept should be used as the Final Chronic Intercept.

I. The Final Chronic Equation is written as $e^{(L[\ln(\text{Water quality characteristic})]+\ln \bar{R})}$, where L=mean chronic slope and $\bar{R}$= Final Chronic Intercept.

VIII. Final Plant Value

A. Appropriate measures of the toxicity of the substance to aquatic plants are used to compare the relative sensitivities of aquatic plants and animals.

B. A value is a concentration which decreased growth (as measured by dry weight, chlorophyll, etc.) in a 96-hr or longer test with an alga or in a chronic test with an aquatic vascular plant.

C. Obtain the Final Plant Value by selecting the lowest plant value from a test in which the toxicant concentrations were measured.

IX. Final Residue Value

A. The Final Residue Value is derived in order to (1) prevent commercially or recreationally important aquatic organisms from exceeding relevant FDA action levels and (2) protect wildlife, including fishes and birds, that eat aquatic organisms from demonstrated adverse effects. A residue value is calculated by dividing a maximum permissible tissue concentration by an appropriate bioconcentration factor (BCF), where the BCF is the quotient of the concentration of a substance in all or part of an aquatic organism divided by the concentration in water to which the organism has been exposed. A maximum permissible tissue concentration is either (1) an action level from the FDA Administrative Guidelines Manual for fish oil or for the edible portion of fish or shellfish, or (2) a maximum acceptable dietary intake based on observations on survival, growth or reproduction in a chronic wildlife feeding study. If no maximum permissible tissue concentration is available, go to Section X because no Final Residue Value can be derived.

B. 1. A BCF determined in a laboratory test should be used only if it was calculated based on measured concentrations of the substance in the test solution and was based on an exposure that continued until either steady-state or 28-days was reached. Steady-state is reached when the BCF does not change significantly over a period of time, such as two days or 16 percent of the length of the exposure, whichever is longer. If a steady-state BCF is not available for a species, the available BCF for the longest exposure over 28 days should be used for that species.

2. A BCF from a field exposure should be used only when it is known that the concentration of the substance was reasonably constant for a long enough period of time over the range of territory inhabited by the organisms.

3. If BCF values from field exposures are consistently lower or higher than those from laboratory exposures, then only those values from field exposures should be used if possible.

4. A BCF should be calculated based on the concentration of the substance and its metabolites, which are structurally similar and are not much more soluble in water than the parent compound, in appropriate tissue and should be corrected for the concentration in the organisms at the beginning of the test.

5. A BCF value obtained from a laboratory or field exposure that caused an observable adverse effect on the test organism may be used only if it is similar to that obtained with unaffected organisms at lower concentrations in the same test.

6. Whenever a BCF is determined for a lipid-soluble substance, the percent lipids should also be determined in the tissue for which the BCF was calculated.

C. A BCF calculated using dry tissue weights must be converted to a wet tissue weight basis by multiplying the dry weight BCF value by 0.1 for plankton and by 0.2 for individual species of fishes and invertebrates.

Note.—The values of 0.2 and 0.1 were derived from data published in:

McDiffett, W. F., 1970. Ecology 51:975–988.
Brocksen, R. W., et al. 1968. J. Wildlife Management 32:52–73.
Cummins, K. W., et al. 1973. Ecology 54: 336–345.
Pesticide Analytical Manual, Volume I. Food and Drug Administration, 1969.
Love, R. M., 1957. In The Physiology of Fishes, Vol. I, M. E. Brown, ed. Academic Press, New York. p. 411.
Ruttner, F., 1963. Fundamentals of Limnology 3rd ed. Trans. by D. G. Frey and F. E. J. Fry Univ. of Toronto Press, Toronto.

Some additional values can be found in
Sculthorpe, C. D., 1967. The Biology of Aquatic Vascular Plants. Arnold Publishing Ltd., London.

D. If enough pertinent data exist, several residue values can be calculated by dividing maximum permissible tissue concentrations by appropriate BCF values.

1. For each available maximum acceptable dietary intake derived from a chronic feeding study with wildlife, including birds and aquatic organisms the appropriate BCF is based on the whole body of aquatic species which constitute or represent a major portion of the diet of the tested wildlife species.

2. For an FDA action level, the appropriate BCF is the highest geometric mean species BCF for the edible portion (muscle for decapods, muscle with or without skin for fishes, adductor muscle for scallops and total living tissue for other bivalve molluscs) of a consumed species. The highest species BCF is used because FDA action levels are applied on a species-by-species basis.

E. For lipid-soluble substances, it may be possible to calculate additional residue values. Because steady-state BCF values for a lipid-soluble chemical seem to be proportional to percent lipids from one tissue to another and from one species to another, extrapolations can be made from tested tissues or species to untested tissues or species on the basis of percent lipids.

1. For each BCF for which the percent lipids is known for the same tissue for which the BCF was measured, the BCF should be normalized to a one percent lipid basis by dividing the BCF by the percent lipids. This adjustment to a one percent lipid basis makes all the measured BCF values comparable regardless of the species or tissue for which the BCF was measured.

2. Calculate the geometric mean normalized BCF. Data for both saltwater and freshwater species can be used to determine the mean normalized BCF, because the normalized BCF seems to be about the same for both kinds of organisms.

3. Residue values can then be calculated by dividing the maximum permissible tissue concentrations by the mean normalized BCF and by a percent lipids value appropriate to the maximum permissible tissue concentration, *i.e.*,

$$\text{Residue Value} = \frac{\text{(maximum permissible tissue concentration)}}{\text{(mean normalized BCF)(appropriate percent lipids)}}$$

a. For an FDA action level for fish oil, the appropriate percent lipids value is 100.

b. For an FDA action level for fish, the appropriate percent lipids value is 15 for freshwater criteria and 16 for saltwater criteria because FDA action levels are applied on a species-by-species basis to commonly consumed species. The edible portion of the freshwater lake trout averages about 15 percent lipids, and the edible portion of the saltwater Atlantic herring averages about 16 percent lipids (Sidwell, V. D., et al. 1974 Composition of the Edible Portion of Raw (Fresh or Frozen) Crustaceans, Finfish, and Mollusks. I. Protein, Fat, Moisture, Ash, Carbohydrate, Energy Value, and Cholesterol. Marine Fisheries Review 36:21–35).

c. For a maximum acceptable dietary intake derived from a chronic feeding study with wildlife, the appropriate percent lipids is the percent lipids of an aquatic species or group of aquatic species which constitute a major portion of the diet of the wildlife species.

F. The Final Residue Value is obtained by selecting the lowest of the available residue values. It should be noted that in many cases the Final Residue Value will not be low enough. For example, a residue value calculated from an FDA action level would result in an average concentration in the edible portion of a fatty species that is at the action level. On the average half of the individuals of the species would have concentrations above the FDA action level. Also, the results of many chronic feeding studies are concentrations that cause adverse effects.

X. Other Data

Pertinent information that could not be used in earlier sections may be available concerning adverse effects on aquatic organisms and their uses. The most important of these are data on flavor impairment, reduction in survival, growth, or reproduction, or any other adverse effect that has been shown to be biologically significant. Especially important are data for species for which no other data are available. Data from behavioral, micorcosm, field, and physiological studies may also be available.

XI. Criterion

A. The criterion consists of two concentrations, one that should not be exceeded on the average in a 24-hour period and one that should not be exceeded at any time during the 24-hour period. This two-number criterion is intended to identify water quality conditions that should protect aquatic life and its uses from acute and chronic adverse effects of both cumulative and noncumulative substances without being as restrictive as a one-number criterion would have to be to provide the same degree of protection.

B. The maximum concentration is the Final Acute Value or is obtained from the Final Acute Equation.

C. The 24-hour average concentration is obtained from the Final Chronic Value, the Final Plant Value, and the Final Residue Value by selecting the lowest available value, unless other data (see Section X) from tests in which the toxicant concentrations were measured show that a lower value should be used. If toxicity is related to a water quality characteristic, the 24-hour average concentration is obtained from the Final Chronic Equation, the Final Plant Value, and the Final Residue Value by selecting the one that results in the lowest concentrations in the normal range of the water quality characteristic, unless other data (see Section X) from tests in which the toxicant concentrations were measured show that a lower value should be used.

D. The criterion is (the 24-hour average concentration) as a 24-hour average and the concentration should not exceed (the maximum concentration) at any time.

XII. Review

A. On the basis of all available pertinent laboratory and field information, determine if the criterion is consistent with sound scientific evidence. If it is not, another criterion, either higher or lower, should be derived using appropriate modifications of the Guidelines.

These Guidelines were written by Charles E. Stephan, Donald I. Mount, David J. Hansen, John H. Gentile, Gary A. Chapman and William A. Brungs of the U.S.E.P.A. Environmental Research Laboratories in Corvallis, Oregon, Duluth, Minnesota, Gulf Breeze, Florida, and Narragansett, Rhode Island. Numerous other people, many of whom do not work for U.S.E.P.A., provided assistance and suggestions.

Appendix C—Guidelines and Methodology Used in the Preparation of Health Effect Assessment Chapters of the Consent Decree Water Criteria Documents

I. Objective

The objective of the health effect assessment chapters of the ambient water criteria documents is to estimate ambient water concentrations which do not represent a significant risk to the public. These assessments should constitute a review of all relevant information on individual chemicals or chemical classes in order to derive criteria that represent, in the case of suspect or proven carcinogens, various levels of incremental cancer risk, or, in the case of other pollutants, estimates of no-effect levels.

Ideally, ambient water quality criteria should represent levels for compounds in ambient water that do not pose a hazard to the human population. However, in any realistic assessment of human health hazard, a fundamental distinction must be made between absolute safety and the recognition of some risk. Criteria for absolute safety would have to be based on detailed knowledge of dose-response relationships in humans, including all sources of chemical exposure, the types of toxic effects elicited, the existence of thresholds for the toxic effects, the significance of toxicant interactions, and the variances of sensitivities and exposure levels within the human population. In practice, such absolute criteria cannot be established because of deficiencies in both the available data and the means of interpreting this information. Consequently, the individual human health effects chapters propose criteria which minimize or specify the potential risk of adverse human effects due to substances in ambient water. Potential social or economic costs and benefits are not considered in the formulation of the criteria.

II. Types of Criteria

Ambient water quality criteria are based on three types of biological endpoints: carcinogenicity, toxicity (i.e., all adverse effects other than cancer), and organoleptic effects.

For the purpose of deriving ambient water quality criteria, carcinogenicity is regarded as a non-threshold phenomenon. Using this assumption, "safe" or "no effect" levels for carcinogens cannot be established because even extremely small doses must be assumed to elicit a finite increase in the incidence of the response. Consequently, water quality criteria for carcinogens are presented as a range of pollutant concentrations associated with corresponding incremental risks.

For compounds which do not manifest any apparent carcinogenic effect, the threshold assumption is used in deriving a criterion. This assumption is based on the premise that a physiological reserve capacity exists within the organism which is thought to be depleted before clinical disease ensues. Alternatively, it may be assumed that the rate of damage will be insignificant over the life span of the organism. Thus, ambient water quality criteria are derived for non-carcinogenic chemicals, and presumably result in no observable-adverse-effect levels (NOAELs) in the exposed human population.

In some instances, criteria are based on organoleptic characteristics, i.e., thresholds for taste or odor. Such criteria are established when insufficient information is available on toxicologic effects or when the estimate of the level of the pollutant in ambient water based on organoleptic effects is lower than the level calculated from toxicologic data. It should be recognized that criteria based solely on organoleptic effects do not necessarily represent approximations of acceptable risk levels for human health.

Several ambient water quality criteria documents deal with classes of compounds which include chemicals exhibiting varying degrees of structural similarity. Because prediction of biological effects based solely on structural parameters is difficult, the derivation of compound-specific criteria is preferable to a class criterion. A compound-specific criterion is defined as a level derived from data on each individual subject compound that does not represent a significant risk to the public. For some chemical classes, however, a compound-specific criterion cannot be derived for each member of a class. In such instances, it is sometimes justifiable to derive a class criterion in which available data on one member of a class may be used to estimate criteria for other chemicals of the class because a sufficient data base is not available for those compounds.

For some chemicals and chemical classes, the data base was judged to be insufficient for the derivation of a criterion. In those cases, deficiencies in the available information are detailed.

III. Approach

The human health effects chapters attempt to summarize all information on the individual chemicals or classes of chemicals which might be useful in the risk assessment process to develop water quality criteria. Although primary emphasis is placed on identifying epidemiologic and toxicologic data, these assessments typically contain discussions on four topics: existing levels of human exposure, pharmacokinetics, toxic effects, and criterion formulation.

For all documents, an attempt is made to include the known relevant information. Review articles and reports are often used in the process of data evaluation and synthesis. Scientific judgment is exercised in the review and evaluation of the data in each document and in the identification of the adverse effects against which protective criteria are sought. In addition, each of these documents is reviewed by a peer committee of scientists familiar with the specific compound(s). These work groups evaluate the quality of the available data, the completeness of the data summary, and the validity of the derived criterion.

In the analysis and organization of the data, an attempt is made to be consistent with respect to the format and the application of acceptable scientific principles. Evaluation procedures used in the hazard assessment process follow the principles outlined by the National Academy of Sciences in *Drinking Water and Health* (1977) and the guidelines of the Carcinogen Assessment Group of the U.S. EPA.

A. Exposure

The exposure section of the health effects chapters reviews known information on current levels of human exposure to the individual pollutant from all sources. Much of the data was obtained from monitoring studies of air, water, food, soil, and human or animal tissue residues. The major purpose of this section is to provide background information on the contribution of water exposure relative to all other sources. Consequently, the exposure section includes subsections reviewing different routes of exposure including water and food ingestion, inhalation, and dermal contact.

Information on exposure can be valuable in developing and assessing a water quality criterion. In these documents exposure from consumption of contaminated water and contaminated fish and shellfish products is used in criterion formulation. Data for all modes of exposure are useful in relating total intake to the expected contribution from contaminated water, fish, and shellfish. In addition, information for all routes of exposure, not limited to drinking water and fish and shellfish ingestion, can be used to justify or assess the feasibility of the formulation of criteria for ambient water.

The use of fish consumption as an exposure factor requires the quantitation of pollutant residues in the edible portions of the ingested species. Accordingly, bioconcentration factors (BCFs) are used to relate pollutant residues in aquatic organisms to the pollutant concentration in the ambient waters in which they reside.

To estimate the average per capita intake of a pollutant due to consumption of contaminated fish and shellfish the results of a diet survey were analyzed to calculate the average consumption of freshwater and estuarine fish and shellfish (U.S. EPA, 1980). A species is considered to be a consumed freshwater or estuarine fish and shellfish species if at some stage in its life cycle, it is harvested from fresh or estuarine water for human consumption in significant quantities (Stephan, 1980).

Three different procedures are used to estimate the weighted average BCF depending upon the lipid solubility of the chemical and the availability of bioconcentration data.

For lipid-soluble compounds, the average BCF is calculated from the weighted average percent lipids in the edible portions of consumed freshwater and estuarine fish and shellfish which was calculated from data on consumption of each species and its corresponding percent lipids to be 3.0 percent (Stephan, 1980). Because the steady-state BCFs for lipid-soluble compounds are proportional to percent lipids, bioconcentration factors for fish and shellfish can be adjusted to the average percent lipids for aquatic organisms consumed by Americans. For many lipid-soluble pollutants, there exists at least one BCF for which the percent lipid value was measured for the tissues for which the BCF is determined.

With 3.0 percent as the weighted average percent lipids for freshwater and estuarine fish and shellfish in the average diet, a BCF, and a corresponding percent lipid value, the weighted average bioconcentration factor can be calculated.

Example:

Weighted average percent lipids for average diet = 3.0 percent

Measured BCF of 17 for trichloroethylene with bluegills at 4.8 percent lipids

Weighted average BCF for average diet equals

$$17 \times \frac{3.0\%}{4.8\%} = 10.6$$

As an estimate, 10.6 is used for the BCF.

In those cases where an appropriate bioconcentration factor is not available, the equation "Log BCF = (0.85 Log P)-0.70" can be used (Veith, et al. 1979) to estimate the BCF for aquatic organisms containing about 7.6 percent lipids (Veith, 1980) from the octanol/water partition coefficient P. An adjustment for percent lipids in the average diet versus 7.6 percent is made in order to derive the weighted average bioconcentration factor.

For non-lipid-soluble compounds, the available BCFs for the edible portion of consumed freshwater and estuarine fish and shellfish are weighted according to consumption factors to determine a weighted BCF representative of the average diet.

B. Pharmacokinetics

This section summarizes the available information on the absorption, distribution, metabolism, and elimination of the compound(s) in humans and experimental mammals. Conceptually, such information is useful in validation of inter- and intraspecies extrapolations, and in characterizing the modes of toxic action. Sufficient information on absorption and excretion in animals, together with a knowledge of ambient concentrations in water, food, and air, could be useful in estimating body burdens of chemicals in the human population. Distribution data which suggest target organs or tissues are desirable for interspecies comparison techniques. In terms of the derivation of criteria, pharmacokinetic data are essential to estimate equivalent oral doses based on data from inhalation or other routes of exposure.

C. Effects

This section summarizes information on biological effects in both humans and experimental mammals resulting in: acute, subacute, and chronic toxicity, synergism and/or antagonism, teratogenicity, mutagenicity, or carcinogenicity.

The major goal of this section is to survey the suitability of the data for use in assessment of hazard and to determine which biological end-point, i.e., non-threshold, threshold, or organoleptic, should be selected for use in criterion formulation.

Because this section attempts to assess potential human health effects, data on documented human effects are thoroughly evaluated. However, several factors inherent in human epidemiological studies usually preclude the use of such data in generating water quality criteria. These problems, as summarized by the National Academy of Sciences (NAS, 1977) are as follows:

1. Epidemiology cannot tell what effects a material will have until after humans have been exposed. One must not conduct what might be hazardous experiments on man.
2. If exposure has been ubiquitous, it may be impossible to assess the effects of a material, because there is no unexposed control group. Statistics of morbidity obtained before use of a new material can sometimes be useful, but when latent periods are variable and times of introduction and removal of materials overlap, historical data on chronic effects are usually unsatisfactory.
3. It is usually difficult to determine doses in human exposures.
4. Usually, it is hard to identify small changes in common effects, which may nonetheless be important if the population is large.
5. Interactions in a "nature-designed" experiment usually cannot be controlled.

Although these problems often prevent the use of epidemiological data in quantitative risk assessments, qualitative similarities or differences between documented effects in humans and observed effects in experimental mammals are extremely useful in testing the validity of animal-to-man extrapolations. Consequently, in each case, an attempt is made to identify and utilize both epidemiologic and animal dose-response data. Criteria derived from such a confirmed data base are considered to be reliable.

The decision to establish a criterion based on a non-threshold model is made after evaluating all available information on carcinogenicity and supportive information on mutagenicity. The approach and conditions for the qualitative decision of carcinogenicity are outlined in the U.S. EPA Interim Cancer Guidelines (41 FR 21402), in a report by Albert, et al. (1977), and in the Interagency Regulatory Liaison Group (IRLG) guidelines on carcinogenic risks (IRLG, 1979). It is assumed that a substance which induces a statistically significant carcinogenic response in animals has the capacity to cause cancer in humans. A chemical which has not induced a significant cancer response in humans or experimental animals is not identified as a carcinogen, even though its metabolites or close structural analogues might induce a carcinogenic response or it was shown to be mutagenic in an *in vitro* system.

It is recognized that some potential human carcinogens may not be identified by the guidelines given above. For example, compounds for which there is plausible but weak qualitative evidence of carcinogenicity in experimental animal systems (such as data from mouse skin painting or strain A mouse pulmonary adenoma) would be included in this category. The derivation of a criterion for human consumption from these studies is not valid, regardless of the qualitative outcome. In addition, there are certain compounds (e.g., nickel and beryllium) which were shown to be carcinogenic in humans after inhalation exposure by chemical form, but have induced thus far no response in animals or humans via ingesting their soluble salts. Nevertheless, a non-threshold criterion is developed for beryllium because tumors have been produced in animals at a site removed from the site of administration; in contrast, a threshold criterion is recommended for nickel because there is no evidence of tumors at sites distant resulting from administration of nickel solutions by either ingestion or injection.

For those compounds which were not reported to induce carcinogenic effects or for those compounds for which carcinogenic data are lacking or insufficient, an attempt is made to estimate a no-effect level. In many respects, the hazard evaluation from these studies is similar to that of bioassays for carcinogenicity. In order to more closely approximate conditions of human exposure, preference is given to chronic studies involving oral exposures in water or diet over a significant portion of the animal life span. Greatest confidence is placed in those studies which demonstrate dose-related adverse effects as well as no-effect levels.

There is considerable variability in the biological endpoints used to define a no-effect level. They may range from gross effects, such as mortality, to more subtle biochemical, physiological, or pathological changes. Teratogenicity, reproductive impairment, and behavioral effects are significant toxic consequences of environmental contamination. In instances where carcinogenic or other chronic effects occur at exposure levels below those causing teratogenicity, reproductive impairment, or behavioral effects, the former are used in deriving the criterion. For most of the compounds evaluated thus far, teratogenicity and reproductive impairment occur at doses near maximum tolerated levels with dose administration schedules well above estimated environmental exposure levels. Moreover, information on behavioral effects, which could be of significance, is not available for most of the compounds under study. Consequently, most NOAELs derived from chronic studies are based either on gross toxic effects or on effects directly related to functional impairment or defined pathological lesions.

For compounds on which adequate chronic toxicity studies are not available, studies on acute and subacute toxicity assume greater significance. Acute toxicity studies usually involve single exposures at lethal or near lethal doses. Subacute studies often involve exposures exceeding 10 percent of the life span of the test organism, e.g., 90 days for the rat with an average life span of 30 months. Such studies are useful in establishing the nature of the compound's toxic effects and other parameters of compound toxicity, such as target organ effects, metabolic behavior, physiological/biochemical effects, and patterns of retention and tissue distribution. The utility of acute and subacute studies in deriving environmentally meaningful NOELs is uncertain, although McNamara (1976) has developed application factors for such derivations.

In some cases where adequate data are not available from studies utilizing oral routes of administration, no-effect levels for oral exposures may be estimated from dermal or inhalation studies. Such estimates involve approximations of the total dose administered based on assumptions about breathing rates and/or magnitude of absorption.

D. Criterion Rationale

This section reviews existing standards for the chemical(s), summarizes data on current levels of human exposure, attempts to identify special groups at risk, and defines the basis for the recommended criterion.

Information on existing standards is included primarily for comparison with the proposed water quality criteria. Some of the present standards, such as those recommended by the Occupational Safety and Health Administration (OSHA) or the American Conference of Governmental Industrial Hygienists (ACGIH), are based on toxicologic data but are intended as acceptable levels for occupational rather than environmental exposure. her levels, such as those ommended by the National Academy Sciences in *Drinking Water and lth* (1977) or in the U.S. EPA Interim mary Drinking Water Standards, are more closely related to proposed water quality criteria. Emphasis is placed on detailing the basis for the existing standards wherever possible.

Summaries of current levels of human exposure, presented in this section, specifically address the suitability of the data to derive water quality criteria. The identification of special groups at risk, either because of geographical or occupational differences in exposure or biological differences in susceptibility to the compound(s), focuses on the impact that these groups should have on the development of water quality criteria.

The basis for the recommended criteria section summarizes and qualifies all of the data used in developing the criteria.

IV. Guidelines for Criteria Derivation

The derivation of water quality criteria from laboratory animal toxicity data is essentially a two-step procedure. First, a total daily intake for humans must be estimated which establishes either a defined level of risk for non-threshold effects or a no-effect level for threshold effects. Secondly, assumptions must be made about the contribution of contaminated water and the consumption of fish/shellfish to the total daily intake of the chemical. These estimates are then used to establish the tolerable daily intake and consequently the water quality criterion.

A. Non-Threshold Effects

After the decision has been made that a compound has the potential for causing cancers in humans and that data exist which permit the derivation of a criterion, the water concentration which is estimated to cause a lifetime carcinogenic risk of 10^{-5} is determined. The lifetime carcinogenicity risk is the probability that a person would get cancer sometime in his or her life assuming continuous exposure to the compound. The water concentration is calculated by using the low-dose extrapolation procedure proposed by Crump (1980). This procedure is an improvement on the multistage low dose extrapolation procedure by Crump, et al. (1977).

The data used for quantitative estimates are of two types: (1) lifetime animal studies, and (2) human studies where excess cancer risk has been associated with exposure to the agent. In animal studies it is assumed, unless evidence exists to the contrary, that if a carcinogenic response occurs at the dose levels used in the study, then proportionately lower responses will also occur at all lower doses, with an incidence determined by the extrapolation model discussed below.

1. Choice of Model.

There is no really solid scientific basis for any mathematical extrapolation model which relates carcinogen exposure to cancer risks at the extremely low levels of concentration that must be dealt with in evaluating the environmental hazards. For practical reasons, such low levels of risk cannot be measured directly either using animal experiments or epidemiologic studies. We must, therefore, depend on our current understanding of the mechanisms of carcinogenesis for guidance as to which risk model to use. At the present time, the dominant view of the carcinogenic process involves the concept that most agents which cause cancer also cause irreversible damage to DNA. This position is reflected by the fact that a very large proportion of agents which cause cancer are also mutagenic. There is reason to expect that the quantal type of biological response that is characteristic of mutagenesis is associated with a linear non-threshold dose-response relationship. Indeed, there is substantial evidence from mutagenesis studies with both ionizing radiation and with a wide variety of chemicals that this type of dose-response model is the appropriate one to use. This is particularly true at the lower end of the dose-response curve; at higher doses, there can be an upward curvature, probably reflecting the effects of multistage processes on the mutagenic response. The linear non-threshold dose-response relationship is also consistent with the relatively few epidemiological studies of cancer responses to specific agents that contain enough information to make the evaluation possible (e.g., radiation-induced leukemia, breast and thyroid cancer, skin cancer induced by arsenic in drinking water, and liver cancer induced by aflatoxin in the diet). There is also some evidence from animal experiments that is consistent with the linear non-threshold hypothesis (e.g., liver tumors induced in mice by 2-acetylaminofluorene in the large scale ED_{01} study at the National Center of Toxicological Research, and the initiation stage of the two-stage carcinogenesis model in the rat liver and the mouse skin).

Because it has the best, albeit limited, scientific basis of any of the current mathematical extrapolation models, the linear non-threshold model has been adopted as the primary basis for risk extrapolation to low levels of the dose-response relationship. The risk assessments made with this model should be regarded as conservative, representing the most plausible upper limit for the risk; i.e., the true risk is not likely to be higher than the estimate, but it could be smaller.

The mathematical formulation chosen to describe the linear, non-threshold dose-response relationship at low doses is the improved multistage model developed by Crump (1980). This model employs enough arbitrary constants to be able to fit almost any monotonically increasing dose-response data and it incorporates a procedure for estimating the largest possible linear slope (in the 95 percent confidence limit sense) at low extrapolated doses that is consistent with the data at all dose levels of the experiment. For this reason, it may be called a "linearized" multistage model.

2. Procedure of Low-Dose Extrapolation Based on Animal Carcinogenicity Data.

A. Description of the Extrapolation Model

Let P(d) represent the lifetime risk (probability) of cancer at dose d. The multistage model has the form

$$P(d) = 1 - \exp\left[-(q_0 + q_1d + q_2d^2 + \ldots + q_kd^k)\right]$$

where:

$q_i \geq 0$, and $i = 0, 1, 2, \ldots, k$

Equivalently,

$$A(d) = 1 - \exp\left[-(q_1d + q_2d^2 + \ldots + q_kd^k)\right]$$

where,

$$A(d) = \frac{P(d) - P(0)}{1 - P(0)},$$

is the extra risk over background rate at dose d.

The point estimate of the coefficients q_i, $i = 0, 1, 2, \ldots, k$, and consequently the extra risk function A(d) at any given dose d, is calculated by maximizing the likelihood function of the data.

The point estimate and the 95 percent upper confidence limit of the extra risk A(d) are calculated by using the computer program GLOBAL 79 developed by Crump and Watson (1979). Upper 95 percent confidence limits on the extra risk and lower 95 percent confidence limits on the dose producing a given risk are determined from a 95 percent upper confidence limit, q_1^*, on parameter q_1. Whenever $q_1 \neq 0$, at low doses extra risk A(d) has approximately the form $A(d) = q_1 \times d$. Therefore, $q_1 \times d$ is a 95 percent upper confidence limit on the extra risk and R/q_1^* is a 95 percent lower confidence limit on the dose producing an extra risk of R. Let L_0 be the maximum value of the log-likelihood function. The upper limit q_1^* is calculated buy increasing q_1 to a value q_1^* such that when the log-likelihood is again maximized subject to this fixed value q_1^* for the linear coefficient, the resulting maximum value of the log-likelihood L_1 satisfies the equation

$$2(L_0 - L_1) = 2.70554$$

where 2.70554 is the cumulative 90 percent point of the chi-square distribution with one degree of freedom, which corresponds to a 95 percent upper limit (one-sided). This approach of computing the upper confidence limit for the extra risk A(d) is an improvement on the Crump, et al. (1977) model. The upper confidence limit for the extra risk calculated at low doses is always linear. This is conceptually consistent with the linear nonthreshold concept discussed earlier. The slope q_1^* is taken as an upper bound of the potency of the chemical in inducing cancer at low doses.

In fitting the dose-response model, the number of terms in the polynomial g is chosen equal to (h−1), where h is the number of dose groups in the experiment, including the control group.

Whenever the multistage model does not fit the data sufficiently, data at the highest dose is deleted and the model is refitted to the rest of the data. This is continued until an acceptable fit to the data is obtained. To determine whether or not a fit is acceptable, the chi-square statistic:

$$X^2 = \sum_{i=1}^{h} \frac{(X_i - N_iP_i)^2}{N_iP_i(1 - P_i)}$$

is calculated, where N_i is the number of animals in the i^{th} dose group, X_i is the number of animals in the i^{th} dose group with a tumor response, P_i is the probability of a response in the i^{th} dose group estimated by fitting the multistage model to the data, and h is the number of remaining groups.

The fit is determined to be unacceptable whenever chi-square (X^2) is larger than the cumulative 99 percent point of the chi-square distribution with f degrees of freedom, where f equals the number of dose groups minus the number of non-zero multistage coefficients.

3. Selection and Form of Data used to Estimate Parameters in the Extrapolation Model.

For some chemicals, several studies in different animal species, strains, and sexes each conducted at several doses and different routes of exposure are available. A choice must be made as to which of the data sets from several studies are to be used in the model. It is also necessary to correct for metabolism differences between species and for differences in absorption via different routes of administration. The procedures, listed below, used in evaluating these data are consistent with the estimate of a maximum-likely-risk.

a. The tumor incidence data are separated according to organ sites or tumor types. The set data (i.e., dose and tumor incidence) used in the model is set where the incidence is statistically significantly higher than the control for at least one test dose level and/or where the tumor incidence rate shows a statistically significant trend with respect to dose level. The data set which gives the highest estimate of lifetime carcinogenic risk q_1^* is selected in most cases. However, efforts are made to exclude data sets which produce spuriously high risk estimates because of a small number of animals. That is, if two sets of data show a similar dose-response relationship and one has a very small sample size, the set of data which has the larger sample size is selected for calculating the carcinogenic potency.

b. If there are two or more data sets of comparable size which are identical with respect to species, strain, sex, and tumor sites, the geometric mean of q_1^*, estimated from each of these data sets is used for risk assessment. The geometric mean of numbers $A_1, A_2, \ldots, A_m$ is defined as $(A_1 \times A_2 \times \ldots \times A_m)^{1/m}$.

c. If sufficient data exist for two or more significant tumor sites in the same study, the number of animals with at least one of the specific tumor sites under consideration is used as incidence data in the model.

d. Following the suggestion of Mantel and Schneiderman (1975), we assume that mg/surface area/day is an equivalent dose between species. Since to a close approximation the surface area is proportional to the 2/3rds power of the weight as would be the case for a perfect sphere, the exposure in mg/2/3rds power of the body weight/day is similarly considered to be an equivalent exposure. In an animal experiment, this equivalent dose is computed in the following manner.

Let:

L_e = duration of experiment

l_e = duration of exposure

m = average dose per day in mg during administration of the agent (i.e., during l_e)

W = average weight of the experimental animal.

Then, the lifetime average exposure is

$$d = \frac{l_e \times m}{L_e \times W^{2/3}}$$

Often exposures are not given in units of mg/day, and it becomes necessary to convert the given exposures into mg/day. For example, in most feeding studies, exposure is expressed as ppm in the diet. In this case the exposure (mg/day) is derived by: $m = ppm \times F \times r$

where ppm is parts per million of the carcinogenic agent in the diet, F is the weight of the food consumed per day in kgms, and r is the absorption fraction.

In the absence of any data to the contrary, r is assumed to be one. For a uniform diet the weight of the food consumed is proportional to the calories required, which, in turn, is proportional to the surface area or the ⅔rds power of the weight, so that: $m \propto ppm \times W^{2/3} \times r$ or

$$\frac{m}{rW^{2/3}} \propto ppm$$

As a result, ppm in the diet is often assumed to be an equivalent exposure between species. However, we feel that this is not justified since the calories/kg of food is significantly different in the diet of man vs. laboratory animals, primarily due to moisture content differences. Instead, we use an empirically derived food factor, $f = F/W$, which is the fraction of a species body weight that is consumed per day as food. We use the rates given below.

Species	W	f
Man	70	0.028
Rat	0.35	0.05
Mice	0.03	0.13

Thus, when the exposure is given as a certain dietary concentration in ppm, the exposure in mg/$W^{2/3}$ is

$$\frac{m}{r \times W^{2/3}} = \frac{ppm \times F}{W^{2/3}} =$$

$$\frac{ppm \times f \times W}{W^{2/3}} = ppm \times f \times W^{1/3}$$

When exposure is given in terms of mg/kg/day $= m/Wr = s$ the conversion is simply:

$$\frac{m}{rW^{2/3}} = s \times W^{1/3}$$

When exposure is via inhalation, the calculation of dose can be considered for two cases where (1) the carcinogenic agent is either a completely water-soluble gas or an aerosol and is absorbed proportionally to the amount of air breathed in, and (2) where the carcinogen is a poorly water-soluble gas which reaches an equilibrium between the air breathed and the body compartments. After equilibrium is reached, the rate of absorption of these agents is expected to be proportional to metabolic rate, which in turn is proportional to the rate of oxygen consumption, which in turn is a function of surface area.

Case 1

Agents that are in the form of particulate matter or virtually completely absorbed gases such as SO_2 can reasonably be expected to be absorbed proportional to the breathing rate. In this case the exposure in mg/day may be expressed as: $m = I \times v \times r$ where I is inhalation rate per day in m^3, v is mg/m^3 of the agent in air, and r is the absorption fraction.

The inhalation rates, I, for various species can be calculated from the observation (FASEB, 1974) that 25 gm mice breathe 34.5 liters/day and 113 gm rats breathe 105 liters/day. For mice and rats of other weights, W, (expressed in kg), the surface area proportionality can be used to determine breathing rates (in m^3/day) as follows:

For mice, $I = 0.0345 (W/0.025)^{2/3} m^3$/day

For rats, $I = 0.105 (W/0.113)^{2/3} m^3$/day

For humans, the values of 20 m^3/day * is adopted as a standard breathing rate (ICRP, 1977).

The equivalent exposure in mg/$W^{2/3}$ for these agents can be derived from the air intake data in a way analogous to the food intake data. The empirical factors for the air intake per kg per day, $i = I/W$ based upon the previously stated relationships, are as tabulated below:

Species	W	i = I/W
Man	70	0.29
Rat	0.35	0.64
Mice	0.03	1.3

Therefore, for particulates or completely absorbed gases, the equivalent exposure in mg/$W^{2/3}$ is:

$$\frac{m}{W^{2/3}} = \frac{Ivr}{W^{2/3}} = \frac{iWvr}{W^{2/3}} = iW^{1/3} vr$$

In the absence of empirical data or a sound theoretical argument to the contrary, the fraction absorbed, r, is assumed to be the same for all species.

Case 2

The dose in mg/day of partially soluble vapors is proportional to the O_2 consumption which in turn is proportional to $W^{2/3}$ and to the solubility of gas in body fluids, which can be expressed as an absorption coefficient r for the gas. Therefore, when expressing the O_2 consumption as $O_2 = k W^{2/3}$, where k is a constant independent of species, it follows that $m = k W^{2/3} \times v \times r$ or

$$d = \frac{m}{W^{2/3}} = kvr$$

As with Case 1, in the absence of experimental information or a sound theoretical argument to the contrary, the absorption fraction, r, is assumed to be the same for all species. Therefore, for these substances a certain concentration in ppm or μ/m^3 in experimental animals is equivalent to the same concentration in humans. This is supported by the observation that the minimum alveolar concentration, necessary to produce a given "stage" of anesthesia, is similar in man and animals (Dripps, et al. 1977) When the animals were exposed via the oral route and human exposure is via inhalation or vice-versa, the assumption is made, unless there is pharmacokinetic evidence to the contrary, that absorption is equal by either exposure route.

e. If the duration of experiment (L_e) is less than the natural life span of the test animal (L), the slope q_1^*, or more generally the exponent g(d), is increased by multiplying a factor $(L/L_e)^3$. We assume that if the average dose, d, is continued, the age specific rate of cancer will continue to increase as a constant function of the background rate. The age specific rates for humans increase at least by the 2nd power of the age and often by a considerably higher power, as demonstrated by Doll (1971). Thus, we would expect the cumulative tumor rate to increase by at least the 3rd power of age. Using this fact, we assume that the slope q_1^*, or more generally, the exponent g(d), would also increase by at least the 3rd power of age. As a result, if the slope q_1^* [or g(d)] is calculated at age L_e, we would expect that if the experiment had been continued for the full life span, L, at the given average exposure, the slope q_1^* [or g(d)] would have been increased by at least $(L/L_e)^3$.

This adjustment is conceptually consistent to the proportional hazard model proposed by Cox (1972) and the time-to-tumor model considered by Crump, et al. (1977) where the probability of cancer at age t and dose d is given by $P(d,t) = 1 - \exp[-f(t) \times g(d)]$

4. **Calculation of Carcinogenic Potency Based on Human Data.** If human epidemiology studies and sufficiently valid exposure information are available for the compound, they are always used in some way. If they show a carcinogenic effect, the data are analyzed to give an estimate of the linear dependence of cancer rates on lifetime average dose, which is equivalent to the factor q_1^*. If they show

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* From "Recommendation of the International Commission on Radiological Protection," page 8, the average breathing rate is 10^7 cm^3 per 8-hour work day and 2×10^7 cm^3 in 24 hours.

no carcinogenic effect when positive animal evidence is available, then it is assumed that a risk does exist but it is smaller than could have been observed in the epidemiologic study, and an upper limit of the cancer incidence is calculated assuming hypothetically that the true incidence is just below the level of detection in the cohort studied, which is determined largely by the cohort size. Whenever possible, human data are used in perference to animal bioassay data.

In human studies, the response is measured in terms of the relative risk of the exposed cohort of individuals compared to the control group. In the analysis of this data, it is assumed that the excess risk, or relative risk minus one, $R(X)-1$, is proportional to the lifetime average exposure, X, and that it is the same for all ages. It follows that the *carcinogenic potency* is equal to $[R(X)-1]/X$ multiplied by the lifetime risk at that site in the general population. Except for an unusually well-documented human study, the confidence limit for the excess risk is not calculated, due to the difficulty in accounting for the uncertainty inherent in the data (exposure and cancer response).

5. Calculation of Water Quality Criteria. After the value of q_1^* in $(mg/kg/day)^{-1}$ has been determined, the lifetime risk, P, from an average daily exposure of x mg/kg/day is found from the equation $P = q_1^* x$. Therefore, if the lifetime risk is set at $P = 10^{-5}$ for calculation purposes, the intake, I, in mg/day for a 70 kg person can be found by the equation: $I = 70 \times 10^{-5}/q_1^*$

The intake of the agent from ambient water is assumed to come from two sources: (1) drinking an average of 2 liters of water per day, and (2) ingesting an average of 6.5 grams of fish per day. Because of accumulation of residues in fish, the amount of the pollutant in fish (mg/kg of edible fish) is equal to a factor R times the water concentration (mg/kg of water). Therefore, the total intake I can be written as sum of two terms: $I(mg/day) = C(mg/l) \times R(l/kg\ fish) \times 0.0065\ kg\ fish/day + C(mg/l \times 2l/day) = C(2+0.0065R)$ where C is the water concentration in mg/l. Therefore, the water concentration in mg/l corresponding to a lifetime risk of 10^{-5} for a 70 kg person is calculated by the formula:

$$C = \frac{70 \times 10^{-5}}{q_1^*(2 + 0.0065\ R)}$$

B. Threshold Effects

1. *Use of Animal Toxicity Data (Oral).* In developing guidelines for deriving criteria based on noncarcinogenic responses, five types of response levels are considered:

NOEL—No-Observed-Effect-Level
NOAEL—No-Observed-Adverse-Effect-Level
LOEL—Lowest-Observed-Effect-Level
LOAEL—Lowest-Observed-Adverse-Effect-Level
FEL—Frank-Effect-Level

Adverse effects are defined as any effects which result in functional impairment and/or pathological lesions which may affect the performance of the whole organism, or which reduce an organism's ability to respond to an additional challenge.

One of the major problems encountered in consideration of these concepts regards the reporting of "observed effect levels" as contrasted to "observed adverse effect levels". The terms "adverse" vs. "not adverse" are at times satisfactorily defined, but due to increasingly sophisticated testing protocols, more subtle responses are being identified, resulting in a need for judgment regarding the exact definition *of adversity.*

The concepts listed above (NOEL, NOAEL, LOEL, LOAEL) have received much attention because they represent landmarks which help to define the threshold region in specific experiments. Thus, if a single experiment yields a NOEL, a NOAEL, a LOAEL, and a clearly defined FEL in relatively closely spaced doses, the threshold region has been relatively well defined; such data are very useful for the purpose of deriving a criterion. On the other hand, a clearly defined FEL has little utility in establishing criteria when it stands alone, because such a level gives no indication how far removed the data point is from the threshold region. Similarly, a free-standing NOEL has little utility, because there is no indication of its proximity to the LOEL, since a free-standing NOEL may be many orders of magnitude below the threshold region.

Based on the above dose-response classification system, the following guidelines for deriving criteria have been adopted:

a. A free-standing FEL is unsuitable for the derivation of criteria.

b. A free-standing NOEL is unsuitable for the derivation of criteria. If multiple NOELs are available without additional data on LOELs, NOAELs, or LOAELs, the highest NOEL should be used to derive a criterion.

c. A NOAEL, LOEL, or LOAEL can be suitable for criteria derivation. A well-defined NOAEL from a chronic (at least 90-day) study may be used directly, applying the appropriate uncertainty factor. For a LOEL, a judgment needs to be made whether it actually corresponds to a NOAEL or a LOAEL. In the case of a LOAEL, an additional uncertainty factor is applied; the magnitude of the additional uncertainty factor is judgmental and should lie in the range of 1 to 10. Caution must be exercised not to substitute "Frank-Effect-Levels" for "Lowest-Observable-Adverse-Effect-Levels".

d. If for reasonably closely spaced doses only a NOEL and a LOAEL of equal quality are available, then the appropriate uncertainty factor is applied to the NOEL.

In using this approach, the selection and justification of uncertainty factors are critical. The basic definition and guidelines for using uncertainty factors has been given by the National Academy of Sciences (1977). "Safety Factor" or "Uncertainty Factor" is defined as a number that reflects the degree or amount of uncertainty that must be considered when experimental data in animals are extrapolated to man. When the quality and quantity of experimental data are satisfactory, a low uncertainty factor is used; when data is judged to be inadequate or equivocal, a larger uncertainty factor is used. The following general guidelines have been adopted in establishing the uncertainty factors:

a. Valid experimental results from studies on prolonged ingestion by man, with no indication of carcinogenicity. Uncertainty Factor = 10

b. Experimental results of studies of human ingestion not available or scanty (e.g., acute exposure only) with valid results of long-term feeding studies on experimental animals, or in the absence of human studies, valid animal studies on one or more species. No indication of carcinogenicity. Uncertainty Factor = 100

c. No long-term or acute human data. Scanty results on experimental animals with no indication of carcinogenicity. Uncertainty Factor = 1,000

Considerable judgment must be used in selecting the appropriate safety factors for deriving a criterion. In those cases where the data do not completely fulfill the conditions for one category and appear to be intermediate between two categories an intermediate uncertainty factor is used. Such an intermediate uncertainty factor may be developed based on a logarithmic scale (e.g., 33, being halfway between 10 and 100 on a logarithmic scale).

In determining the appropriate use of the uncertainty factors, the phrase "no indication of carcinogenicity" is interpreted as the absence of carcinogenicity data from animal experimental studies or human epidemiology. Available short-term carcinogenicity screening tests are reported in the criteria documents, but they are not used either for derivation of numerical criteria nor to rule out the uncertainty factor approach.

Because of the high degree of judgment involved in the selection of a safety factor, the criterion derivation section of each document should provide a detailed discussion and justification for both the selection of the safety factor and the data to which it is applied. This discussion should reflect a critical review of the available data base. Factors to be considered include number of animals, species, and parameters tested; quality of controls; dose levels; route; and dosing schedules. An effort should be made to differentiate between results which constitute a toxicologically sufficient data base and data which may be spurious in nature.

2. Use of Acceptable Daily Intake (ADI). For carcinogens, the assumption of low dose linearity precludes the necessity for defining total exposure in the estimation of increased incremental risk. For non-carcinogens, ADIs and criteria derived therefrom are calculated from total exposure data that include contributions from the diet and air. The equation used to derive the criterion (C) is: $C = ADI - (DT + IN)/[2\ l + (0.0065\ kg \times R)]$ where 2 l is assumed daily water consumption, 0.0065 kg is assumed daily fish consumption, R is bioconcentration factor in units of l/kg, DT is estimated non-fish dietary intake, and IN is estimated daily intake by inhalation.

If estimates of IN and DT cannot be provided from experimental data, an assumption must be made concerning total exposure. It is recognized that either the inability to estimate DT and IN due to lack of data or the wide variability in DT and IN in different states may add an additional element of uncertainty to the criterion formulation process. In terms of scientific validity, the accurate estimate of the Acceptable Daily Intake is the major factor in satisfactory derivation of water quality criteria.

3. Use of Threshold Limit Values or Animal Inhalation Studies. Threshold Limit Values (TLVs) are established by the American Conference of Governmental and Industrial Hygienists (ACGIH) and represent 8-hour time-weighted average concentrations in air that are intended to protect workers from various adverse health effects over a normal working lifetime. Similar values are set by NIOSH (criteria) and OSHA (standards) for 10- and 8-hour exposures, respectively. To the extent that these values are based on sound toxicologic assessments and have been protective in the work environment, they provide useful information for deriving or evaluating water quality criteria. However, each TLV must be carefully examined to determine if the basis of the TLV contains data which can be used directly to derive a water quality criterion using the uncertainty factor approach. In addition, the history of each TLV must be examined to assess the extent to which it has assured worker safety. In each case, the types of effects against which TLVs are designed to protect are examined in terms of their relevance to exposure from water. It must be demonstrated that the chemical is not a localized irritant and that there is no significant effect at the site of entry irrespective of the routes of exposure (i.e., oral or inhalation).

If the TLV or similar value is recommended as the basis of the criterion, consideration of the above points is explicitly stated in the criterion derivation section of the document. Particular emphasis is placed on the quality of the TLV relative to the available toxicity data that normally is given priority over TLVs or similar established values. If the TLV can be justified as the basis for the cirterion, then the problems associated with the estimation of acceptable oral doses from inhalation data must be addressed.

Estimating equivalencies of dose-response relationships from one route of exposure to another introduces an additional element of uncertainty in the derivation of criteria. Consequently, whenever possible, ambient water quality criteria should be based on data involving oral exposures. If oral data are insufficient, data from other routes of exposure may be useful in the criterion derivation process.

Inhalation data, including TLVs or similar values, are the most common alternatives to oral data. Estimates of equivalent doses can be based upon: (1) available pharmacokinetic data for oral and inhalation routes, (2) measurements of absorption efficiency from ingested or inhaled chemicals, or (3) comparative excretion data when the associated metabolic pathways are equivalent to those following oral ingestion or inhalation. Given that sufficient pharmacokinetic data are available, the use of accepted pharmacokinetic models provides the most satisfactory approach for dose conversions. However, if available pharmacokinetic data are marginal or of questionable quality, pharmacokinetic modeling is inappropriate.

The Stokinger and Woodward (1958) approach, or similar models based on assumptions of breathing rate and absorption efficiency, represents possible alternatives when data are not sufficient to justify pharmacokinetic modeling. Such alternative approaches, however, provide less satisfactory approximations because they are not based on pharmacokinetic data. Consequently, in using the Stokinger and Woodward or related models, the uncertainties inherent in each of the assumptions and the basis of each assumption must be clearly stated in the derivation of the criterion.

The use of data pertaining to other routes of exposure to derive water quality criteria may also be considered. As with inhalation data, an attempt is made to use accepted toxicologic and pharmacokinetic principles to estimate equivalent oral doses. If simplifying assumptions are used, their bases and limitations must be clearly specified.

Because of the uncertainties involved in extrapolating from one route of exposure to another and the consequent limitations that this may place on the derived criterion, the decision to disallow such extrapolation and recommend no criterion is highly judgmental and must be made on a case-by-case basis. A decision for or against criteria derivation must balance the quantity and quality of the available data against a perceived risk to the human population.

If the Stokinger and Woodward (1958) approach is used to calculate an ADI from a TLV, the general equation is: $ADI = TLV \times BR \times DE \times d \times A_A/(A_o \times SF)$ where:

ADI = Acceptable daily intake in mg
TLV = Concentration in air in mg/m^3
DE = Duration of exposure in hours per day
d = 5 days/7 days
A_A = Efficiency of absorption from air
A_o = Efficiency of absorption from oral exposure
SF = Safety factor following guidelines given above
BR = Amount of air breathed per day; assume 10 m^3

For deriving an ADI from animal toxicity data, the equation is: $ADI = C_A \times D_E \times d \times A_A \times BR \times 70\ kg/(BW_A \times A_o \times SF)$ where:

ADI = Acceptable daily intake in mg
C_A = Concentration in air in mg/m^3
D_E = Duration of exposure in hours per day
d = Number of days exposed/number of days observed
A_A = Efficiency of absorption from air
BR = Volume of air breathed per day in m^3
70 kg = Assumed human body weight
BW_A = Body weight of experimental animals in kg

A_o = Efficiency of absorption from oral exposure

SF = Safety factor following guidelines given above.

More formal pharmacokinetic models must be developed on a compound-by-compound basis.

It should be noted that the safety factors used in the above formulae are intended to account for species variability. Consequently, the mg/surface area/day conversion factor is not used in the derivation of toxicity based criterion.

C. Organoleptic Criteria

Organoleptic criteria define concentrations of materials which impart undesirable taste and/or odor to water. In developing and utilizing such criteria, two factors must be appreciated: the limitations of most organoleptic data and the human health significance of organoleptic properties.

The publications which report taste and odor thresholds are, with very few exceptions, cryptic in their descriptions of test methodologies, number of subjects tested, concentration-response relationships, and sensory characteristics at specific concentrations above threshold. Thus, the quality of organoleptic data is often significantly less than that of toxicologic data used in establishing other criteria. Consequently, a critical evaluation of the available organoleptic data must be made and the selection of the most appropriate data base for the criterion must be based on sound scientific judgment.

Organoleptic criteria are not based on toxicologic information and have no direct relationship to potential adverse human health effects. Although sufficiently intense organoleptic characteristics could result in depressed fluid intake which, in turn, might aggravate a variety of functional disease states (i.e., kidney and circulatory diseases), such effects are not used in the derivation process of organoleptic criteria unless available data would indicate an indirect human health effect via decreased fluid consumption. criteria derived solely from organoleptic data are based upon aesthetic qualities only.

Since organoleptic and human health effects criteria are based on different endpoints, a distinction must be made between these two sets of information. In criteria summaries involving both types of data, the following format is used:

> For comparison purposes, two approaches were used to derive criterion levels for ———. Based on available toxicity data, for the protection of public health the derived level is ——. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water the estimated level is ——. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have no demonstrated relationship to potential adverse human health effects.

In those instances where a level to limit toxicity cannot be derived, the following statement is to be appropriately inserted:

> Sufficient data are not available for ——— to derive a level which would protect against the potential toxicity of this compound.

D. Criteria for Chemical Classes

A chemical class is broadly defined as any group of chemical compounds which are reviewed in a single risk assessment document. In criterion derivation, isomers should be regarded as a part of a chemical class rather than as a single compound. A class criterion is an estimate of risk/safety which applies to more than one member of a class. It involves the use of available data on one or more chemicals of a class to derive criteria for other compounds of the same class in the event that there are insufficient data available to derive compound-specific criteria.

A class criterion usually applies to each member of a class rather than to the sum of the compounds within the class. While the potential hazards of multiple toxicant exposure are not to be minimized, a criterion, by definition, most often applies to an individual compound. Exceptions may be made for complex mixtures which are produced, released, and toxicologically tested as mixtures (e.g., toxaphene and PCBs). For such exceptions, some attempt is made to assess the effects of environmental partitioning (i.e., different patterns of environmental transport and degradation) on the validity of the criterion. If these effects cannot be assessed, an appropriate statement of uncertainty should accompany the criterion.

Since relatively minor structural changes within a class of compounds can have pronounced effects on their biological activities, reliance on class criteria should be minimized. Whenever sufficient toxicologic data are available on a chemical within a class, a compound-specific criterion should be derived. Nonetheless, for some chemical classes, scientific judgment may suggest a sufficient degree of similarity among chemicals within a class to justify a class criterion applicable to some of all members of a class.

The development of a class criterion takes into consideration the following:

1. A detailed review of the chemical and physical properties of chemicals within the group should be made. A close relationship within the class with respect to chemical activity would suggest a similar potential to reach common biological sites within tissues. Likewise, similar lipid solubilities would suggest the possibility of comparable absorption and tissue distribution.
2. Qualitative and quantitative data for chemicals within the group are examined. Adequate toxicologic data on a number of compounds within a group provides a more reasonable basis for extrapolation to other chemicals of the same class than minimal data on one chemical or a few chemicals within the group.
3. Similarities in the nature of the toxicologic response to chemicals in the class provides additional support for the prediction that the response to other members of the class may be similar. In contrast, where the biological response has been shown to differ markedly on a qualitative and quantitative basis for chemicals within a class, the extrapolation of a criterion to other members of that class is not appropriate.
4. Additional support for the validity of extrapolation of a criterion to other members of a class could be provided by evidence of similar metabolic and pharmacokinetic data for some members of the class.

Based on the above considerations, it may be reasonable in some cases to divide a chemical class into various subclasses. Such divisions could be based on biological endpoints (e.g., carcinogens/non-carcinogens), potency, and/or sufficiency of data (e.g., a criterion for some members of a class but no criterion for others). While no *a priori* limits can be placed on the extent of subclassification, each subclassification must be explicitly justified by the available data.

Class criteria, if properly derived and supported, can constitute valid scientific assessments of potential risk/safety. Conversely, the development of a class criterion from an insufficient data base can lead to serious errors in underestimating or overestimating risk/safety and should be rigorously avoided. Although scientific judgment has a proper role in the development of class criteria, such criteria are useful and defensible only if they are based on adequate data and scientific reasoning. The definition of sufficient data on similarities in physical, chemical, pharmacokinetic, or toxicologic properties to justify a class criterion may vary markedly depending on the degree of structural similarity and the gravity of the perceived risk. Consequently, it is imperative that the criterion derivation section of each document in which a class criterion is recommended explicity address each of the key issues discussed above, and define, as clearly as possible, the limitations of the proposed criterion as well as the type of data needed to generate a compound-specific criterion.

A class criterion should be abandoned when there is sufficient data availabe to derive a compound-specific criterion which protects against the biological effect of primary concern; e.g., the availability of a good subchronic study would not necessarily result in the abandonment of a class criterion based on potential carcinogenicity.

The inability to derive a valid class criterion does not, and should not preclude regulation of a compound or group of compounds based on concern for potential human health effects. The failure to recommend a criterion is simply a statement that the degree of concern cannot be quantified based on the available data and risk assessment methodology.

E. Essential Elements

Some chemicals, particularly certain metals, are essential to biological organisms at low levels but may be toxic and/ or carcinogenic at high levels. Because of potential toxic effects, it is legitimate to establish criteria for such essential elements. However, criteria must consider essentiality and cannot be established at levels which would result in deficiency of the element in the human population.

Elements are accepted as essential if listed by NAS Food and Nutrition Board or a comparably qualified panel. Elements not yet determined to be essential but for which supportive data on essentiality exists need to be further reviewed by such a panel.

To modify the toxicity and carcinogenicity based criteria, essentiality must be quantified either as a "recommended daily allowance" (RDA) or "minimum daily requirement" (MDR). These levels are then compared to estimated daily doses associated with the adverse effect of primary concern. The difference between the RDA or MDR and the daily doses causing a specified risk level for carcinogens or ADIs for non-carcinogens defines the spread of daily doses from which the criterion may be derived. Because errors are inherent in defining both essential and maximum tolerable levels, the criterion is derived from dose levels near the center of such a dose range. The decision to use either the MDR or RDA is guided by the spread of the doses and the quality of the essentiality and toxicity estimates.

The modification of criteria by consideration of essentiality must take into account all routes of exposure. If water is a significant source of the MDR or RDA, the criterion must allow for attainment of essential intake. Conversely, even when essentiality may be attained from nonwater sources, standard criteria derivation methods may be adjusted if the derived criterion represents a small fraction of the ADI or MDR. On a case-by-case basis, the modification in the use of the guidelines may include the use of different safety factors for non-carcinogens or other modifications which can be explicitly justified.

F. Use of Existing Standards

For some chemicals for which criteria are to be established, drinking water standards already exist. These standards represent not only a critical assessment of literature, but also a body of human experience since their promulgation. Therefore, it is valid to accept the existing standard unless there is compelling evidence to the contrary. This decision should be made after considering the existing standards vs. new scientific evidence which has accumulated since the standards have been established. There are several instances where the peer review process recommended usage of the present drinking water standards.

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Health Effects Methodology—Authors, Contributors and Reviewers

Jerry F. Stara, ECAO-Cin, U.S. Environmental Protection Agency
Elizabeth L. Anderson, OHEA, U.S. Environmental Protection Agency
Roy E. Albert, N.Y. University Medical School, New York, NY
Patrick R. Durkin, Syracuse Research Corporation, Syracuse, NY
Steven D. Lutkenhoff, ECAO, U.S. Environmental Protection Agency
Robert E. McGaughy, CAG, U.S. Environmental Protection Agency
Charles Ris, OHEA, U.S. Environmental Protection Agency
Lawrence Anderson, CAG, U.S. Environmental Protection Agency
Dolph Arnicar, CAG, U.S. Environmental Protection Agency
Steven Bayard, CAG, U.S. Environmental Protection Agency
Edward Calabrese, University of Massachusetts, Amherst, MA
Thomas Clarkson, University of Rochester Rochester, NY

Joseph Cotruvo, ODW, U.S. Environmental Protection Agency
Christopher DeRosa, ECAO-Cin, U.S. Environmental Protection Agency
Kurt Enslein, Genesee Computer Center, Inc., Syracuse, NY
Jeffrey Gaba, OGC, U.S. Environmental Protection Agency
Frank Gostomski, OWRS, U.S. Environmental Protection Agency
Daniel Greathouse, HERL-Cin, U.S. Environmental Protection Agency
Joseph Arcos, Tulane University, New Orleans, LA
Dev Barnes, OWRS, U.S. Environmental Protection Agency
David L. Bayliss, CAG, U.S. Environmental Protection Agency
Chao W. Chen, CAG, U.S. Environmental Protection Agency
Herbert Cornish, University of Michigan, Ann Arbor, MI
Kenneth Crump, Science Research Systems, Inc., Ruston, LA
Michael Dourson, ECAO-Cin, U.S. Environmental Protection Agency
John R. Fowle III, CAG, U.S. Environmental Protection Agency
R. John Garner, HERL-Cin, U.S. Environmental Protection Agency
Terrence Grady, ECAO-Cin, U.S. Environmental Protection Agency
Bernard Haberman, CAG, U.S. Environmental Protection Agency
Paul Hammond, University of Cincinnati, Cincinnati, OH
Charalingayya Hiremath, CAG, U.S. Environmental Protection Agency
Dinko Kello, Institute for Medical Research and Occupational Health, Zagreb, Yugo
Chang S. Lao, CAG, U.S. Environmental Protection Agency
Marvin Legator, University of Texas Medical Branch, Galveston, TX
Jack McGinnity, OTS, U.S. Environmental Protection Agency
Debdas Mukerjee, ECAO-Cin, U.S. Environmental Protection Agency
Ellen O'Flaherty, University of Cincinnati, Cincinnati, OH
Fred Passman, Energy Resources Co., Inc. Cambridge, MA
John F. Risher, ECAO-Cin, U.S. Environmental Protection Agency
Jeffery Rosenblatt, OTS, U.S. Environmental Protection Agency
Samuel Shibko, US FDA, Washington, DC
Harry T. Skalsky, Reynolds Metal Company
Todd W. Thorslund, CAG, U.S. Environmental Protection Agency
Benjamin VanDuuren, N.Y. University Medical School, New York, NY
James R. Withey, National Health and Welfare Canada, Ottawa, Canada
Rolf Hartung, University of Michigan, Ann Arbor, MI
Rudolf Jaeger, Harvard School of Public Health, Cambridge, MA
Arnold M. Kuzmack, CAG, U.S. Environmental Protection Agency
Si Duk Lee, ECAO-Cin, U.S. Environmental Protection Agency
Leland McCabe, HERL-Cin, U.S. Environmental Protection Agency
Myron Mehlman, Mobil Oil Corporation, New York, NY
Jean Munson, University of Cincinnati, Cincinnati, OH
Nancy Othmer, OGC, U.S. Environmental Protection Agency
David J. Reisman, ECAO-Cin, U.S. Environmental Protection Agency
Paula K. Roberson, U.S. Environmental Protection Agency
H. Daniel Roth, Roth Associates
Dharm V. Singh, CAG, U.S. Environmental Protection Agency
Robert G. Tardiff, National Academy of Sciences, Washington, DC
Anne W. Trontell, Energy Resources Co., Inc., Cambridge, MA
John Van Ryzin, Columbia University, New York, NY
Ronald E. Wyzga, Electric Power Research Institute

Appendix D—Response to Comments on Guidelines for Deriving Water Quality Criteria for the Protection of Aquatic Life and Its Uses

Introduction

Two versions of the Guidelines were published in the Federal Register for comment. The first version (43 FR 21506, May 18, 1978 and 43 FR 29028, July 5, 1979) was simply published for comment. The second (44 FR 15926, March 15, 1979) was published as part of the request for comments on the water quality criteria for 27 of the 65 pollutants. The second version was meant to be clearer and more detailed than the first, but very similar technically. Since the two versions were so similar, comments on both will be dealt with simultaneously.

Many comments were received that no draft water quality criteria for any of the 65 pollutants should have been issued for public comment until the comments on the first version of the Guidelines had been dealt with adequately and the Guidelines changed appropriately. The comments on the first version were read and the Guidelines were revised in an attempt to make the second version clearer and more detailed than the first. However, an extensive revision of the technical content of the Guidelines was not attempted between the first and second versions because the Agency was preparing water quality criteria based on the Guidelines. The Agency could have avoided this criticism simply by not publishing any version of the Guidelines for comment until March 15, 1979, but this would have greatly reduced the length of time available for people to consider the Guidelines and comment on them. As it was, some people commented that the comment period announced on March 15, 1979, was too short.

1. Comment—The procedures used to derive criteria in the "Red Book" were upheld in court and probably should still be used.

Response—The procedures used in the Guidelines are similar to some of the procedures used to develop criteria in the "Green Book", "Blue Book", and "Red Book". The Guidelines are designed to be more objective and systematic, to deal more adequately with residues, and to incorporate the concept of a minimum data base.

2. Comment—Criteria should be compilations of critically reviewed data with no synthesis or interpretation.

Response—Neither P.L. 92–500 nor the Consent Decree specify the form which a criterion must take. The Consent Decree (para. 11, p. 14) specifies that such criteria "shall state, *inter alia*, recommended maximum permissible concentrations". Adequate precedents have been set in the "Green Book", "Blue Book", and "Red Book" for the form of criteria used in the Guidelines.

3. Comment—The Guidelines and criteria should be developed by a consensus of aquatic toxicologists rather than by EPA personnel only.

Response—EPA certainly wants the Guidelines and the criteria to be as good as possible and as acceptable to as many interested people as possible. To this end, EPA has widely distributed draft versions of the Guidelines and the criteria documents, discussed them with many people, considered the comments received, and made many significant technical changes and editorial revisions. It is questionable whether or not a true consensus could have been reached by any means within the time available. In addition, EPA has a legislative responsibility which it should not delegate to someone else.

4. Comment—The Guidelines should be updated regularly.

Response—The Guidelines are not being promulgated as a regulation or directive. The purpose of presenting these Guidelines is to show how the water quality criteria for aquatic life were derived for the 65 pollutants. If EPA uses these Guidelines again, they will be revised to take into account new data, concepts, and ideas.

5. Comment—The objectives, purpose, and limitations of the Guidelines should be stated.

Response—The introductory portion of the Guidelines has been expanded to address these subjects more fully.

6. Comment—The Guidelines are too ambiguous.

Response—The Guidelines have been revised and rewritten, partly to improve clarity and provide additional details. It is not possible to provide explicit details on all items; in some areas only general guidance can be provided at this time.

The following Federal Register notice contains summaries of nine documents containing proposed ambient water quality criteria for the protection of aquatic life and its uses. Of particular interest for section 301(g) purposes are new criteria for ammonia and chlorine. Also included in this notice is a summary of revisions to the document entitled "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Life and Its Uses" (which is an updated and revised version of the guidelines previously published at 45 FR 79341, November 28, 1980.

[OW-FRL 2514-2]

Water Quality Criteria; Request for Comments

AGENCY: Environmental Protection Agency.

ACTION: Notice of request for comments on ambient water quality criteria documents.

SUMMARY: EPA announces the availability for public comment, and provides summaries of nine ambient water quality criteria documents. When published in final form after the review of public comments, these water quality criteria may form the basis for enforceable standards. These criteria are published pursuant to section 304(a)(1) of the Clean Water Act.

DATES: Written comments should be submitted to the person listed directly below by May 7, 1984.

FOR FURTHER INFORMATION CONTACT: Dr. Frank Gostomski, Criteria and Standards Division (WH-585), U.S. Environmental Protection Agency, 401 M Street, SW., Washington, D.C. 20460, (202) 245-3030.

Availability of Documents

This notice contains summaries of nine documents containing proposed ambient water quality criteria for the protection of aquatic life and its uses, and also contains a summary of revisions to the document entitled "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Life and Its Uses" (which is an updated and revised version of the Guidelines previously published at 45 FR 79341 November 28, 1980). Copies of the complete criteria documents and the revised Guidelines may be obtained upon request from the person listed above. These documents are also available for public inspection and copying during normal business hours at: Public Information Reference Unit, U.S. Environmental Protection Agency, Room 2404 (rear), 401 M St., SW., Washington, D.C. 20460. As provided in 40 CFR Part 2, a reasonable fee may be charged for copying services. Copies of these documents are also available for review in the EPA Regional Office libraries. A list of the proposed documents is presented below:

1. Ambient Water Quality Criteria for Ammonia
2. Ambient Water Quality Criteria for Arsenic
3. Ambient Water Quality Criteria for Cadmium
4. Ambient Water Quality Criteria for Chlorine
5. Ambient Water Quality Criteria for Chromium
6. Ambient Water Quality Criteria for Copper
7. Ambient Water Quality Criteria for Cyanide
8. Ambient Water Quality Criteria for Lead
9. Ambient Water Quality Criteria for Mercury
10. Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Life and Its Uses

SUPPLEMENTARY INFORMATION:

Background

Section 304(a)(1) of the Clean Water Act (33 U.S.C. 1314(a)(1)) requires EPA to publish and periodically update ambient water quality criteria. These criteria are to reflect the latest scientific knowledge on the identifiable effects of pollutants on public health and welfare, aquatic life, and recreation.

EPA has periodically issued ambient water quality criteria, beginning in 1973 with publication of the "Blue Book" (Water Quality Criteria 1972). In 1976, the "Red Book" (Quality Criteria for Water) was published. On November 28, 1980 (45 FR 79318), EPA announced the publication of 64 individual ambient water quality criteria documents for pollutants listed as toxic under section 307(a)(1) of the Clean Water Act.

Today EPA is announcing the availability for public comment of nine individual water quality criteria documents which, upon final publication, will update and revise certain criteria previously published in the "Red Book" and the 1980 ambient water quality criteria documents. The criteria documents for ammonia, and chlorine are intended to eventually replace criteria previously published in the "Red Book." The criteria documents for arsenic, cadmium, chromium, copper, cyanide, lead, and mercury will replace the aquatic life criteria previously published in the 1980 ambient water quality criteria documents.

Dated: January 13, 1984.

Jack E. Ravan,

Assistant Administrator for Water.

Summary of Proposed Water Quality Criteria

1. Ammonia

Freshwater Aquatic Life. To protect freshwater aquatic life, the criteria for ammonia are based upon ambient water temperature and pH with maximum concentration and 30-day average values provided.

Criteria values for the pH range 6.5 to 9.0 and the temperature range 0°C to 30°C are provided in the following tables. Total ammonia concentrations equivalent to each NH_3 criterion are also provided in these tables.

(1) MAXIMUM ALLOWED CONCENTRATIONS FOR AMMONIA [1]

pH	0 C	5 C	10 C	15 C	20 C	25 C	30 C
Un-ionized Ammonia (mg/liter NH_3)							
6.50	0.0081	0.012	0.019	0.019	0.019	0.019	0.019
6.75	0.014	0.021	0.031	0.031	0.031	0.031	0.031
7.00	0.021	0.032	0.048	0.048	0.048	0.048	0.048
7.25	0.030	0.046	0.069	0.069	0.069	0.069	0.069
7.50	0.040	0.061	0.091	0.091	0.091	0.091	0.091
7.75	0.049	0.074	0.110	0.110	0.110	0.110	0.110
8.00	0.056	0.084	0.125	0.125	0.125	0.125	0.125
8.25	0.061	0.091	0.135	0.135	0.135	0.135	0.135
8.50	0.065	0.096	0.141	0.141	0.141	0.141	0.141
8.75	0.068	0.100	0.145	0.145	0.145	0.145	0.145
9.00	0.071	0.104	0.147	0.147	0.147	0.147	0.147
Total Ammonia (mg/liter NH_3)							
6.50	31.8	31.8	31.8	21.8	15.0	10.5	7.41
6.75	29.5	29.5	29.5	20.1	13.8	9.69	6.64
7.00	25.7	25.7	25.7	17.6	12.1	8.48	6.00
7.25	20.8	20.8	20.8	14.2	9.84	6.82	4.68
7.50	15.5	15.5	15.5	10.6	7.34	5.15	3.66
7.75	10.6	10.6	10.6	7.29	5.06	3.56	2.55
8.00	6.84	6.84	6.84	4.71	3.28	2.33	1.68
8.25	4.22	4.22	4.22	2.92	2.05	1.47	1.08
8.50	2.54	2.54	2.54	1.78	1.27	0.93	0.70
8.75	1.53	1.53	1.53	1.09	0.80	0.60	0.47
9.00	0.94	0.94	0.94	0.68	0.52	0.41	0.33

[1] To convert these values to mg/liter N, multiply by 0.622

(2) 30-DAY AVERAGE ALLOWED CONCENTRATIONS FOR AMMONIA [1]

pH	0 C	5 C	10 C	15 C	20 C	25 C	30 C
Un-ionized Ammonia (mg/liter NH_3)							
6.50	0.0019	0.0027	0.0040	0.0040	0.0040	0.0040	0.0040
6.75	0.0027	0.0041	0.0061	0.0061	0.0061	0.0061	0.0061
7.00	0.0042	0.0063	0.0094	0.0094	0.0094	0.0094	0.0094
7.25	0.0064	0.0096	0.0144	0.0144	0.0144	0.0144	0.0144
7.50	0.0098	0.0146	0.0220	0.0220	0.0220	0.0220	0.0220
7.75	0.0138	0.0206	0.0310	0.0310	0.0310	0.0310	0.0310
8.00	0.0139	0.0209	0.0310	0.0310	0.0310	0.0310	0.0310
8.25	0.0140	0.0210	0.0310	0.0310	0.0310	0.0310	0.0310
8.50	0.0142	0.0211	0.0310	0.0310	0.0310	0.0310	0.0310
8.75	0.0145	0.0214	0.0310	0.0310	0.0310	0.0310	0.0310
9.00	0.0150	0.0219	0.0310	0.0310	0.0310	0.0310	0.0310
Total Ammonia (mg/liter NH_3)							
6.50	6.82	6.82	6.83	4.65	3.21	2.24	1.58
6.75	5.87	5.87	5.88	4.01	2.76	1.92	1.37
7.00	5.08	5.08	5.07	3.45	2.38	1.67	1.18
7.25	4.38	4.38	4.37	2.98	2.06	1.44	1.02
7.50	3.77	3.77	3.78	2.58	1.78	1.25	0.89
7.75	2.99	2.99	3.00	2.05	1.42	1.00	0.72
8.00	1.70	1.70	1.70	1.17	0.81	0.58	0.42
8.25	0.87	0.87	0.87	0.67	0.47	0.34	0.25
8.50	0.56	0.56	0.56	0.39	0.28	0.20	0.15
8.75	0.33	0.33	0.33	0.23	0.17	0.13	0.10
9.00	0.20	0.20	0.20	0.14	0.11	0.08	0.07

[1] To convert these values to mg/liter N, multiply by 0.822

Saltwater Aquatic Life. Data available for saltwater species are insufficient to derive a criterion for saltwater.

Criteria Implementation Guidance. EPA is considering developing implementation guidance to accompany the revised ammonia criteria. The Agency envisions that such guidance would provide information pertaining to the selection of appropriate criteria for a given water body, and the application of these selected criteria in the establishment of water quality based pollutant controls.

EPA is soliciting written comments on the following questions pertaining to implementation guidance for the ammonia criteria: (1) Should the Agency develop criteria implementation guidance for ammonia, or does adequate information and knowledge already exist about the selection and application of ammonia criteria? If the response to the former question is "yes," then (2) what topics, issues, and technical information should be included in this guidance?

2 Arsenic

Freshwater Aquatic Life. To protect freshwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of dissolved trivalent inorganic arsenic (operationally defined as the trivalent inorganic arsenic that passes through a 0.45 micron membrane filter) should not exceed 72 μg/l; (b) the maximum concentration should not exceed 140 μg/l; and (c) the concentration may be between 72 and 140 μg/l for up to 96 hours. This criterion will probably not be protective wherever the toad, *Gastrophryne carolinensis*, is an important species.

Not enough data are available to allow derivation of numerical national water quality criteria for freshwater aquatic life for pentavalent inorganic arsenic or any organic arsenic compound. Pentavalent inorganic arsenic is acutely toxic to freshwater aquatic animals at concentrations as low as 850 μg/l. An acute-chronic ratio of 28 for pentavalent inorganic arsenic was obtained with the fathead minnow. Pentavalent arsenic may be toxic to freshwater aquatic plants at concentrations as low as 48 μg/l. Monosodium methanearsenate (MSMA) is acutely toxic to aquatic animals at concentrations as low as 1,900 μg/l but no data are available concerning chronic toxicity to animals or toxicity to plants.

Saltwater Aquatic Life. To protect saltwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of dissolved trivalent inorganic arsenic should not exceed 63 μg/l; (b) the maximum concentration should not exceed 120 μg/l; and (c) the concentration may be between 63 and 120 μg/l for up to 96 hours. This criterion will probably not be protective wherever *Skeletonema costatum, Thalassiosira aestivalis*, or *Champia parvula* are important species.

Very few data are available concerning the toxicity of any form of arsenic other than trivalent inorganic arsenic to saltwater aquatic life. The available data do show that pentavalent inorganic arsenic is acutely toxic to saltwater animals at concentrations as low as 2,319 μg/l and may be toxic to saltwater plants at 5-30 μg/l. No data are available concerning the chronic toxicity of any form of arsenic other than trivalent inorganic arsenic to saltwater aquatic life.

3 Cadmium

Freshwater Aquatic Life. Because the acute and chronic toxicities of cadmium to sensitive important freshwater species are about the same, to protect freshwater aquatic life and its uses, the concentration (in μg/l) of active cadmium (operationally defined as the cadmium that passes through a 0.45 μm membrane filter after the sample is acidified to pH=4 with nitric acid) should not exceed the numerical value given by $e^{(1.16[\ln(\text{hardness})]-3.841)}$. For example, at hardness of 50, 100, and 200 mg/l as $CaCO_3$, the maximum concentrations of active cadmium are 2.0, 4.5, and 10 μg/l. Data on the acute toxicity of cadmium to brook trout and striped bass cover a wide range, but if these species are as sensitive as some of the values indicate they might be, they may not be protected by this criterion.

Saltwater Aquatic Life. To protect saltwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of active cadmium should not exceed 12 μg/l; (b) the maximum concentration should not exceed 38 μg/l; and (c) the concentration may be between 12 and 38 μg/l for up to 96 hours.

4. Chlorine

Freshwater Aquatic Life. To protect freshwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of total residual chlorine should not exceed 8.3 μg/l; (b) the maximum concentration should not exceed 14 μg/l; and (c) the concentration may be between 8.3 μg/l and 14 μg/l for up to 96 hours.

Saltwater Aquatic Life. To protect saltwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of chlorine produced oxidants should not exceed 7.4 μg/l; (b) the maximum concentration should not exceed 13 μg/l; and (c) the concentration may be between 7.4 μg/l and 13 μg/l for up to 96 hours.

Criteria Implementation Guidance. EPA is considering developing criteria implementation guidance to accompany the revised chlorine criteria. The Agency envisions that such guidance would provide information pertaining to the selection of appropriate criteria for a given water body, and the application of those selected criteria in the establishment of water quality based pollutant controls.

EPA is soliciting written comments on the following questions pertaining to implementation guidance for the chlorine criteria: (1) Should the Agency develop criteria implementation guidance for chlorine, or does adequate information and knowledge already exist about the selection and application of chlorine criteria? If the response to the former question is "yes," then (2) what topics, issues, and technical information should be included in this guidance?

5. Chromium

Freshwater Aquatic Life. To protect freshwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of dissolved hexavalent chromium (operationally defined as the hexavalent chromium that passes through a 0.45 μm membrane filter) should not exceed 7.2 μg/l; (b) the maximum concentration should not exceed 11 μg/l; and (c) the concentrations may be between 7.2 and 11 μg/l for up to 96 hours.

To protect freshwater aquatic life and its uses, in each 30 consecutive days:

(a) The average concentration (in μg/l) of active trivalent chromium (operationally defined as the trivalent chromium that passes through a 0.45 μm membrane filter after the sample is acidified to pH=4 with nitric acid) should not exceed the numerical value given by $e^{(0.819[\ln(\text{hardness})]+0.537)}$;

(b) The maximum concentration (in μg/l) should not exceed the numerical value given by $e^{(0.819[\ln(\text{hardness})]+3.568)}$; and

(c) The concentration (in μg/l) may be between $e^{(0.819[\ln(\text{hardness})]+0.537)}$ and $e^{(0.819[\ln(\text{hardness})]+3.568)}$ for up to 96 hours.

For example, at hardnesses of 50, 100, and 200 mg/l as $CaCO_3$, the criterion average concentrations of active trivalent chromium are 42, 74, and 130 μg/l and the criterion maximum concentrations are 870, 1,500, and 2,700 μg/l.

Saltwater Aquatic Life. To protect saltwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of dissolved hexavalent chromium should not exceed 54 μg/l; (b) the maximum concentration should not exceed 1,200 μg/l; and (c) the concentration may be between 54 and 1,200 μg/l for up to 96 hours.

No saltwater criterion can be derived for trivalent chromium but levels of

10,300 µg/l were lethal to the eastern oyster

6. Copper

Freshwater Aquatic Life. To protect freshwater aquatic life and its uses, in each 30 consecutive days:

(a) The average concentration (in µg/l) of active copper (operationally defined as the copper that passes through a 0.45 µm membrane filter after the sample is acidified to pH = 4 with nitric acid) should not exceed the numerical value given by $e^{(0.905[\ln(\text{hardness})]-1.785)}$.

(b) The maximum concentration (in µg/l) should not exceed the numerical value given by $e^{(0.905[\ln(\text{hardness})]-1.413)}$; and

(c) The concentration (in µg/l) may be between $e^{(0.905[\ln(\text{hardness})]-1.785)}$ and $e^{(0.905[\text{hardness})]-1.413)}$ for up to 96 hours

For example, at hardnesses of 50, 100, and 200 mg/l as $CaCO_3$ the criterion average concentrations of active copper are 5.8, 11, and 20 µg/l and the criterion maximum concentrations are 8.4, 16, and 29 µg/l.

Saltwater Aquatic Life. To protect saltwater aquatic life and its uses, in each 30 consecutive days (a) The average concentration of active copper should not exceed 2.0 µg/l; (b) the maximum concentration should not exceed 3.2 µg/l; and (c) the concentration may be between 2.0 and 3.2 µg/l for up to 96 hours

7. Cyanide

Freshwater Aquatic Life. To protect freshwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of free cyanide (the sum of cyanide present as HCN and CN^-, expressed as CN) should not exceed 4.2 µg/l; (b) the maximum concentration should not exceed 22 µg/l, and (c) the concentration may be between 4.2 and 22 µg/l for up to 96 hours.

Saltwater Aquatic Life. To protect saltwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of free cyanide (the sum of cyanide present as HCN and CN^-, expressed as CN) should not exceed 0.57 µg/l; (b) the maximum concentration should not exceed 1.0 µg/l; and (c) the concentration may be between 0.57 and 1.0 ug/l for up to 96 hours.

8. Lead

Freshwater Aquatic Life. To protect freshwater aquatic life and its uses, in each 30 consecutive days:

(a) The average concentration (in µg/l) of active lead (operationally defined as the lead that passes through a 0.45 µm membrane filter after the sample is acidified to pH = 4 with nitric acid) should not exceed the numerical value given by $e^{(1.34[\ln(\text{hardness})]-5.245)}$;

(b) The maximum concentration (in µg/l) should not exceed the numerical value given by $e^{(1.34[\ln(\text{hardness})]-2.014)}$; and

(c) The concentration (in µg/l) may be between $e^{(1.34[\ln(\text{hardness})]-5.245)}$ and $e^{(1.34[\ln(\text{hardness})]-2.014}$ for up to 96 hours

For example, at hardnesses of 50, 100, and 200 mg/l as $CaCO_3$ the criterion average concentrations of active lead are 1.0, 2.5, and 64 µg/l and the criterion maximum concentrations are 25, 64, and 160 µg/l.

Saltwater Aquatic Life. To protect saltwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of active lead should not exceed 8.6 µg/l, (b) the maximum concentration should not exceed 220 ug/l; and (c) the concentration may be between 8.6 and 220 µg/l for up to 96 hours.

9. Mercury

Freshwater Aquatic Life. To protect freshwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of active mercury (operationally defined as the mercury that passes through a 0.45 µm membrane filter after the sample is acidified to pH = 4 with nitric acid) should not exceed 0.20 µg/l; (b) the maximum concentration should not exceed 1.1 µg/l, and (c) the concentration may be between 0.20 and 1.1 µg/l for up to 96 hours. These values are based on tests on divalent inorganic mercury and will be too high if a substantial portion of the active mercury is methylmercury. These values will also be too high if bioaccumulation is greater in a field situation than in laboratory tests. In addition, the value of 0.20 µg/l may not protect some salmonids and centrarchids from chronic toxicity and at that level, bioaccumulation in some species will be at the FDA action level of 1.0 mg/kg.

Saltwater Aquatic Life: To protect saltwater aquatic life and its uses, in each 30 consecutive days: (a) The average concentration of active mercury should not exceed 0.10 µg/l; (b) the maximum concentration should not exceed 1.9 µg/l; and (c) the concentration may be between 0.10 and 1.9 µg/l for up to 96 hours. These values are based on tests on divalent inorganic mercury and will be too high if a substantial portion of the active mercury is methylmercury. These values will also be too high if bioaccumulation is greater in a field situation than in laboratory tests

10. Summary of Revisions to "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Life and Its Uses"

This draft revised version of the National Guidelines provides clarifications, additional details, technical and editorial changes from the guidelines published at 45 FR 79341–79347, November 28, 1980. These modifications are the result of comments received on the previous Guidelines and also reflect advances in aquatic toxicology and related fields. The major technical changes are:

1. The acute data required for freshwater animals has been changed to include more tests with invertebrate species.

2. The Final Acute Value is now defined in terms of Family Mean Acute Values rather than Species Mean Acute Values previously defined. A Family Mean Acute Value is the geometric mean of all the Species Mean Acute Values available for species in the family. On the average, species within a family are toxicologically much more similar than species in different families and so the use of Family Mean Acute Values will prevent data sets from being biased by an overabundance of species in one or a few families.

3. The Final Acute Value is now calculated using a method that is not subject to the bias encountered with the previous method. In addition, it is not influenced by one very low value as the previous method was.

4. The criterion consists of two numbers. The criterion average concentration and the criterion maximum concentration.

a. The criterion average concentration is now used as a 30-day average, rather than as a 24-hour average.

b. Excursions over the average are limited to allow only one 96-hour episode in any 30 days.

c. Instead of being equal to the Final Acute Value, the criterion maximum concentration is now obtained by dividing the Final Acute Value by 2. The Final Acute Value is intended to protect 95 percent of a group of diverse species, unless an important species is more sensitive. However, a concentration that would severely harm 50 percent of the fifth percentile or 50 percent of a sensitive important species cannot be considered to be protective of that percentile or that species, especially because this concentration may exist for 96 hours on twelve different occasions every year. Dividing the Final Acute

Value by 2 is intended to result in a concentration that will not severely adversely affect too many of the organisms.

5. The preferred duration for acute tests with all species of aquatic animals is 96 hours, although tests as short as 48 hours are acceptable for freshwater cladocerans and midges, and for embryos and larvae of saltwater barnacles, bivalve molluscs, sea urchins, lobsters, crabs, shrimps and abalones.

6. When available, 96-hour EC50 values based on the percentage of organisms immobilized plus the percentage of organisms killed are used instead of 96-hour LC50 values for fish; comparable EC50 values are used instead of LC50 values for other species.

7. The requirements for using the results of tests with aquatic plants have been made more stringent.

Two additional appendices (Appendix 1 and 2) were added as part of the guidance. Appendix 1 was added to aid in determining whether a species should be considered resident in North America and its taxonomic classification. Appendix 2 provides guidance for calculating of a Final Acute Value.

[FR Doc. 84-3322 Filed 2-6-84; 8:45 am]

BILLING CODE 6560-50-M

FEDERAL COMMUNICATIONS COMMISSION

Meeting of the Telecommunications Industry Advisory Group Steering Committee

Pursuant to section 10(a)(2) of the Federal Advisory Committee Act (Pub. L. 92-463), notice is hereby given of a meeting of the Telecommunications Industry Advisory Group Steering Committee scheduled to meet on Thursday and Friday, February 23 and 24, 1984. The meeting will be open to the public. The meeting times and location are as follows:

Thursday, February 23, 1984—9:30 a.m.

FCC Meeting Room #330, 1200 19th Street NW., Washington, D.C.

Friday, February 25, 1984

FCC Meeting Room #856, 1919 M Street NW., Washington, D.C.

The agenda is as follows:

I. Review of Minutes of Previous Meeting
II. General Administrative Matters
III. Review of Auditing and Regulatory Subcommittee Report on Recent Tax Law Changes
IV. Review of Reports to be submitted to the TIAG Assembly
V. Other Business
VI. Presentation of Oral Statements
VII. Adjournment

With prior approval of the Chairman, Gerald P. Vaughan, oral statements while not favored or encouraged, may be allowed if time permits and if the Chairman determines that an oral presentation is conducive to the effective attainment of Steering Committee objectives. Anyone not a member of the Steering Committee and wishing to make an oral presentation should contact Stephen T. Duffy, Group Vice-Chairman (202) 634-1509) at least five days prior to the meeting date.

William J. Tricarico,

Secretary, Federal Communications Commission.

[FR Doc. 84-3213 Filed 2-6-84; 8:45 am]

BILLING CODE 6712-01-M

Telecommunications Industry Advisory Group Income and Other Accounts Subcommittee

Pursuant to section 10(a)(2) of the Federal Advisory Committee Act (Pub. L. 92-463), notice is herby given of a meeting of the Telecommunications Industry Advisory Group's (TIAG) Income and Other Accounts Subcommittee scheduled for Thursday and Friday, February 16 and 17, 1984. The meeting will begin on February 16 at 9:30 a.m. in the office of GTE Service Corporation, in Tampa, Florida, and will be open to the public. Please contact the Subcommittee Chairman, Glenn L. Griffin (214) (659-3484) for details on meeting locations. The agenda is as follows:

I. General Administrative Matters
II. Discussion of Assignments
III. Other Business
IV. Presentation of Oral Statements
V. Adjournment

With prior approval of Subcommittee Chairman Glenn L. Griffin, oral statements, while not favored or encouraged, may be allowed at the meeting if time permits and if the Chairman determines that an oral presentation is conducive to the effective attainment of Subcommittee objectives. Anyone not a member of the Steering Committee and wishing to make an oral presentation should contact Mr. Griffin ((214) 659-3484) at least five days prior to the meeting date.

William J. Tricarico,

Secretary, Federal Communications Commission.

[FR Doc. 84-3212 Filed 2-6-84; 8:45 am]

BILLING CODE 6712-01-M

Camac Broadcasting Co., Inc., and Walda Rose Spears; Applications for Consolidated Hearing

1. The Commission has before it the following mutually exclusive applications for a new FM station:

Applicant, city/state	File No	MM Docket No
A. Camac Broadcasting Co. Inc., Ravenel, S.C.	BPH-821115AR	84-2
B. Walda Rose Spears, Ravenel, S.C.	BPH-830321AA	84-3

2. Pursuant to Section 309(e) of the Communications Act of 1934, as amended, the above applications have been designated for hearing in a consolidated proceeding upon issues whose headings are set forth below. The text of each of these issues has been standardized and is set forth in its entirety in a sample standardized Hearing Designation Order (HDO) which can be found at 48 FR 22428, May 18, 1983. The issue headings shown below correspond to issue headings contained in the referenced sample HDO. The letter shown before each applicant's name, above, is used below to signify whether the issue in question applies to that particular applicant.

Issue Heading and Applicant(s)

1. Air Hazard, B.
2. Comparative, A, B
3. Ultimate, A, B

3. If there is any non-standardized issue(s) in this proceeding, the full text of the issue and the applicant(s) to which it applies are set forth in an Appendix to this Notice. A copy of the complete HDO in this proceeding may be obtained, by written or telephone request, from the Mass Media Bureau's Contact Representative, Room 242, 1919 M Street, NW., Washington, D.C. 20554. Telephone (202) 632-6334.

W. Jan Gay,

Assistant Chief, Audio Services Division, Mass Media Bureau.

[FR Doc. 84-3308 Filed 2-6-84; 8:45 am]

BILLING CODE 6712-01-M

New FM Stations; Applications for Consolidated Hearing; Don and Gail Stubblefield and John E. Elsner

1. The Commission has before it the following mutually exclusive applications for a new FM station:

Applicant, city, and state	File No	MM docket No
A. Don and Gail Stubblefield, Webb City, Mo	BPH-821110AL	84-4

BENCH SCALE TREATMENT TECHNOLOGIES

APPENDIX C

REMOVABILITY MATRIX

The removability matrix (Table 1, next page) on the following pages shows technologies which have the potential to remove a specific pollutant. Thus, if an industry has a pollution problem for one of the listed nonconventional pollutants, technologies which have the potential to remove the pollutant of concern can be determined, and investigation of the technologies can commence.

Blank spaces within the matrix indicate that data relating the technology with the pollutant is not available and therefore it is assumed that the technology is not a feasible alternative for the removal of that specific pollutant. Due to a limited data base approximate removal percentages of each pollutant by each technology were not available. However, further investigation into the Treatability Manual and many of the other references listed in the back of this report may reveal the effectiveness of the technology in removing a nonconventional pollutant.

BENCH-SCALE STUDIES

Bench scale treatability studies are normally recommended to determine if a treatment technology is applicable for a specific pollutant. These studies can determine pollutant removability and optimum operating parameters. The following section describes a general approach in performing a bench-scale study for each technology mentioned in the matrix table (Table 1). This approach will provide the reader with general knowledge of the bench-scale study, its chemicals, materials, equipment, treatment variables, general process steps, and design criteria. This report is limited to the extent that the criteria and design steps given provide the reader with a general knowledge of what is required in a bench-scale study, not a detailed experimental design for either a full-scale or bench-scale study. When a detailed bench-scale study is desired, the technologies should be investigated further in the references given in Table 2 (page 4).

The approach taken for this report is broken into two main parts for each technology: pollutant applicability and treatability approach. The pollutant applicability lists the nonconventional pollutants removed by the technology. The treatability approach lists the chemicals and materials required for the bench-scale study. Also listed is the type of apparatus, the approximate apparatus size needed, and the pollutant loading factors, if applicable. A general operating procedure for the study is included, as well as the operating parameters to be tested and the recommended results and analyses to be obtained.

Procedures and equipment needed to analyze for the various nonconventional pollutants can be found in Reference 17.

TABLE 1. NONCONVENTIONAL POLLUTANT - TREATMENT TECHNOLOGY REMOVABILITY MATRIX

	COD	Iron	Phosphorous	Ammonia	Color	Aluminum	Fluoride	Manganese	TOC
Sedimentation	X								X
Sedimentation with Chemical Addition	X	X	X		X	X	X	X	X
Gas Flotation	X								X
Gas Flotation with Chemical Addition	X		X						X
Filtraton (Granual Media)	X				X				X
Ultrafiltration	X				X				X
Activated Sludge	X		X	X	X				X
Trickling Filter	X			X	X				X
Lagoon	X		X	X[a]	X				X
Rotating Biological Contactors	X		X	X	X				X
Steam Stripping	X			X					X
Solvent Extraction	X				X				X
Carbon Adsorption	X		X		X				X
Chemical Oxidation	X			X	X				X
Air Stripping				X					
Nitrification/Denitrification				X					
Ion Exchange		X	X	X	X	X		X	
Reverse Osmosis		X	X	X	X	X	X	X	
Dechlorination									
Ozonation	X			X	X				X

(continued)

TABLE 1 (continued)

	Barium	Tin	TKN	Free Chlorine	Sulfide	Nitrate	Organic Nitrogen	Corrosion Inhibitor	Surfactants
Sedimentation	X		X				X		
Sedimentation with Chemical Addition	X	X	X				X	X	
Gas Flotation			X				X		
Gas Flotation with Chemical Addition			X				X		
Filtraton (Granual Media)			X				X		
Ultrafiltration			X				X		X
Activated Sludge			X				X		X
Trickling Filter			X		X		X		X
Lagoon			X[a]			X[b]	X		X
Rotating Biological Contactors			X		X	X	X		X
Steam Stripping			X		X		X		
Solvent Extraction			X				X		X
Carbon Adsorption			X				X	X	X
Chemical Oxidation			X		X		X		X
Air Stripping			X	X					
Nitrification/Denitrification			X			X	X		
Ion Exchange	X	X	X			X		X	X
Reverse Osmosis	X	X	X			X	X	X	X
Dechlorination				X					
Ozonation			X		X		X		X

[a] Not removed by anaerobic lagoon.

[b] Not removed by aerobic lagoon.

TABLE 2. REFERENCES FOR DETAILED DESCRIPTION AND DESIGN OF NONCONVENTIONAL TREATMENT TECHNOLOGIES[a]

Technology	Reference	Page
Sedimentation	2	201-221
	3	A-88
Gas Flotation	2	221-227
	3	A-96
Filtration	2	227-252 362-373
	3	A-98
	4	22-1
Ultrafiltraton	4	43-1
Activated Sludge	2	470-522
	5	725
	3	A-38
Trickling Filter	2	442-452 534-546
	3	A-80
	5	433
Lagoon	2	552-553
	3	A-58
	5	551
Rotating Biological Contactors	2	452-453
	3	A-70
	3	A-70
Steam Stripping	4	42-1
	12	78
	15	121
Solvent Extraction	4	32-1
	14	64
Carbon Adsorption	2	277-284
	3	A-126
	5	728
Chemical Oxidation	4	35-1
Air Stripping	2	734-739
	4	41-1
	3	A-114
Nitrification/Denitrification	2	712-719 721-734
	7	
	3	A-48, A-72
Ion Exchange	4	30-1
	2	753
	19	
Reverse Osmosis	4	39-1
	2	754
	18	
Dechlorination	3	
Ozonation	9	591
	4	36-1
	13	65

[a] All technologies are included in Volume III of the Treatability Manual.

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SEDIMENTATION

Pollutant Applicability

Sedimentation can be used to remove the following nonconventional pollutants: chemical oxygen demand (COD), total organic carbon (TOC), total Kjeldahl nitrogen (TKN) and organic nitrogen. Sedimentation with chemical addition can be used to remove these nonconventional pollutants: COD, iron, phosphorus, color, aluminum, fluoride, manganese, TOC, barium, tin, TKN, organic nitrogen and corrosion inhibitor.

Treatability Approach

Chemicals such as lime, alum, polymers, ferric chloride, and sulfide may be added to enhance the settling characteristics of suspended particles or to precipitate dissolved materials. These chemicals may be added either individually or in various combinations.

For gravity settling of discrete particles (no chemicals added), a bench-scale study would require a 1 or 2 liter cylinder as the necessary equipment. Particles of known diameter and density that are representative of the wastewater of concern are inserted into the cylinder filled with water. Measurements of distance settled versus time are taken. A settling rate can be determined and used to design a pilot-scale grit and settling chamber. This pilot-scale study is described later in this section.

For flocculant-aided settling, which commonly occurs when chemicals are added, the apparatus for a bench-scale study should approximate a 20-liter cylinder with sample ports at several intervals. The chemical is added to the wastewater in the cylinder and mixed by stirring until a uniform mixture is obtained. The mixture is allowed to settle and the settling distance is measured at various time intervals. Samples are also taken at various time intervals to determine solids loadings. From these samples and measurements settling rates and total percent removals can be determined. Variables for this study include the chemical(s) added, its concentration, and the influent wastewater solids concentration.

A larger scale, continuous-flow, bench study may be performed. Apparatus needed include a 3-liter rapid mixing tank, a 1-m^3 floculation tank and a 6-m^3 setting tank which has the inlet at one end and the effluent weir at the opposite end. Note these are approximate and may vary based on hydraulic load, detention time and settling rate. The influent wastewater and flucculating chemical(s) are added to the rapid mix tank. Slow mixing occurs in the flocculation tank and settling occurs in the final tank. Concentrations of the influent and effluent from the settling tank are measured and percent removals determined. Parameters for this continuous-flow system include the influent solids concentration, the chemical(s) added and its concentration, flocculation time, settling time, settling rates and settling tank size (length to width ratio).

GAS FLOTATION (DISSOLVED AIR FLOTATION)

Pollutant Applicability

Nonconventional pollutants removed by gas flotation may include COD, phosphorus, TOC, TKN, and organic nitrogen.

Treatability Approach

To enhance the flotation characteristics of the pollutants, chemicals, such as alum, lime, polymers, ferrous sulfate, ferric chloride, and sodium aluminate may be added. Apparatus required to conduct a bench-scale study include a 1- to 2-liter capacity pressurized cylinder, a mixing tank, and a 2- to 3-liter flotation tank with an effluent removal point. Steps for the bench-scale study may be as follows: saturate water with air in the pressurized cylinder at about 40 to 50 psig for several minutes. Add wastewater and flotation-aid (if applicable) in the rapid mix tank, which flows to the flotation unit. Allow the air-saturated water to mix with the influent by introducing the two streams near the same point in the flotation unit. Air bubbles will adhere to the pollutants and rise to the top of the flotation unit carrying the pollutants to the top. Influent and effluent concentrations are measured by sampling the appropriate streams and percent removals are determined for the pollutant of concern. Performance is based on the air to solids ratio required to achieve a given degree of clarification. Other parameters include the concentration of particulate matter, the quantity of air used, the particle rise velocity, the solids loading rate, and the chemical added and its concentration.

FILTRATION

Pollutant Applicability

Nonconventional pollutants removed by the filtration process may include COD, color, TOC, TKN, and organic nitrogen.

Treatability Approach

A large variety of media can be used for bench-scale studies on filtration. Gravel fine sand, and anthracite coal, used individually or in combinations, are the most widely used media. The suggested apparatus for the study is an approximately 1- to 3-m deep cylinder with a cross-sectional area of about 0.1 m^2. For proper operation, the cylinder will require a wastewater influent and overflow valve at the top and an effluent and backwash influent valve at the bottom. Media is placed in the cylinder at a desired depth and the influent is introduced to the filter at the top at a rate between 80 and 400 L/m²·min. The wastewater flows through the media and exists at the filter bottom. Measurements of influent and effluent concentrations are taken and percent removals are determined. When a desired head loss is reached or a breakthrough in the effluent concentration occurs backwashing is required. Backwashing is accomplished by adding water to the filter at the bottom and fluidizing the bed. The polluting material is removed from the media by the washing and flows out the overflow at the top of the filter. Average backwash rates vary between 0.8 and 2.0 m³/m²·min depending on the media used. The principal factors to be determined by the bench-scale study are: the percent removal of pollutant; the selection of the optimally sized filter medium or media and their respective depths; the determination of the most appropriate filtration rate and terminal head loss; and the establishment of the expected duration of filter run.

ULTRAFILTRATION

Pollutant Applicability

Ultrafiltration has been demonstrated to remove in some portion the following nonconventional pollutants: COD, color, TOC, TKN, organic nitrogen, and surfactants.

Treatability Approach

The apparatus and material needed for a bench-scale study would include an ultrafiltration membrane having characteristics of approximately 10^{-3}- to 10^{-2}-micron membrane size and 0.1- to 1.0-micron membrane thickness, and a pressurized chamber having one inlet and two outlets, one outlet on each side of the membrane. Influent wastewater is added to the unit on the top side of the membrane under a pressure of 10 to 100 psig and a filtration flux rate of approximately 0.5 to 10 gal/ft²/day/psi. Particles of a large molecular size will be excluded and concentrated by the membrane and this concentrate will exit at the end opposite the wastewater influent. The filtered wastewater passes through the membrane and exits at the bottom of the unit. Measurements for influent and effluent concentrations are taken and percent removals determined. The actual size of the membrane will be based on the pollutant to be removed. Variables for testing would include the membrane pore size (exclusion rating), influent concentration, upstream pressure, and filtration flux rate.

ACTIVATED SLUDGE

Pollutant Applicability

Activated sludge may be effective in removing the following nonconventional pollutants: COD, phosphorus, ammonia, color, TOC, TKN, sulfide, organic nitrogen and surfactants.

Treatability Approach

The apparatus needed for a continuous-flow bench-scale study on activated sludge is a chamber of approximately 0.5- to 1.0-m^3 volume with an inlet for air, a second inlet for the wastewater feed, an outlet for the treated effluent, and an adjustable baffle to separate the chamber into the aeration and settling steps. The wastewater feed unit should be a flow controlled system. Before the study is initiated a desired mean cell retention time should be determined. The first step in the procedure is to seed the unit with sludge from a well-operating system having an initial volatile-solids concentration of about 1,500 mg/L. Stabilize the unit by supplying air and complete mixing in the aeration zone while allowing for satisfactory settling in the settling zone. Begin feeding the wastewater at a flow rate necessary to achieve the desired hydraulic detention time. The test is maintained until approximate steady-state conditions are reached. This is detected when the effluent BOD or COD is stabilized or a constant oxygen-uptake rate is achieved. Sample for BOD, COD, suspended solids, volatile suspended solids, nitrogen and phosphorus to ensure that healthy conditions for the biological degradation process are maintained. The effluent is removed after the settling portion of the chamber. Removal percentages for the pollutants of concern are determined by comparing the influent and effluent concentrations. Other desired results are the optimum mean cell residence time, the biological growth yield and the decay coefficient. Parameters for operation of the activated sludge system are hydraulic retention time, mean cell residence time, amount of air introduced to the system, initial solids concentration, and oxygen uptake rate. If activated sludge is going to be used for a nitrification process longer detention times and lower organic loadings are required.

TRICKLING FILTER

Pollutant Applicability

Nonconventional pollutants removed by trickling filters are COD, ammonia, color, TOC, TKN, organic nitrogen, and surfactants.

Treatability Approach

The types of media most widely used in trickling filter applications are rocks, wooden slats or plastic forms. Apparatus needed to perform a bench-scale study is a drum approximately 0.5- to 1.0-m in diameter with supports at the bottom to contain the media but allow the effluent to flow through, and a system that will provide an even distribution of the wastewater over the media. Media is placed in the drum at the desired depth. Influent is applied to the media and allowed to trickle through the media. A microbial growth occurs on the media which in turn provides for the uptake and oxidation of the organics in the wastewater. An adequate air supply for the microorganisms to prevent anaerobic conditions is required. Effluent exits at the bottom of the drum. Hydraulic loadings are approximately 0.24 to 0.48 kg/m^3·day, both for an intermediate-rate filter. Effluent is collected and analyzed and compared to the influent concentrations to obtain the percent removals. Settling of the effluent after the trickling filter may be necessary to eliminate the biological solids. Recycling of the effluent to the influent line to reduce the organic loading concentration and improve treatment efficiencies is often used and should be considered. Treatment parameters are pH, temperature, media type and depth. and organic and hydraulic loadings. Slow rate and high rate filters may also be analyzed by varying the organic and hydraulic loadings and media depths. Information about all the variable rate systems may be found in Metcalf and Eddy [2].

LAGOONS

Pollutant Applicability

Lagoons are often used to remove these nonconventional pollutants: COD, phosphorus, ammonia, color, TOC, TKN, nitrate organic nitrogen, and surfactants. Anaerobic lagoons should not be used to remove ammonia and TKN and aerobic lagoons should not be used to remove nitrates.

Treatability Approach

Lagoons may be operated in three general methods: aerobic, facultative, and anaerobic. The aerobic method may be mechanically or naturally aerated. The mechanically aerated lagoon is similar to an activated sludge process, except that there is usually no recycle of the biological solids. Thus, a bench-scale study for the aerated lagoon would be similar to the activated sludge study discussed previously. The aerobic lagoon utilizes the natural growth of algae to supply oxygen to the system along with other natural mechanisms. A bench-scale study for the aerobic lagoon would be similar to the activated sludge but without the forced air to the system. Depths for the aerobic lagoon study should be slightly less than the activated sludge in order to maintain aerobic conditions throughout the lagoon. Algae must be maintained in the system at approximately 40 to 100 mg/L concentration as the oxygen released by the algae is used by the bacteria in the aerobic degradation of organic matter. The nutrients and carbon dioxide released in this degradation are, in turn, used by the algae. Performance depends on organic loading degree of pond mixing, pH, nutrients, sunlight and temperature. As in the activated sludge process influent and effluent concentrations are measured to determine efficiency of the system. Aerobic lagoons are often used in series to improve removal efficiencies. Full-scale aerobic lagoons vary in depth (0.30 to 1.5 m), pond size (0.25 to 4 hectares) and detention time (4 to 20 days) depending on rate desired, available area, and organic loading.

A facultative lagoon bench-scale study would be similar to the aerobic lagoon study except that the bottom portion of the lagoon is allowed to go to anaerobic conditions while the top layer is aerobic with algae growth. The layer between is the intermediate zone that is partly aerobic and anaerobic. Beside the factors that affect performance mentioned in the aerobic section, additional factors are sludge accumulation and suspended solids content in the effluent. Additional information concerning facultative lagoons may be found in Metcalf and Eddy [2].

An anaerobic lagoon bench-scale study is similar to the study for an anaerobic digestion process. A typical anaerobic digestion study is performed in an airtight container that is void of dissolved oxygen, heavy metals and sulfides. A detention time of 20-50 days is required for a full-scale unit. The wastewater sludge is added to the digester and under the anaerobic conditions is converted to methane and carbon dioxide gas. Analysis of influent and effluent concentrations will determine the process efficiency. Lagoons are often used in series to improve treatment efficiencies and should be considered. Operating parameters include pH, nutrient levels, alkalinity, temperature, mean cell residence time and loading factors.

ROTATING BIOLOGICAL CONTACTORS (RBC)

Pollutant Applicability

Nonconventional pollutants removed by an RBC unit are COD, phosphorus, ammonia, color, TOC, TKN, sulfide, nitrate, organic nitrogen, and surfactants.

Treatability Approach

Apparatus needed for a bench-scale study of an RBC is a disc unit (usually plastic) with a surface area of approximately 20 to 30 m^2/m^3 that is submerged about 40 to 50 percent in the wastewater and rotates at approximately 7.3 m/min (peripheral speed). These figures are approximately 40% of full-scale unit requirements [2]. A continuous flow of wastewater is applied to the system as the influent enters the tank where the disc is submerged. Biological growth occurs on the plastic disc surface. As the disc rotates, contact between the biomass and organic material in the wastewater occurs, providing for the uptake of the organics. The rotation of the disc also keeps solids from settling in the disc tank, provides oxygen to the biological growth, and shears excess growth from the disc surface. After desired detention times are achieved the effluent exits the tank area. Usually settling of the solids is required of the disc tank effluent. Influent and settled effluent concentrations are measured to determine removal efficiencies. Organic and hydraulic loadings for the disc unit must be similar to a large scale facility. Recommended values are: an organic loading of about 0.48 to 1.0 kg of BOD_5/m^3 of media and a hydraulic loading of 0.03 to 0.06 $m^3/day/m^2$ of media[a]. In most cases multiple units are applied in series to improve treatment efficiencies. Treatment parameters are organic and hydraulic loadings, temperature, detention time, percent submerged, rotational velocity and pollutant to be removed. For nitrification of ammonia and organic nitrogen and denitrification of nitrates, detention times are extended, organic and hydraulic loadings should be less, and additional units may be necessary.

STEAM STRIPPING

Pollutant Applicability

Steam stripping can be used to remove the following nonconventional pollutants: COD, ammonia, TOC, TKN, sulfide, and organic nitrogen.

Treatability Approach

A variety of columns can be used for the stripping process. Among them are a packed tower, a sieve tray distillation and a bubble cap distillation column. Equipment required for a bench-scale treatability study using a packed column includes feed tanks, heat exchanger, and pumps. The column should be about 6- to 30-cm in diameter, 1.2- to 1.8-m high, with Rashig rings or Berl saddles as commonly used packing materials. Full-scale columns vary between 0.6- and 3.1-m in diameter and 1.2- to 12-m high. The feed water is pumped from the feed tank though the heat exchanger where it is brought to near boiling point temperatures. The wastewater enters the column near the top from the side and is distributed evenly by a common unit such as a spray distributor. The wastewater flows down the column by gravity. Steam enters from the side at the bottom of the column and flows up the column in a countercurrent fashion. The liquid and steam flow rates are sometimes expressed as a liquid to gas ratio. Bench-scale flow rates should be approximately 0.36 m^3/day for liquid and 0.1 m^3/day for steam at about 1 to 2 psi[a]. Full-scale rates are as high as 45 m^3/hr at 5 to 11 psi [4]. Effluent is drawn off the bottom of the column and can be recycled to the

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[a] Data from Treatability Manual, Volume III.

influent. Condensate is removed from the top of the column. The influent and effluent are analyzed and compared for final treatment efficiency. Operating parameters are feed concentrations, wastewater temperature, pressure, pH and liquid and gas feed rates. Stripping columns are often divided into several transfer units, each unit being separated by a redistribution and packing support plate, to improve treatment efficiency. Calculating the number of transfer units for a bench-scale or full-scale unit is described in several of the reference publications.

SOLVENT EXTRACTION

Pollutant Applicability

Nonconventional pollutants removed by solvent extraction (liquid-liquid extraction) are COD, color, TOC, TKN, organic nitrogen, and surfactants.

Treatability Approach

Among the many solvents that can be used for the extraction process are crude oil, light oil, benzene, toluene, isopropyl ether, tricresyl phosphate, and others. There are two types of extraction columns that can be used, simple gravity and mechanically agitated. The simple gravity can be the spray, simple packed or perforated plate type. The mechanically agitated type can be the pulsed packed, pulsed perforated or reciprocating plate type. Packed towers use a common packing material, such as Berl saddles. Apparatus for a laboratory bench-scale study are standard separatory funnels. Using large batches of solutions, add the solvent and wastewater to the funnels. Invert the funnels approximately 50 times per 1 to 2 minutes to reach equilibrium extraction steady-state conditions.

CARBON ADSORPTION

Pollutant Applicability

Carbon adsorption can be used to remove the following nonconventional pollutants: COD, phosphorus, color, TOC, TKN, organic nitrogen, corrosion inhibitor, and surfactants.

Treatability Approach

Materials and apparatus needed to perform the bench-scale study are several 1-liter jars and mixers, and granular or powdered carbon. Various known amounts of carbon are placed in each jar ranging from approximately 0.5 to 50 grams depending on the pollutant concentration to be removed. Five hundred milliliters of wastewater are placed into each jar and mixed for 3 to 6

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[a] Obtained from Treatability Manual data sheets, Volume III.

hours. Samples are taken and analyzed for pollutant concentrations. Removal efficiency is determined by comparing the initial and the final concentration of the pollutant. This data can also be used to determine an adsorption isotherm that describes the amount of pollutant adsorbed as a function of the pollutant concentration. Depending on the results obtained, with the suggested carbon dosage range, it may be desirable to repeat the above procedure using a different set of dosages to further define the isotherm characteristics and removability potential. Additional continuous-flow bench-scale studies can be performed similar to the filtration bench-scale study previously discussed, except that activated carbon is used as the media. This type of bench-scale study is performed to compare various carbon samples, check head loss against flow rates and bed depths, check backwash flow rate and efficiency of the system for pollutant removal. In either study, parameters that affect performance are the influent characteristic and concentration, the adsorptive properties of the carbon and the amount of activated carbon used.

CHEMICAL OXIDATION

Pollutant Applicability

Nonconventional pollutants removed by chemical oxidation are: COD, ammonia-nitrogen, color, TOC, TKN, sulfide, organic nitrogen, and surfactants.

Treatability Approach

Many oxidizing agents can be used in this chemical process, such as chlorine, ozone, potassium permanganate, hydrogen peroxide, chromic acid, sodium hypochlorite, calcium hypochlorite and many others. (Ozone and ozonation are discussed in a later section.) Depending on the oxidizing agent used, the pH may need to be adjusted to provide optimum conditions for the oxidizing process and this can be accomplished by adding an appropriate acid or alkali. Apparatus required for the bench-scale study is a mixing tank, used to mix the oxidizing agent and wastewater, and a settling tank to precipitate any insoluble oxidized material, metals, or other residues. The first step in the process is to add the appropriate chemical to adjust the pH. Next, in the mixing tank add the oxidizing agent and the wastewater. Additional time may be allowed to ensure complete mixing and oxidizing. Depending on the oxidizing agent used, heat may be liberated and cooling of the sample may be necessary. Additional steps of adding more oxidant, readjusting the pH and adding more oxidant, may be desired. After all reactions are complete precipitation in the settling basin is suggested. The effluent from the settling basin is compared to the original concentration to determine percent removals. Parameters for this test include the oxidizing agent used, its concentration, pollutant removal desired, and pH.

AIR STRIPPING

Pollutant Applicability

Air stripping may be used to remove the following nonconventional pollutants: ammonia, TKN, and free chlorine.

Treatability Approach

Chemicals and materials required to perform a bench-scale study are lime [$Ca(OH)_2$] which is used to raise the pH of the wastewater prior to the stripping tower and a packing material, either plastic, wood, or PVC pipe, about 1.3-cm diameter. Apparatus required for the bench-scale study inludes a rapid mix tank, a flocculation tank (for slow mixing), a settling tank, and the stripping tower. A full-scale stripping tower is about 6- to 7.5-m high and equipped to handle a 2.4 to 6.0 $m^3/m^2/hr$ hydraulic loading and a 2,250 to 3,740 m^3 air/m^3 liquid air flow. Bench-scale apparatus should not be as tall as a full-scale unit, however, the hydraulic loading and air flow should be similar to the full-scale unit. The first step in the procedure is to determine the approximate amount of lime to add to achieve a pH between 10.5 and 11.5. The lime slurry and the continuous flow of wastewater are mixed in the rapid mix tank and slow mixed in the flocculation tank. Calcium phosphate and calcium carbonate are settled out in the settling basin. The wastewater flows to the top of the tower and trickles down through the packing while the air flow enters from the sides and up the tower in countercurrent fashion. The interaction of air and treated wastewater strips the ammonia and releases it into the atmosphere through an outlet at the top of the tower. The effluent, which flows out the bottom of the tower, is analyzed and compared with the influent concentration of ammonia to determine treatment efficiency. Recarbonation and settling of the final effluent may be desired. Parameters for the study are pH, temperature, air to liquid ratio and packing material and density.

NITRIFICATION/DENITRIFICATION

Pollutant Applicability

Nonconventional pollutants removed by the nitrification/denitrification process are: ammonia, TKN, nitrate, and organic nitrogen.

Treatability Approach

There are several ways in which the nitrification/denitrification of wastewater can be performed. Some of the methods are a trickling filter, a rotating biological contactor (RBC), an oxidation ditch (modified low-rate activated sludge process), and a packed-bed reactor. Bench-scale studies have been presented previously for all of these processes, except an oxidation ditch. In all cases longer detention times are required so that all of the nitrogen in the raw wastewater is converted to nitrate (nitrification step) prior to the anaerobic (denitrification) step. Lower BOD loadings are also required. The effects of temperature on the nitrification/denitrification process should be considered.

An oxidation ditch is similar to an aerated lagoon, except that there is a constant flow around the ring-shaped ditch. The full-scale operation for an oxidation ditch requires a ring-shaped channel approximately 1- to 1.5-m deep, a mean cell retention time of 20-30 days, and a hydraulic detention time of 18-36 hours. Bench-scale operations may need to operate at near full-scale conditions to ensure proper removal efficiency. Influent is added at one end of the ring where it is aerated and circulated by a rotor. The effluent is drawn off at the opposite end of the ring from the influent. Further description of the process can be found in Metcalf and Eddy [2]. Treatment parameters include organic and hydraulic loadings, detention time, mean cell retention time, and flow velocity.

ION EXCHANGE

Pollutant Applicability

Nonconventional pollutants removed by the ion exchange process are: iron, phosphorus, ammonia, color, aluminum, manganese, barium, tin, TKN, nitrate, corrosion inhibitor, and surfactants.

Treatability Approach

There are a large number of ion exchange materials that can be used for pollutant removal depending on the contaminant and its influent concentration. Some consideration to the proper exchange material should be completed prior to commencing the study. Apparatus required for a bench-scale study includes a cylindrical ion exchange bed, tanks for solution storage, and a number of pumps. Depending on the wastewater to be treated and the exchange resin used, filtration units before or an ammonia-stripping unit after the ion exchange unit may be necessary. Steps for the treatability tests are to pack the column with the exchange resin to a depth of approximately 0.25- to 1.0-m. Wastewater is added at the top of the exchanger under pressure, passes through the resin bed and exits at the bottom. Hydraulic loadings should be approximately 0.2 to 0.4 $m^3/m^2 \cdot min$. Once the bed is exhausted backwasing, regeneration and rinsing processes should be tested to check on economics of the technology. Influent and effluent concentrations are measured and percent removals calculated to determine the technology feasibility. The factors that affect performance are the exchange capacity (a measure of the total uptake of a specific ion), selectivity (preference of one kind of exchangeable ion over another), and functionality (types of ions that are exchanged) of the resin. Two stage exchangers are often used to improve treatment performance and remove a larger variety of pollutants. The wastewater is first passed through a cation exchanger where the positively charged ions are replaced by hydrogen ions. Then the wastewater passes over an anionic exchange resin where negative ions are replaced by hydroxide ions.

REVERSE OSMOSIS (RO)

Pollutant Applicability

Nonconventional pollutants removed by reverse osmosis are iron, phosphorus, ammonia, color, aluminum, fluoride, manganese, barium, tin, TKN, nitrate, organic nitrogen, corrosion inhibitor, and surfactants.

Treatability Approach

The chemicals required for a bench-scale treatability study would be those used to lower the pH to a range of 4 to 7 in order to prevent scaling. Membrane materials are widespread, with the two most common types being cellulose acetate and nylon. The apparatus for the treatability study includes pretreatment equipment, a reverse osmosis unit and a high pressure pump. A typical full-scale operation would require about 400 to 600 psi pressure at about 20 to 25°C. The wastewater is first pretreated, usually with a carbon adsorption unit. The flow then goes into the RO unit at one end under pressure and the membrane separates the pollutant and product water. The product effluent exits at ports at the side and the concentrated brine exits at the opposite end to the influent. Influent and effluent concentrations are measured and compared to determine treatment efficiencies. Flux rates through the membrane should be approximately 0.20 to 0.81 $m^3/day/m^2$. Parameters affecting performance include the membrane type, the operating pressure and the pollutant to be removed.

DECHLORINATION

Pollutant Applicability

Dechlorination is used to remove the free or combined chlorine in wastewater.

Treatability Approach

Commonly used chemicals for the reduction of the chlorine are sulfur dioxide (SO_2), sodium sulfite, sodium metabisulfate, and sodium thiosulfate. For a bench-scale treatability study apparatus required will be holding tanks for the SO_2 gas and wastewater, injection lines for the SO_2 gas, an eductor, and a mixing tank. Because the required contact time for the SO_2 and chlorine is small (less than 5 seconds) a contact chamber is not necessary. Chemical (commonly sulfur dioxide) feed rate should be approximately 1.1 lb/lb residual chlorine. Feed rates for other chemicals will vary. The bench-scale procedure requires the SO_2 gas to flow from the holding tank to an eductor where the SO_2 is mixed with water to form a liquid solution. This solution is then fed into a mixing tank where the solution water and chlorinated influent are thoroughly mixed. The effluent from the mixing tank and the chlorinated influent concentrations are measured and treatment efficiency can be determined.

The key control parameters for this process are proper dosage of SO_2 based on precise monitoring of the chlorine residual and adequate mixing at the point of application of SO_2.

OZONATION

Pollutant Applicability

Nonconventional pollutants removed by ozonation are: COD, TOC, ammonia, color, TKN, sulfide, surfactants, and organic nitrogen.

Treatability Approach

The chemical required for the bench-scale batch reactor treatability study is potassium iodide. Equipment required for the study includes an ozone generator, four 1-liter sealed glass containers, a 3-liter glass reactor, a glass Frit diffuser, a two-way glass valve mounted on the side of the reactor in order to withdraw periodic samples, a rotometer to control gas flow, and a wet test meter to measure the gas flow. The procedure is as follows: Start up the ozone generator with oxygen cylinder attached. Fill the sealed glass containers with one-liter of potassium iodide solution at about a 20 g/L concentration. Fill the 3-liter reactor with wastewater. Adjust the ozonator gas flow to the desired flow rate using the rotometer and divert 3-meters of the gas flow through one of the glass containers. The gas stream is then diverted through the waste sample and ozonation continues for the desired contact time. Samples should be taken at intermediate times. Pass the gas to the remaining glass containers to ensure that all the ozone is captured. At the end of the contact time stop the gas flow and remove the solutions from the reactors. Measure the residual concentration of the pollutant of concern and compare to the original concentration for treatment efficiency. Treatment parameters are the contact time, the quantity of ozone applied, pH, temperature, concentration of wastewater constituents and the efficiency of the ozone wastewater contactor. A continuous-flow pilot study may also be analyzed. For this pilot study or information on the batch study see Reference 9.

RATIONALE FOR THE DEVELOPMENT OF TREATABILITY PROTOCOLS

PURPOSE

The objective of this report is, first, to provide to industrial or municipal personnal a list of feasible treatment alternatives for controlling specific nonconventional pollutants. And, second, to present a general bench-scale treatability approach for each treatment alternative.

These objectives are achieved in a matrix table of eighteen nonconventional pollutants and the various treatment alternatives that can be used to remove these pollutants, and by providing a general approach to the bench-scale treatability study for each treatment alternative listed in the matrix. This general approach is broken down into the following sections: pollutant applicability, which lists the pollutants that the technology has the potential to remove; and treatability approach, which describes the chemicals, materials and apparatus required, the general steps, the important design factors, the results to be obtained, and the operating parameters for the bench-scale study.

APPROACH

A. Matrix Table

1. Methods

The data gathered for the matrix table was compiled through two methods. First, data was compiled from Volumes III and V of the Treatability Manual. Volume III's subject material is Technologies. This volume gives a technological description, primary function, basic operating principles, design criteria, common modifications and applications, limitations, status, environmental impact and chemical requirements for each technology. In addition, pollutant removability data sheets for various industries and summary tables for each technology are included. Volume V of the Manual summarizes much of Volumes I to IV and provides a quick reference and evaluation scheme for the NPDES permit writers, enforcement personnel and industrial or municipal personnel. In Appendices C and D of Volume V are tables showing Median Removal Efficiencies and Pollutant Treatability Index of different control technologies for various pollutants. From Volume III and Volume V, Appendix C and D, information on pollutant removability potential by the various technologies was gathered.

The second method for data gathering was through a general literature search. A bibliography of this literature is shown at the end of the report so that additional information on technologies and pollutant removability may be obtained.

2. Explanation

The focus of Volumes III and V of this Treatability Manual is on the conventional and toxic pollutants with little emphasis on the nonconventional pollutants. The matrix table presented in this report has been designed to emphasize the nonconventional pollutants as a continuation of the Treatability Manual's information. The purpose of the matrix, then, is to show that the marked technologies have the potential to remove a specific pollutant. For example, if an industry has a problem of iron in their wastewater, potential treatment alternatives are sedimentation with chemical addition, filtration, chemical oxidation, ion exchange, reverse osmosis and ozonation.

Blank spaces within the matrix indicate that data relating the technology with the pollutant is not available and, therefore, it is assumed that the technology is not a feasible alternative for the removal of that specific pollutant. Technologies not mentioned in the matrix were not considered in the study because data were not available.

B. Bench-Scale Studies

1. Methods

Bench-scale treatability study information was obtained through a general literature search. The bibliographies are listed at the back of this report. Various jar-test and bench-scale studies, operating parameters, design criteria and process steps were found in the various reports and the tests and criteria most representative of this report were used.

2. Explanation

The bench-scale treatability studies are presented in a general format to allow personnel with a treatment problem to prepare for and understand the magnitude of the study and to provide the approximate steps required for the study. For many of the technologies, additional information may be desired if an in-depth bench-scale study is to take place and it is suggested that the references at the end of this report be consulted. Some pollutants may be removed best by a combination of treatment processes, such as filtration before a carbon adsorption system, however, these combinations are not within the scope of this report.

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APPENDIX D

Review of State Mixing Zone Policies

A review of individual State mixing zone policies (listed on pages 3 and 4 of this appendix) shows that forty eight of the 50 States make mention of a mixing zone in some form. Thirty-one out of 50 states (and 2 territories) include actual mixing zone dimensions in their water quality standards. For streams, 17 of these 31 states model their mixing zone guidelines requirements on the Green Book (Water Quality Criteria, 1968 guidelines. Those guidelines provide that the zone of mixing shall not exceed 1/4 of the cross-sectional area and/or volume of the stream flow, and the remaining 3/4 of the stream shall be maintained as a zone of passage for swimming and drifting organisms and shall remain of such quality that stream ecosystems are not significantly affected.

The remaining States with defined mixing zones vary in their requirements, allowing dimensions from as low as 1/5 of the cross-sectional area (Ohio) to as high as 3/4 of the cross-sectional area (South Dakota). Ohio uses 1/2 of the stream width as a mixing zone boundary. West Virginia includes a length dimension in its mixing zone policy: for warm water fisheries, no mixing zone may have a length exceeding ten times the average width of the mixing zone, and for cold-water fisheries streams, no mixing zone may have a length exceeding five times the average width of the mixing zone.

Two states make no reference to mixing zones at all: Arizona and Pennsylvania. Accordingly, EPA does not recognize any mixing zones in those States, and water quality requirements must be met at the point of discharge unless the State and the applicant develop a case-by-case mixing zone.

Mixing zone dimensions for lakes vary from State to State depending on the relative size of lakes in each State. Three of the six states that include mixing zone dimensions for lakes (Alaska, Delaware, Florida) use 10% surface area as a general boundary.

The other three (Illinois, Michigan, West Virginia) offer 300-1000' radial limits around discharge points as a mixing zone limit. (Florida also employs a radial limit as well as their 10% surface area limit depending on whichever proves smaller.)

The policy on estuaries has been somewhat similar to that for lakes. In most cases they are both grouped together. Those states that do mention estuaries mixing zone dimensions (Florida and D.C.) use 10% cross-sectional area as their mixing zone boundary.

CS = cross-sectional area
SA = surface area
0 = not listed

State-by-State Mixing Zone Dimensions

State	Water Body	Dimensions
Alabama	0	0
Alaska	river, streams	≤ 1/3 CS
	lakes	≤ 10 % SA
Arizona	0	0
Arkansas	large streams	≤ 1/4 CS
California	0	0
Colorado	0	0
Connecticut	streams	≤ 1/4 CS
Delaware	streams	≤ 1/3 CS
	lakes	≤ 10% SA
D.C.	estuary	≤ 10% CS
Georgia	0	0
Florida	streams, rivers	≤ 800 meters
		≤ 10% total length
	lakes, estuaries	≤ 125,600 m^2 (600'radius.
		≤ 10% SA
Hawaii	0	0
Idaho	0	0
Illinois	all	≤ 600 ft radius
	streams	≤ 1/4 CS
Indiana	streams	≤ 1/4 CS
Iowa	streams	≤ 1/4 CS
Kansas	streams	≤ 1/4 CS
Kentucky	streams	≤ 1/3 CS
Louisiana	streams	≤ 1/4 CS
Maine	streams	≤ 1/4 CS
Maryland	0	0
Massachussetts	0	0
Michigan	streams	≤ 1/4 CS
	Lake Michigan	≤ 1000 ft radius
Minnesota	streams	≤ 1/4 CS
Mississippi	0	0
Missouri	streams	≤ 1/4 CS
Montana	0	0
Nebraska	0	0
New Jersey	streams	≤ 1/4 CS (thermal)
New Hampshire	streams	≤ 1/4 CS
New Mexico	streams	≤ 1/4 CS
New York	streams	≤ 1/2 CS (thermal)
Nevada	streams	≤ 1/3 CS
North Carolina	0	0
North Dakota	streams	≤ 1/4 CS

Ohio	receiving watercourse	≤ 1/3 CS
	mouth of receiving	≤ 1/5 CS
Oklahoma	streams	≤ 1/4 CS
Oregon	0	0
Pennsylvania	0	0
Rhode Island	streams	≤ 1/4 CS (thermal)
South Carolina	0	0
South Dakota	streams	≤ 3/4 CS or 100 yards of stream width
Tennessee	0	0
Texas	streams	≤ 1/4 CS
Utah	0	0
Vermont	streams	≤ 1/4 CS
Virginia	0	0
Washington	0	0
West Virginia	warm water fish streams	≤ 33% CS
	cold water fish streams	≤ 20% CS
	lakes	≤ 300' any direction
Wisconsin	streams	≤ 1/4 CS
Wyoming	0	0
Guam	0	0
Puerto Rico	streams	≤ 1/4 CS
	IMZ	≤ 400 ft
	FMZ	≤ 4000 ft
Virgin Islands	streams	≤ 1/4 CS

Dilution Considerations for Marine Discharges

(excerpted from the 301(h) Technical Support Document)

PHYSICAL ASSESSMENT

A physical assessment of the applicant's discharge is necessary to determine the initial dilution that will be achieved, the zone of initial dilution (ZID), and the farfield transport and dispersion of the effluent.

Municipal wastewater effluent discharged into the ocean through submerged outfalls creates a buoyant plume that rises quickly toward the surface, entraining significant amounts of ambient saline water. The momentum and buoyancy of the effluent relative to seawater are primarily responsible for entrainment of seawater, although in some circumstances ambient currents and turbulence also contribute to initial dilution.

One consequence of the entrainment process is that the density of the rising plume becomes greater and approaches that of the ambient waters along its trajectory. If a sufficient ambient vertical density gradient or a stratification zone (like a pycnocline) is present, the plume can spread horizontally at a level of neutral buoyancy below the sea surface. If a sufficient density gradient is not present, the diluted wastewater plume reaches the surface and flows horizontally.

INITIAL DILUTION

Data Requirements

Characteristics of the discharge and physical environmental conditions at the discharge site are needed to calculate initial dilution. Information is required for the period(s) of maximum stratification and other critical periods. A diagram or verbal description of the diffuser length and diameter, port orientation, and arrangement with respect to the seabed and to other ports will be used by EPA to assess the adequacy of the calculations and the adequacy of the design. For multiport diffusers, the design flow of each port is requested, as unequal flow may influence the actual dilution achieved. It is also helpful to have information for the period(s) of minimum stratification. It is not necessary for the applicant to calculate the initial dilution for each port but only for that segment of the diffuser with the highest flow rate per unit diffuser length or for the port with the highest flow rate.

Effluent flow data are required for the computations. Historical data should be used to determine the minimum, average dry-weather, average wet-weather, annual average, and maximum flows.

Since initial dilution calculations can be strongly dependent on the vertical gradient of density relative to the density of the wastewater, larger applicants will need to evaluate a substantial amount of data from both the discharge site and nearby areas having similar environmental conditions before selecting a worst-case density profile. Since ambient currents may affect the initial dilution achieved, a modest amount of current (the lowest 10 percentile) can be used in predicting initial dilution.

Initial dilution is the flux-averaged dilution (averaged over the cross-sectional area of the plume) achieved during the period when dilution is primarily a result of plume entrainment. It is characterized by a time scale on the order of minutes. With proper location and design, marine outfalls can achieve initial dilution values of about 100 to 1 or better before the plume begins a transition from essentially vertical flow to an essentially horizontal flow dominated by ambient oceanographic conditions. For the purpose of this evaluation process, "dilution" is defined as the ratio of the total volume of a sample (ambient water plus wastewater) to the volume of wastewater in that sample. A dilution of 100 to 1, therefore, is a mixture composed of 99 parts of ambient water and 1 part of wastewater.

Adequate initial dilution is necessary to assure compliance with water quality standards. A number of factors influence the degree of initial dilution which will be achieved. These factors include:

Discharge depth
Flow rates
Density of effluent
Density gradients in the receiving water

Ambient current speed and direction
Diffuser characteristics
    Port sizes
    Port spacing
    Port orientation

There are a number of methods and models available to calculate the initial dilution to be expected for different oceanographic and diffuser conditions. This section describes several methods of computing initial dilution.

Computer Models

Several mathematical models are available from EPA which are appropriate for different oceanographic and diffuser conditions. A summary of the characteristics of these models is presented in Table V-1 and a brief description of them is provided here:

- PLUME - Analyzes a single, positively buoyant plume in an arbitrarily stratified stagnant environment.
- OUTPLM - Analyzes a single, positively buoyant plume in an arbitrarily stratified flowing environment.
- DKHPLM - Analyzes a multiport, positively buoyant plume in a linearly stratified flowing receiving water.
- MERGE - Analyzes either positively or negatively buoyant discharges. The model analyzes a plume element through the history of its trajectory and dilution, accounting for the effects of adjacent plume interference in a receiving water with arbitrary vertical density and current variation.
- LINE - Treats discharges as a line source accounting for adjacent plume interference. The model is capable of analyzing positively buoyant discharges in an arbitrarily stratified receiving water with a current flowing parallel or perpendicular to the diffuser.

TABLE V-1. SUMMARY OF PLUME MODEL CHARACTERISTICS

Model Name	Current Speed	Current Direction ϵ [a]	Port Type	Density Profile Type
PLUME	no		single	arbitrary
OUTPLM	yes	90°	single	arbitrary
DKHPLM	yes	$70^{\circ} < \epsilon < 110^{\circ}$	multiple	linear
MERGE	yes	90°	multiple	arbitrary
LINE	yes	$0 \leq \epsilon \leq 180^{\circ}$	line	arbitrary

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[a] A current flowing perpendicular to the diffuser axis has current direction $\epsilon = 90^{\circ}$. The widest range of possible angles is 0 to 180°.

The first three of these models are described in detail by Teeter and Baumgartner (1979) and are adequate for most situations. The model MERGE is a generalization of OUTPLM. The model LINE is a generalization of Roberts (1979). Neither MERGE nor LINE has been published in the open literature but both have been used in the evaluation of section 301(h) applications. All of these models are available from the EPA. Applicants are not required to use any of the models listed in Table V-1. If other methods are used, however, the application should include a detailed description of the method(s) employed and demonstrate that the method(s) provides reasonable estimates of initial dilution.

Other methods to determine initial dilution may include in situ observations. However, if in situ observations are used, the applicant should demonstrate that they represent the critical dilutions, not merely a typical dilution. In addition, there are a number of other mathematical models available in the published literature which can be adapted for estimating initial dilution. References which describe several of these models are: Abraham (1963, 1971); Baumgartner and Trent (1970); Baumgartner et al. (1971); Briggs (1969); Brooks (1973); Cederwall (1971); Davis (1975); Davis and Shirazi (1978); Fan (1967); Hirst (1971a, b); Kannberg and Davis (1976); Kor and Fan (1970); Morton (1959); Morton et al. (1956); Priestley and Ball (1955); Rouse et al. (1952); Sotil (1971); Teeter and Baumgartner (1979); and Winiarski and Frick (1976).

ZONE OF INITIAL DILUTION (ZID)

The ZID is the region of initial mixing surrounding or adjacent to the end of the outfall pipe or diffuser ports and includes the underlying seabed. The ZID describes an area in which inhabitants, including the benthos, may be chronically exposed to concentrations of pollutants in excess of water quality standards or at least to concentrations greater than those predicted for the critical conditions described above. The ZID does not attempt to describe the area bounding the entire mixing process for all conditions, or the total area impacted by the sedimentation of settleable material.

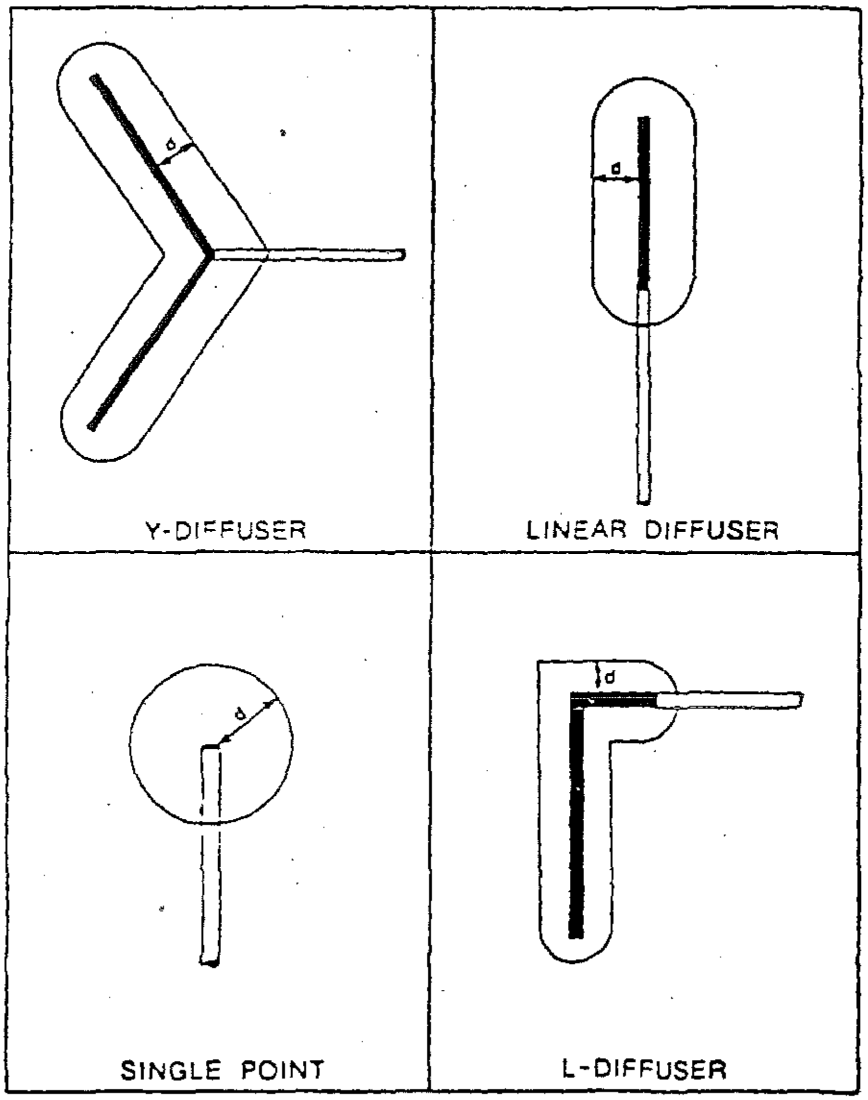
In general, the ZID can be considered to include that bottom area within a distance equal to the water depth from any point of the diffuser and the water column above that area. Figure V-1 shows several examples for different diffuser configurations and corresponding ZID dimensions.

DISPERSION AND TRANSPORT

A general description of the ambient currents expected within the influence of the diffuser site is required by EPA. Since this description is primarily of use in the determination of where the effluent wastefield is likely to be transported during several days' time, the response to this subsection should be of sufficient detail for this purpose. In a region where currents are predominantly tidal in nature, current persistence and the mean current speed and its variance, with respect to the primary direction(s) of water flow, should be given. If the currents have large components unrelated to tidal influences (e.g., wind induced currents), then a more detailed analysis should be performed. The mean, variance, and direction of the tidal component should be determined, as well as a synopsis of the nontidal current speed, direction, and persistence. Depth variations in currents are important at depths where the effluent wastefield is trapped.

The basis for the current estimates should be provided. Acceptable sources of information are site-specific measurements and/or published measurements or predictions. The Tidal Current Tables published annually by the U.S. Department of Commerce [see USDOC (1979a, b)] provide tidal current information for a large number of locations. Information from other published documents is usable if the documents are available to EPA on request.

Expected or measured dilutions at significant shoreline stations should be included. Section VI of this document provides further guidance on computing farfield dilutions for water quality parameters.



NOTE: d = water depth

Figure V-1. Diffuser types and corresponding ZID configurations

7. 301(g) COMPUTER MODELS FOR PREDICTING DILUTION

The following section recommends computer models that can be used to predict the mixing characteristics of NPDES discharges under a variety of hydrological conditions. (Not included in this section are individual program listings. These are available from EPA headquarters.)

Additional guidance on the use of mathematical models in developing wasteload allocations is available from the Wasteload Allocation section of the Monitoring and Data Support Division, Office of Water Regulations and Standards (Phone (202) 382-7056). Also see Appendix H.

I. INTRODUCTION

Dilution of effluents discharged into receiving waters is accomplished by different mixing mechanisms along the path of the plume. In the "near field" of the source, dilution is primarily caused by jet induced entrainment. This is a rapid process and far overshadows dilution caused by ambient turbulence. As the excess velocity of the jet decreases, entrainment rates decrease to the point where ambient diffusion also becomes important. This is called the intermediate field. Further out, the excess plume velocity is so small that ambient diffusion is the predominant mixing mechanism. This is called the far field or passive diffusion zone.

Mixing at all stages is affected by ambient currents, physical boundaries and buoyancy. Forces due to buoyancy are usually characterized by the densimetric Froude number defined as $F_o = U_o/(g'L)^{\frac{1}{2}}$ where g' is the density reduced gravity $g|\rho_o-\rho_a|/\rho_o$ and L is a characteristic length usually taken as discharge diameter for circular submerged jets and discharge channel depth for rectangular surface jets. High Froude numbers of the order of 100 or greater mean buoyancy is negligible as compared to momentum and discharge is called a momentum jet. Froude numbers less than unit imply high buoyancy and result in buoyant plumes or thermals. Buoyant forces may be either positive as in thermal discharges or negative where dissolved solids or salinity cause the discharge to be more dense than the ambient.

It is beyond the scope of this document to present a history and development of plume modeling along with a complete literature review. Interested readers may find good reviews in references (1-4)*.

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* Underlined numbers refer to references. Other numbers refer to equations.

II. DILUTION OF POLLUTANTS IN FRESH WATER

The discharge of pollutants into inland rivers, lakes and estuaries is accomplished through a variety of outfalls. They vary from discharges into deep lakes from submerged single port or multiple port diffusers to surface discharge into a shallow, fast moving river. As a result, there is no single analytical model that can be used to predict the fate of these pollutants from all types of discharges and ambient conditions. The most direct way of determining pollutant concentrations downstream of the discharge of an existing outfall is by physical measurement. Such field surveys are quite satisfactory if properly conducted. Non-polluting tracers can also be injected into the effluent that give more accurate indications of dilution than measurements of pollutants themselves (5). Care must be taken to insure accuracy and a number of readings should be made at each location in question so a good statistical average can be determined.

Large grid type transient numerical models have been developed to describe discharges into a few heavily used water ways including tidal estuaries (6). These models usually require considerable time and effort to run and are therefore costly. Their accuracy is highly dependent on the users ability to describe ambient conditions and on the diffusion model employed in the program. These models can be used to predict the fate of pollutants if sufficient validation data are available to insure accuracy.

The simplist method of predicting dilution values for these discharges is through integral computer models or closed form analytical models. These models are in most cases as good or better in predicting dilution from the outfalls in question than present numerical models (6). The difficulty with these models is that they tend to become specialized and only give accurate results for a particular type of outfall. The user must, therefore, be careful to use only a model that was intended to predict the condition he is concerned with.

The output from these models is not always in the form a user wishes and some modifications may be required. For example, some models give the minimum dilution at the center of the plume. This dilution is defined as the local volumetric flow rate divided by the discharge flow rate. This can be interpreted as the inverse of the ratio of local centerline pollutant concentration, C/CO. Other models give average plume dilution which is always greater than that at the centerline and an expression depending on plume shape must be used to determine maximum concentrations at the center.

The object of this document is to suggest models that can be used to predict the fate of pollutants for a variety of conditions and give details on each model as to input, output and limitations.

III. RECOMMENDATIONS

Other than physical measurements and validated numerical models, the following integral models are recommended for predicting dilution of pollutants in fresh water. It is expected that these recommendations will be up-dated as better methods become available. Table I presents several types of discharge conditions and the suggested model to be used to predict concentrations. Each model is discussed in detail in the following sections.

TABLE I. RECOMMENDED MODEL APPLICATIONS

	Discharge Conditions	Suggested Model
1.	Submerged discharge from a single or multiple port diffuser at sufficent depth that desired concentrations are reached before the plume reaches the surface. Ambient currents permitted.	DKHPLM
2.	Surface discharge into a deep receiving water such that the plume floats on the surface and is not attached to the bottom. Ambient currents moderate, $U_a/U_o < 0.5$.	PDS
3.	Surface discharge into a deep receiving water such that the plume is not attached to the bottom but at high ambient currents causing the plume to attach to the near shore, $U_a/U_o > 0.7$.	PDSM
4.	Surface discharge into a shallow receiving water such that the plume is attached to the bottom. Ambient currents moderate, $U_a/U_o < 0.5$. Discharge density equal to ambient density.	MOBEN
5.	Surface discharge into a shallow receiving water with ambient currents high enough to cause the plume to be attached to both bottom and near shore. Discharge density equal to ambient density.	PSY

There are many conditions not covered in the above table such as long term predictions in a tidal estuary or submerged discharge into shallow water with buoyant plumes that surface. For those cases that are not adequately described in the above table, it is suggested that field measurements be used to determine dilution. Conservative predictions can be made for submerged discharge into shallow receiving water where the plume surfaces rapidly by using the PDS model assuming the plume is entirely at the surface. For submerged discharges of non-buoyant fluids into shallow water at an orientation such that the plume does not surface, the DKHPLM model can be used.

IV. "DKHPLM" MODEL

THEORETICAL DEVELOPMENT

The computer model DKHPLM (7, 8) is an approach to the problem of submerged single or merging multiple plumes. For multiple plumes the detailed dynamics of the merging process is considered instead of simplifying the problem to an idealized slot plume or to a combination of plume and slot plume. DKHPLM considers three zones of plume behavior; zones of flow establishment, single plume established flow and merging. The first two zones are based on the analysis of Hirst (4, 9) for a plume in a stratified, flowing environment. In the zone of merging, neighboring plumes are superimposed. This allows a smooth transition as single plumes begin to compete for dilution water then gradually merge with their neighbors. Equations for the conservation of mass, pollutant, energy and momentum are developed for all three zones. Entrainment is an explicit function dependent on the local Froude number, plume spacing, excess velocity and ambient velocity. Similar lateral profiles, a 3/2 power approximation of a Gaussian, are assumed for velocity, concentration and temperature. These profiles are superimposed in the merging zone. A complete theoretical development of this model is beyond the scope of this paper but can be found in the references cited above. The following is a brief summary.

Zone of Flow Establishment

All quantities are assumed uniformly distributed in the plume at the point of discharge. In the zone of flow establishment, these uniform profiles change to similar profiles as the boundary layer diffuses inward to the centerline of the jet. The rate at which the profiles of velocity, concentration and temperature develop may vary. The integrated forms of the governing equations are:

conservation of mass,

$$d/ds \int_0^\infty U \; r \, dr = -\lim r \to \infty \, (r \, v) = E \qquad (1)$$

conservation of energy,

$$d/ds \int_0^\infty U (T-T_\infty) \; r \, dr = - \, d \, T_\infty/ds \int_0^\infty U \; r \, dr - \lim r \to \infty \, (r \, v'T') \qquad (2)$$

conservation of pollutant,

$$d/ds \int_0^\infty U \; (C-C_\infty) \; r \, dr = -d \, C_\infty/ds \int_0^\infty U \; r \, dr - \lim r \to \infty \, (r \, v' \, C') \qquad (3)$$

conservation of momentum in the s equation,

$$d/ds \int_0^\infty U^2 \; r \, dr = U \, E \, \sin\theta_1 \, \cos\theta_2 + \int_0^\infty g \; (\rho_\infty - \rho)/\rho_d) \; r \, dr \, \sin\theta_2 \qquad (4)$$
$$- \lim r \to \infty \, (r \, u' \, v')$$

where θ_1 is the horizontal angle between the centerline and the x axis and θ_2 is the angle between the centerline and the horizontal. Two additional integral equations have been developed from equation (4) to describe momentum in two additional plume coordinants. These "natural" coordinants of the plume, described in (4), are converted to conventional three-dimensional Cartesian coordinantes for model output. Implicit in the derivation of these equations are the assumptions that:

a) flow is steady in the mean,

b) flow is fully turbulent,

c) fluid is incompressible and density variations are included only in the buoyancy terms,

d) all other fluid properties are constant,

e) no frictional heating,

f) pressure variations are purely hydrostatic,

g) changes in density are small enough to be approximated by a linear equation of state,

h) flow within the jet is axisymmetric,

i) flow within the jet can be approximated as boundary layer flow,

j) the ambient is infinite in extent.

Several of the assumptions are compensated for in the solution. The zone of flow establishment uses a special entrainment function (see Equation (128) of (8) which is a function of local Froude number, velocities, port diameter, spacing, and thickness of the developed flow region.

Zone of Established Flow

The equations of mass, energy, pollutant, and momentum (equations 1 - 4), and the additional momentum equations mentioned above are also solved in the zone of established flow, but are cast into a slightly different form. The governing equations are written in a cylindrical coordinant system where ϕ is the circumferential angle around the plume and cross section and the independent variables are r and s. These are evaluated using the assumed 3/2 power approximation to Gaussian lateral profiles. The angle θ_1 is the angle between the centerline projected to the xy plane and the x axis, θ_2 is the angle between the centerline and the xy plane. These angles relate the two coordinate systems. Another entrainment function is used in the zone of established flow which is a function of the local Froude number, velocities, plume diameter, and spacing.

Zone of Merging

When adjacent plumes begin to overlap, the discharge is no longer considered axisymmetric. The distributions of plume properties are superimposed. Another entrainment function is used which also considers the variable entrainment surface during merging. A drag term is also introduced to account for the additional bending of the plumes after merging.

MODEL DESCRIPTION

In the zone of flow establishment, the system of six governing equations are solved simultaneously (subroutine SIMQ) and stepped forward in space by a Hamming's modified predictor-corrector method (subroutine HPCG). This procedure continues until velocity, temperature and concentration become fully developed. Subroutine OUTP1 contains the results which are stored as initial conditions for the zone of established flow.

In the zone of established flow, similar profiles and the integral method allow solution of the six governing equations for the six unknowns initially by Runge-Kutta integral approximation and then by the Hamming's modified predictor-corrector method. At the point where the plumes overlap, the assumed similarity no longer applies. The merging plumes have axes of symmetry along the discharge line and normal to it. Only one quadrant of a plume, taken to a midpoint of the overlap area, is evaluated. The profiles are superimposed in this region using integral similarity coefficients. Above the point where the plume and the ambient have equal density, results are obtained by extrapolation.

The program itself contains many comments and explanations which serve as further documentation.

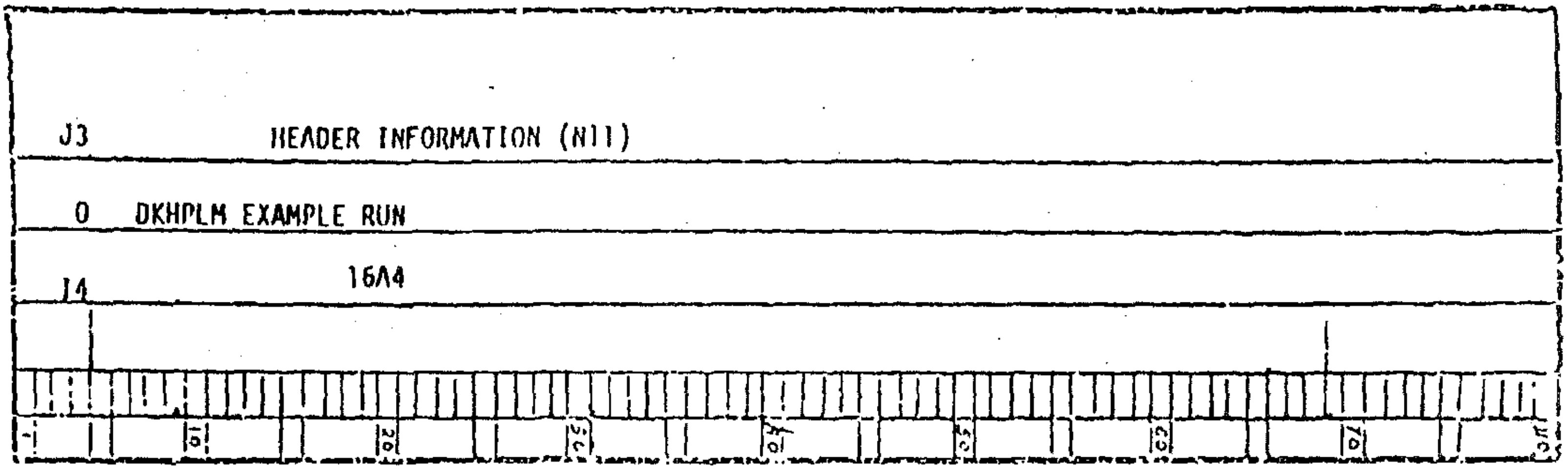
EXAMPLE INPUT, OUTPUT AND MODEL LISTING

Input

As an example case, suppose a diffuser 50 m long discharges 0.5 m^3/sec. The ports are 0.178 m in diameter, oriented vertically, and spaced 5 m apart. The ambient currents are assumed to be 0.4 m/sec and normal to the discharge line. (Note that the angle of currents to the diffuser should be within about 20° of normal.) The velocity through the discharge ports is 2.0 m/sec. The effluent is 17.00°C and 0.09 ^{o}/oo. (Note that the effluent should have some finite temperature difference with the ambient.) The ambient at the level of discharge is 15.0°C. The ambient temperature gradient is negligible but must be finite. Discharge is 50 m below the surface. Computer punch card format for this input follows.

Some computers do not initialize storage to zero automatically. If not, a control card must be used to set the core to zero before DKHPLM will run.

DKHPLM
Card 1
Example Input


J3 HEADER INFORMATION (NI1)

0 DKHPLM EXAMPLE RUN

I4 16A4

J3 - Number of runs to follow (0=one run).

UO	UA	TO	CO	TAO	CAO	TIZ	CIZ
2.0	0.4	17.00	0.09	15.00	0.0	.00001	0.0
F10.6	F10.6	F10.6	F10.6	F10.6	F10.6	F10.6	F10.6

UO - Initial jet velocity, m/sec.
UA - Current speed, m/sec.
TO - Initial jet temperature, °C.
CO - Initial jet salinity, o/oo.
TAO- Ambient temperature at the level of discharge, °C.
CAO- Ambient salinity at the level of discahrge, °C.
TIZ- Temperature gradient, °C/m.
CIZ- Salinity gradient, o/oo/m.

DKHPLM
Card 2
Example Input

DO	TH1	TH2	SF	SPACE	H
0.178	90.0	90.0	500.0	5.0	50.0
F10.6	F10.6	F10.6	F10.6	F10.6	F10.6

DO - Port diameter, m.
TH1 - Horizontal discharge angle (DEG) relative to the current (70<TH1<110).90° normal to current.
TH2 - Angle of disbharge from the horizontal, DEG.
SF - Number of diameters along centerline at cutoff.
SPACE - Port spacing, m.
H - Depth, m.

DKHPLM
Card 3
Example Input

Output

Example output and program listing follow. The initial input conditions are printed along with dimensionless conditions. The first section of data listing concerns the zone of flow establishment. The columns list: length along the plume axis (S), horizontal distance parallel with discharge line (X), horizontal distance normal to the discharge line (Y), vertical distance from the level discharge (Z), the horizontal angle from the plume's axis to the discharge line (TH1), the angle the plume's axis makes from the horizontal (TH2), the radius (B), potential core widths for velocity, temperature and concentration (RU, RT and RC), normalized centerline disparities of velocity, temperature and concentration with the ambient (DUCL, DTCL and DCCL), the ambient density normalized by the density of the discharge (PI) and non-dimensional time (TIME).

In the zone of established flow, width and average dilution (Q/Q_o) are also given. Time is given in seconds. The centerline dilution before zone of merging is:

$$Q_m/Q_o = 0.52\ Q/Q_o \qquad (5)$$

after complete merging,

$$Q_m/Q_o = 0.70\ Q/Q_o \qquad (6)$$

based on the assumed distributions of concentration and velocity.

DKHPLM SAMPLE OUTPUT

```
      SOLUTION TO MULTIPLE BUOYANT DISCHARGE PROBLEM WITH AMBIENT CURRENTS AND VERTICAL GRADIENTS

                    DKHPLM EXAMPLE RUN                                                        I.D.

 DISCHARGE VELOCITY =  2.00-M/S   * TEMP. = 17.00-DEG C    ** SALINITY =   .09-PPT
  DIAMETER =   .18-M   ** SPACING =  5.00-M   ** DEPTH =   50.00-M
 AMBIENT CONDITIONS AT DISCHARGE ELEVATION, VELOCITY  =     .40-M/S ** TEMP. =   15.00-DEG C  ** SALINITY =     .90  PPT
 AMBIENT STRATIFICATION GRADIENTS ** TEMPERATURE      **    .000010-DEG C/M   ** SALINITY **   0.000000-PPT/M


   AMBIENT CONDITIONS AT DISCHARGE -  NONDIMENSIONAL
 TEMP=  .88235  SALINITY=10.00000  DENSITY= 1.00091   TEMPGR=  .000000  SALGR= 0.000000  DENGR= -.0000000

    PORT SPACING  L/D =  28.09
0 FROUDE NO =     49.10   ,VELOCITY RATIO =    .200    STRATIFICATION NO = *******

0                   ZONE OF FLOW ESTABLISHMENT  --  ALL LENGTHS ARE IN METERS
      S          X          Y          Z        TH1       TH2          D        RU         RT         RC       DUCL      DTCL      DCCL        PI         TIME

     0.00       0.00      0.00       0.00     90.00     90.00      0.000      .089      .089      .089    1.000     1.000     1.000      1.00091       0.
      .09        .00       .00        .09     90.00     88.74       .033      .078      .078      .078     .996     1.000     1.000      1.00091        .
      .18       -.00       .00        .18     90.00     87.18       .071      .066      .066      .066     .990     1.000     1.000      1.00091        .
      .27       -.00       .01        .27     90.00     85.31       .112      .051      .051      .051     .984     1.000     1.000      1.00091        .
      .36       -.00       .02        .36     90.00     83.10       .156      .035      .035      .035     .976     1.000     1.000      1.00091        .
      .44       -.00       .03        .44     90.00     80.57       .204      .016      .016      .016     .967     1.000     1.000      1.00091        .
   STARTING LENGTH, T =      .510
      .51       -.00       .04        .51     90.00     78.55       .241      .000                           .960     1.000     1.000      1.00091        .
   STARTING LENGTH, VELOCITY =      .510
      .51        .00       .04        .51     90.00     78.54       .242      .000                           .960      .998      .998      1.00091       5.7
0                   ZONE OF ESTABLISHED FLOW
      S         X         Y          Z        TH1       TH2      WIDTH      DUCL      DTCL       DCCL      PI         TIME       Q/QO

      .51       .00       .04        .51     90.00     78.54       .48      .960      .998       .998    1.00091       .26       2.11
     1.22       .00       .50       1.01     90.00     28.18      1.21      .127      .356       .356    1.00091       .99       9.60
     1.93       .00      1.16       1.28     90.00     17.50      1.55      .047      .243       .243    1.00091      2.34      15.36
     2.65       .00      1.84       1.46     90.00     13.22      1.70      .024      .191       .191    1.00091      3.91      20.09
```

```
  3.36     .00    2.54    1.61   90.00   10.85    1.96    .015    .160    .160  1.00091    5.57   24.24
  4.25     .00    3.42    1.76   90.00    9.03    2.14    .009    .135    .135  1.00091    7.70   28.91
  4.96     .00    4.12    1.87   90.00    8.03    2.27    .006    .121    .121  1.00091    9.43   32.35
  5.67     .00    4.83    1.96   90.00    7.28    2.30    .004    .111    .111  1.00091   11.18   35.59
  6.38     .00    5.53    2.05   90.00    6.68    2.48    .003    .102    .102  1.00091   12.94   38.68
  7.10     .00    6.24    2.13   90.00    6.20    2.57    .002    .095    .095  1.00091   14.71   41.64
  7.81     .00    6.95    2.20   90.00    5.80    2.66    .002    .089    .089  1.00091   16.48   44.48
  9.23     .00    8.36    2.34   90.00    5.18    2.82    .001    .079    .079  1.00091   20.03   49.92
 10.66     .00    9.78    2.46   90.00    4.71    2.96    .000    .072    .072  1.00091   23.59   55.06
 12.08     .00   11.20    2.57   90.00    4.34    3.09    .000    .066    .066  1.00091   27.16   59.99
 13.50     .00   12.62    2.68   90.00    4.04    3.21   -.000    .061    .061  1.00091   30.73   64.74
 14.93     .00   14.04    2.77   90.00    3.79    3.32   -.000    .057    .057  1.00091   34.30   69.35
 16.35     .00   15.47    2.87   90.00    3.59    3.42   -.000    .054    .054  1.00091   37.87   73.84
        DKHPLM EXAMPLE RUN                                                      I.D. =   0

   S        X       Y       Z     TH1     TH2    WIDTH    DUCL    DTCL    DCCL     PI      TIME    0/00

 17.78     .00   16.89    2.95   90.00    3.41    3.52   -.000    .051    .051  1.00091   41.44   78.23
 19.20     .00   18.31    3.04   90.00    3.26    3.62   -.000    .048    .048  1.00091   45.02   82.53
 20.62     .00   19.73    3.12   90.00    3.12    3.71   -.000    .046    .046  1.00091   48.59   86.76
 22.05     .00   21.15    3.19   90.00    3.00    3.80   -.001    .044    .044  1.00091   52.16   90.92
 24.90     .00   24.00    3.34   90.00    2.80    3.97   -.001    .040    .040  1.00091   59.31   99.07
 27.74     .00   26.84    3.47   90.00    2.64    4.12   -.001    .037    .037  1.00091   66.46  107.04
 30.59     .00   29.69    3.60   90.00    2.50    4.27   -.001    .034    .035  1.00091   73.60  114.85
 33.44     .00   32.53    3.72   90.00    2.39    4.41   -.001    .032    .032  1.00091   80.75  122.54
 36.29     .00   35.38    3.84   90.00    2.29    4.54   -.000    .030    .030  1.00091   87.89  130.13
 39.14     .00   38.22    3.95   90.00    2.20    4.67   -.000    .029    .029  1.00091   95.04  137.63
 41.98     .00   41.07    4.06   90.00    2.13    4.80   -.000    .027    .027  1.00091  102.18  145.06
 44.83     .00   43.92    4.16   90.00    2.06    4.92   -.000    .026    .026  1.00091  109.32  152.44

            PLUMES MERGING

 47.68     .00   46.76    4.26   90.00    1.98    5.04   -.000    .025    .025  1.00091  116.46  159.75
 50.53     .00   49.61    4.36   90.00    1.87    5.16   -.000    .024    .024  1.00091  123.60  166.71
 56.22     .00   55.30    4.53   90.00    1.70    5.40   -.000    .022    .022  1.00091  137.87  179.60
 61.92     .00   60.99    4.70   90.00    1.58    5.64   -.000    .020    .020  1.00091  152.15  191.47
 67.62     .00   66.69    4.85   90.00    1.50    5.87   -.000    .018    .018  1.00091  166.42  202.62
 73.31     .00   72.38    4.99   90.00    1.43    6.09   -.000    .017    .017  1.00091  180.69  213.23
 79.01     .00   78.08    5.13   90.00    1.38    6.31   -.000    .016    .016  1.00091  194.95  223.43
 84.70     .00   83.77    5.27   90.00    1.35    6.52   -.000    .015    .015  1.00091  209.22  233.31
 90.40     .00   89.47    5.40   90.00    1.31    6.73   -.000    .014    .014  1.00091  223.48  242.92
 96.10     .00   95.16    5.53   90.00    1.27    6.94   -.000    .013    .013  1.00091  237.73  252.33
```

```
101.79     .00  100.85   5.66  90.00   1.27    7.15   -.000    .012    .012  1.00091   251.99   261.56
107.49     .00  106.55   5.78  90.00   1.25    7.35   -.000    .011    .012  1.00091   266.25   270.65
118.00     .00  117.94   6.03  90.00   1.22    7.76   -.000    .010    .010  1.00091   294.75   280.50
130.27     .00  129.33   6.27  90.00   1.20    8.16   -.000    .009    .009  1.00091   323.25   305.99
141.65     .00  140.72   6.51  90.00   1.19    8.56   -.000    .008    .008  1.00091   351.74   323.23
153.06     .00  152.11   6.74  90.00   1.18    8.96   -.000    .008    .008  1.00091   380.24   340.28
164.45     .00  143.50   6.97  90.00   1.17    9.36   -.000    .007    .007  1.00091   408.72   357.18
175.84     .00  174.89   7.21  90.00   1.16    9.75    .000    .006    .006  1.00091   437.21   373.97
186.03     .00  185.92   7.43  90.00   1.15   10.14    .000    .006    .006  1.00091   464.80   390.13
198.27     .00  197.31   7.66  90.00   1.15   10.53    .000    .006    .006  1.00091   493.28   406.79
209.65     .00  208.70   7.89  90.00   1.15   10.93    .000    .005    .005  1.00091   521.76   423.37
221.05     .00  220.09   8.11  90.00   1.14   11.33    .000    .005    .005  1.00091   550.24   439.91
243.84     .00  242.87   8.57  90.00   1.14   12.12    .000    .005    .005  1.00091   607.19   472.09
266.62     .00  265.65   9.02  90.00   1.14   12.91    .000    .004    .004  1.00091   664.14   505.77
209.40     .00  288.43   9.47  90.00   1.13   13.71    .000    .004    .004  1.00091   721.08   538.58
312.19     .00  311.21   9.92  90.00   1.13   14.51    .000    .004    .004  1.00091   778.01   571.33
334.97     .00  333.99  10.37  90.00   1.13   15.30    .000    .004    .004  1.00091   834.95   604.05
357.76     .00  356.77  10.82  90.00   1.13   16.10    .000    .004    .004  1.00091   891.87   636.73
          DKHPLM EXAMPLE RUN                                                I.D. =  0

   S         X       Y       Z     TH1     TH2    WIDTH     DUCL    DTCL    DCCL     PI       TIME    0/00

380.54     .00  379.55  11.27  90.00   1.13   16.90    .000    .003    .003  1.00091   948.80   669.40
403.32     .00  402.33  11.72  90.00   1.13   17.70    .000    .003    .003  1.00091  1005.72   702.04
426.11     .00  425.11  12.17  90.00   1.13   18.50    .000    .003    .003  1.00091  1062.65   734.67
448.09     .00  447.89  12.61  90.00   1.13   19.31    .000    .003    .003  1.00091  1119.56   767.20
494.46     .00  493.44  13.51  90.00   1.13   20.91    .000    .003    .003  1.00091  1233.40   832.47

NO OF INTEGRATION STEPS=2892   NO OF HALVINGS=  0   ABSERR=   .00100   PRNT(5)=    0.000  FINAL SPACE  =    4.000
 16.036 CP SECONDS EXECUTION TIME
```

V. PDS MODEL

THEORETICAL DEVELOPMENT

The theoretical analysis used to develop the steady three-dimensional surface plume program (PDS) is based on a model by Prych (10). It has been modified considerably and tuned to a large set of field and laboratory data by Shirazi and Davis (11).

The following is a brief verbal summary of the model. The method of analysis is an integral approach which assumes similarity of temperature and velocity profiles and the principle of entrainment and ambient diffusion. The zone of flow establishment near the discharge is handled in an approximate manner. It assumes that the plume makes no contact with the bottom or shoreline. As a result, it should not be used where geometric boundaries interfere with the plume unless it is beyond the region of interest. Profiles of temperature and velocity are assumed to be Gaussian in shape with maximum values at the surface. These profiles are superimposed on the ambient current. Other assumptions implicit in the derivation of the governing equations are the same as outlined in the DKHPLM model except the geometry of the discharge is assumed to be rectangular in shape of depth, HO, and width, WO, at the surface of the receiving water.

The integral form of the conservation of mass is satisfied by calculating vertical and horizontal jet induced entrainment as well as vertical and horizontal ambient diffusion. The vertical components are a function of the local Richardson number which accounts for reduced entrainment due to buoyant convection. The momentum equation includes drag forces, viscous shear forces, internal pressure forces due to density differences and changes in momentum due to entrainment of ambient fluid. The energy equation includes heat loss to the atmosphere by convection. Spreading in the horizontal direction is broken into two parts. One is spreading due to non-buoyant entrainment and the other is a buoyant spreading term which is a function of the density difference and local aspect ratio of the plume.

The program is written in FORTRAN 4 and consists of a main program entitled PDS and six subroutines KHPCG, AREA, FCT, RED, SIGMAT and OUTP. The main program PDS reads the input variables, initializes constants and calls subroutine KHPCG which performs the actual calculation. Subroutine KHPCG is a standard IBM scientific subroutine which performs the step-wise integration of differential equations by the Hamming Predictor-Corrector Method.

Subroutine AREA is a step-wise integration of the area enclosed by isotherms. Subroutine FCT calculates the derivatives of the program variables which are used in KHPCG. Subroutine RED calculates the reduction in vertical entrainment as a function of local Richardson number. SIGMAT is used to calculate water density from temperature and salinity. Subroutine OUTP prints out the input parameters followed by desired output variables at each integration step along the trajectory of the plume.

EXAMPLE INPUT, OUTPUT AND MODEL LISTING

Input

Input to the PDS program consists of one card giving the number of cases to be calculated followed by a set of three cards for each case. As an example case, consider the discharge of 1.0 m^3/s of water at an angle of 90° relative to the off-shore current in a large fresh water lake. The ambient current is 0.2 m/s. The discharge channel is 2.0 m wide and the water depth in the channel is 0.5 m. The discharge temperature is 17°C and the ambient temperature is 15°C. Winds and relative humidity are moderate. The computer punch card format for this input follows.

Output

Output for the example case given in the Input section follows along with a complete program listing. Output includes a printout of input values in dimensional and dimensionless form. Then for each integration step, the following are listed: distance along the plume centerline (S - meters), distance downstream of the discharge in the direction of the ambient current (X - meters), distance out into the receiving water normal to the ambient current (Y - meters), local plume flow direction relative to the ambient current (TH - degrees), excess temperature at plume centerline (T - °C), time it has taken a partical of fluid to travel from the point of discharge to the printout point traveling along the plume centerline (TIME - sec.), average dilution (Q/Q0), minimum centerline dilution (QM/Q0) (note: dilution values cannot be obtained from temperature data unless the heat loss to the atmosphere is zero), depth of plume given as $\sqrt{2}\ \sigma_h$ (H - meters), width of plume given as $2\sqrt{2}\ \sigma_z$ (W - meters) where σ is the standard deviation of the Gaussian distribution. At the end of this printout follows a table giving the area enclosed within surface isotherms. If integration did not progress far enough to have the isotherms close at the plume centerline only partial areas are listed and so designated.

The output for the example case listed above follows along with a complete listing of the program.

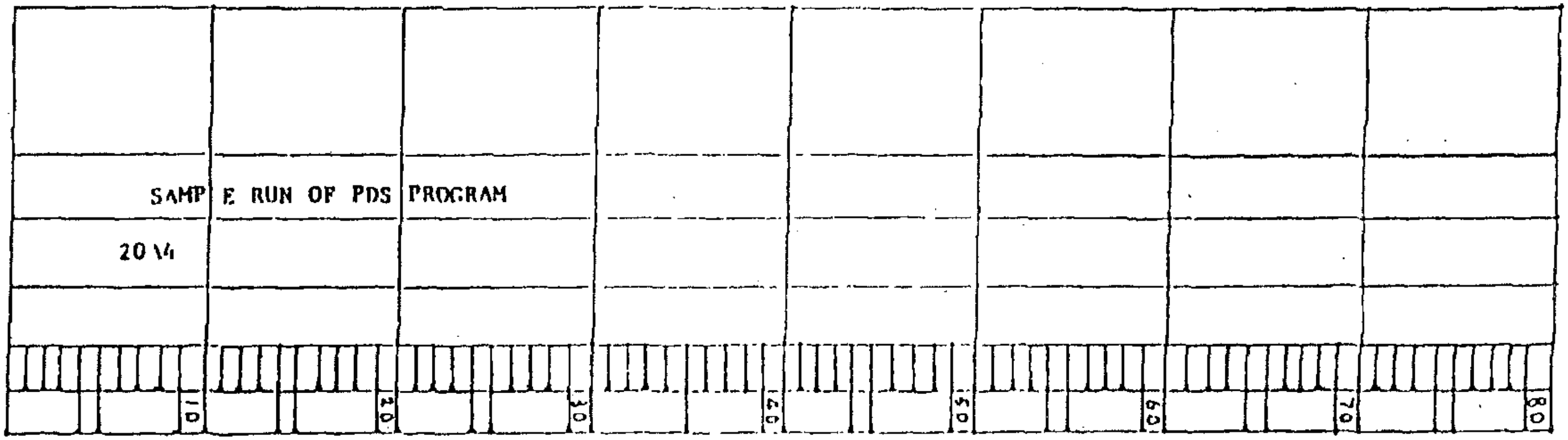
KK							
1							
I3							
10	20	30	40	50	60	70	80

KK = Number of runs to be made

(This card is only required at the beginning of each data deck. Following this card are sets of three cards for each case to be run as described on the following three cards)

PDS
Card #1
Example Input

PDS
Card # 2
Example Input



SAMPLE RUN OF PDS PROGRAM
20 \4

Anything on this card is printed out at the top of every page of output.

WO	HO	UO	UA	TO	TA	THO	
2.0	0.5	1.0	0.2	17.0	15.0	90.0	
F10.5	F10.5	F10.5	F10.5	F10.5	F10.5	F10.5	
10	20	30	40	50	60	70	80

WO = Discharge width - meters
HO = Discharge depth - meters
UO = Discharge velocity - Meters/sec.
UA = Ambient velocity - meters/sec.
TO = Discharge temperature - C
TA = Ambient temperature - C
THO = Discharge direction relative to ambient current - degrees

PDS
Card #3
Example Input

SAL	AK	E	EV	EH	SLIM		
0,0	0.00001	.05	0.2	0.02	500.		
F10.5	F10.5	F10.5	F10.5	F10.5	F10.5		
10	20	30	40	50	60	70	80

SAL = Salinity o/oo (The ambient and discharge salinity are assumed to be the same)

AK = Dimensionless surface heat transfer coefficient, $h/\rho C_p U_o$. A value of 10^{-5} is average. For calm days at high humidity, use 10^{-6}. For dry, windy days use 10^{-4}.

E = Entrainment coefficient. A value of 0.05 is suggested unless a better value is known.

EV = RATIO of vertical to horizontal ambient diffusion coefficient. A value of 0.2 is suggested unless a better value is known.

EH = Dimensionless horizontal ambient turbulent diffusion coefficient, $\mathcal{E}_h/U_o H_o$. A value of 0.02 is suggested unless a better value is known for the particular receiving water in question.

FDS
Card #4
Example Input

PDS SAMPLE OUTPUT

```
FLOATING WARM WATER JETS --     SAMPLE RUN OF PDS PROGRAM                                                     PAGE 1

AMBIENT CONDITIONS    :  TEMP. TA=  15.0 DEG. C  ,    VEL. UA=    .20 M/SEC  ,HEAT CONVECTION  =   .100E-04

DISCHARGE CONDITIONS :  TEMP. TO=  17.0 DEG. C ,VEL. UO=  1.00 M/SEC  ,WIDTH WO=   2.00 M.  ,DEPTH HO=    .50 M.  ,ANGLE  90.00

FRO = 25.0   E =  .0500  ,CD = 1.0000   CF = 0.0000   RE = 0.          EV =  .200E+00   EH =  .200E-01

     S(M.)       X(M.)       Y(M.)    TH(DEG.)   EX.TEMP (DEG. C)    TIME(SEC.)    Q/QO   QN/QO      DEPTH(M.)    WIDTH(M.

      2.27        .49         2.21      77.5        2.000             .458E+01    2.000  1.000         .722        3.447
      2.42        .52         2.36      76.8        1.952             .490E+01    2.049  1.024         .740        3.522
      2.58        .56         2.52      76.1        1.907             .523E+01    2.097  1.049         .758        3.598
      2.73        .60         2.67      75.4        1.864             .557E+01    2.146  1.073         .775        3.674
      2.89        .64         2.82      74.7        1.823             .592E+01    2.194  1.097         .792        3.749
      3.05        .68         2.97      74.0        1.784             .628E+01    2.242  1.121         .809        3.825
      3.20        .73         3.12      73.3        1.747             .664E+01    2.290  1.145         .826        3.900
      3.52        .82         3.42      72.0        1.677             .739E+01    2.385  1.193         .858        4.051
      3.83        .92         3.71      70.6        1.613             .818E+01    2.480  1.240         .889        4.202
      4.14       1.03         4.01      69.3        1.554             .900E+01    2.574  1.287         .920        4.352
      4.45       1.14         4.30      67.9        1.500             .985E+01    2.667  1.334         .949        4.502
      5.08       1.39         4.87      65.3        1.403             .116E+02    2.852  1.426        1.004        4.799
      5.70       1.66         5.43      62.8        1.318             .136E+02    3.034  1.517        1.055        5.093
      6.33       1.96         5.98      60.4        1.245             .156E+02    3.212  1.606        1.103        5.382
      6.95       2.28         6.52      58.1        1.180             .178E+02    3.388  1.694        1.148        5.667
      7.58       2.62         7.04      56.0        1.123             .201E+02    3.561  1.781        1.189        5.946
      8.20       2.98         7.56      53.9        1.072             .225E+02    3.731  1.866        1.227        6.221
      8.83       3.35         8.05      51.9        1.026             .251E+02    3.898  1.949        1.262        6.490
      9.45       3.75         8.54      50.0         .984             .277E+02    4.062  2.031        1.295        6.754
     10.70       4.58         9.47      46.6         .913             .333E+02    4.382  2.191        1.353        7.267
     11.95       5.46        10.36      43.5         .852             .393E+02    4.692  2.346        1.404        7.761
     13.20       6.39        11.19      40.8         .801             .457E+02    4.992  2.496        1.448        8.236
     14.45       7.35        11.99      38.3         .757             .524E+02    5.282  2.641        1.486        8.694
```

16.95	9.37	13.47	34.2	.685	.667E+02	5.839	2.919	1.550	9.565
19.45	11.48	14.81	30.8	.628	.820E+02	6.367	3.183	1.602	10.301
21.95	13.66	16.04	28.1	.582	.982E+02	6.870	3.435	1.644	11.152
24.45	15.89	17.17	25.8	.544	.115E+03	7.353	3.677	1.679	11.884
26.95	18.16	18.22	23.9	.512	.133E+03	7.819	3.910	1.710	12.582
29.45	20.46	19.19	22.2	.484	.151E+03	8.270	4.135	1.737	13.249
34.45	25.13	20.97	19.5	.438	.188E+03	9.139	4.569	1.785	14.506
39.45	29.87	22.55	17.4	.402	.227E+03	9.967	4.984	1.825	15.600
44.45	34.67	23.97	15.8	.372	.267E+03	10.769	5.385	1.861	16.705
49.45	39.50	25.27	14.4	.346	.308E+03	11.552	5.776	1.895	17.832
54.45	44.35	26.47	13.2	.325	.350E+03	12.320	6.160	1.927	18.830
59.45	49.23	27.57	12.3	.306	.393E+03	13.078	6.539	1.958	19.705
64.45	54.12	28.60	11.4	.289	.435E+03	13.828	6.914	1.989	20.702
69.45	59.03	29.56	10.7	.274	.479E+03	14.574	7.287	2.019	21.588
74.45	63.95	30.45	10.1	.261	.523E+03	15.317	7.658	2.048	22.444
79.45	68.87	31.30	9.5	.249	.567E+03	16.058	8.029	2.078	23.274
84.45	73.81	32.10	9.0	.238	.611E+03	16.800	8.400	2.107	24.080
89.45	78.75	32.86	8.5	.228	.656E+03	17.542	8.771	2.137	24.865
94.45	83.70	33.58	8.1	.219	.701E+03	18.285	9.143	2.166	25.630
99.45	88.65	34.27	7.7	.210	.746E+03	19.031	9.515	2.195	26.378
104.45	93.61	34.92	7.3	.202	.792E+03	19.779	9.890	2.225	27.109
109.45	98.57	35.55	7.0	.195	.838E+03	20.531	10.266	2.254	27.825
114.45	103.53	36.14	6.7	.188	.884E+03	21.286	10.643	2.283	28.527
119.45	108.50	36.72	6.4	.181	.930E+03	22.044	11.022	2.313	29.215
124.45	113.47	37.27	6.2	.175	.976E+03	22.806	11.403	2.342	29.891
129.45	118.44	37.80	6.0	.169	.102E+04	23.572	11.786	2.371	30.556
134.45	123.42	38.31	5.7	.164	.107E+04	24.340	12.170	2.401	31.210
139.45	128.39	38.80	5.5	.159	.112E+04	25.113	12.556	2.430	31.853
144.45	133.37	39.27	5.3	.154	.116E+04	25.888	12.944	2.459	32.487
149.45	138.35	39.73	5.2	.150	.121E+04	26.667	13.334	2.487	33.111
154.45	143.33	40.17	5.0	.145	.126E+04	27.449	13.725	2.516	33.727
159.45	148.31	40.60	4.8	.141	.130E+04	28.235	14.117	2.545	34.335
164.45	153.29	41.01	4.7	.137	.135E+04	29.024	14.512	2.573	34.935
169.45	158.28	41.41	4.5	.134	.140E+04	29.816	14.908	2.602	35.527
174.45	163.26	41.80	4.4	.130	.144E+04	30.611	15.305	2.630	36.112
179.45	168.25	42.18	4.3	.127	.149E+04	31.408	15.704	2.658	36.691
184.45	173.24	42.55	4.2	.124	.154E+04	32.209	16.105	2.686	37.263
189.45	178.22	42.90	4.0	.121	.159E+04	33.013	16.507	2.713	37.828
194.45	183.21	43.25	3.9	.118	.164E+04	33.820	16.910	2.741	38.387
199.45	188.20	43.59	3.8	.115	.168E+04	34.630	17.315	2.768	38.941
204.45	193.19	43.92	3.7	.112	.173E+04	35.442	17.721	2.796	39.489
209.45	198.18	44.24	3.6	.110	.178E+04	36.257	18.128	2.823	40.032
214.45	203.17	44.55	3.5	.108	.183E+04	37.075	18.537	2.850	[illegible]

```
   219.45      208.16      44.86      3.5        .105              .187E+04    37.895  18.947      2.876       41.102
   224.45      213.15      45.15      3.4        .103              .192E+04    38.717  19.359      2.903       41.629
   229.45      218.14      45.45      3.3        .101              .197E+04    39.542  19.771      2.930       42.152
   234.45      223.13      45.73      3.2        .099              .202E+04    40.370  20.185      2.956       42.671
   239.45      228.13      46.01      3.1        .097              .207E+04    41.200  20.600      2.982       43.185
   244.45      233.12      46.28      3.1        .095              .211E+04    42.032  21.016      3.008       43.694
   249.45      238.11      46.54      3.0        .093              .216E+04    42.867  21.433      3.034       44.200
   254.45      243.10      46.80      2.9        .091              .221E+04    43.703  21.852      3.059       44.702



  A R E A S  OF  E X C E S S   T E M P E R A T U R E   F O R
     SAMPLE RUN OF PDS PROGRAM


  EXC.  TEMP. (DEG. C)          AREA (SQ. M)

        .10                    .207E+04
        .20                    .556E+03
        .30                    .224E+03
        .40                    .111E+03
        .50                    .639E+02
        .60                    .404E+02
        .70                    .272E+02
        .80                    .195E+02
        .90                    .146E+02
       1.00                    .111E+02
       1.10                    .865E+01
       1.20                    .683E+01
       1.30                    .552E+01
       1.40                    .444E+01
       1.50                    .361E+01
       1.60                    .301E+01
       1.70                    .248E+01
       1.80                    .204E+01
       1.90                    .167E+01
       2.00                    .113E+01
  2.610 CP SECONDS EXECUTION TIME
```

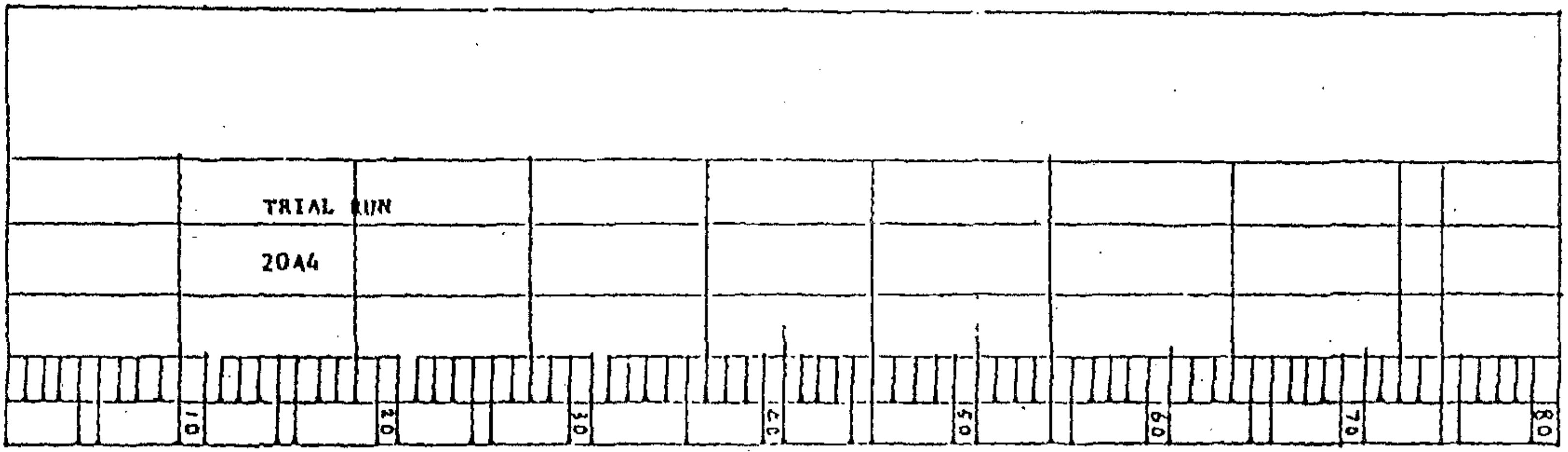
VI. "PDSM" MODEL

THEORETICAL DEVELOPMENT

The modified PDSM model is designed to predict the dilution of three-dimensional surface plumes that are attached to the near shore but not attached to the bottom. The model is essentially the same as the PDS model except it assumes that the maximum concentration and temperature are at the near shore. To do this, a method of images is used with the shore used as the line of symmetry. The input and output to the PDSM model is identical to the PDS model and therefore will not be discussed further. A FORTRAN listing of the computer program follows.

F-29

MOBEN
Card #1
Example Input


TRIAL RUN
20A4

Anything on this card is printed out at the top of the output

VII. "MOBAN" MODEL

THEORETICAL DEVELOPMENT

The MOBAN model is a two-dimensional surface plume model developed by Motz and Benetict. Details can be found in reference (13). It assumes that the plume is attached to the bottom of the receiving basin or river but not attached to the shore. This model is valid for low ambient currents ($U_o/U_a < 0.5$) and shallow receiving water. It is an integral model similar to the PDS model but buoyancy effects are not included, as a result it is limited to discharge fluids at or near the receiving water density. It solves the vertically averaged conservation equations using the principal of entrainment and fluid drag. Integration of the equations is carried out in a step-wise manner along the trajectory of the plume. In the original MOBAN model, the entrainment coefficient was an input variable that varied depending on the ratio of ambient to discharge velocity. An empirical expression has been included in the present program that approximates this dependence in accordance with the authors suggested values. This expression is $E = 0.05 + 0.49\ (U_a/U_o)^{\frac{1}{2}}$. The plume width and distance to the end of the initial zone of flow establishment are also approximated by emperical expressions.

The program is written in FORTRAN IV and consists of a main program, MOBAN, and three subroutines, ZRKGS, FCT and OUTP. The main program reads in the input variables, calls ZRKGS that performs the actual integration, using a Runge-Kutta method, and then calculates surface isotherm areas and prints them out. Subroutine FCT calculates the derivatives of the program variables for use in ZRKGS. OUTP prints out desired variables as called by ZRKGS.

BETAD	TO	QO	WO	ZO	UA	TAM	TO4	KF
60.	1.5	24.7	10.8	4.2	0.1	9.2	0.2	2
F9.4	F9.4	F9.4	F9.4	F9.4	F9.4	F9.4	F9.4	I2

BETAD = Discharge direction relative to ambient current - degrees
TO = Discharge excess temperature relative to ambient - C
QO = Discharge volumetric flow rate - m^3/s
WO = Width of discharge channel - meters
ZO = Discharge fluid Depth - meters
UA = Ambient velocity - m/s
TAM = Ambient temperature - C
TO4 = Temperature cut-off factor - T/TO . Program stops when the excess temperature ratio reaches this value
KF = Surface convection heat transfer factor
Blank or 1 for zero convection
2 for moderate convection
3 for high convection
(The value picked has no effect on dilution in this program, just the rate of temperature decay)

MOBEN
Card #2
Example Input

Output

Output for the sample case given above follows along with a complete listing of the program. Output consists of all the input variables. Then for each integration step the following are listed: distance along the plume centerline, ARC(m), centerline temperature, TEMP(C), centerline excess temperature, EX TEMP(C), centerline velocity, U(cm/s), plume width, WIDTH(m), average dilution, Q/Q0, minimum centerline dilution, QM/QC, distance downstream, X(m), distance out into the receiving water normal to the ambient current, Y(m), local plume flow direction, BETA(degrees), and time of travel from discharge to printout point, TIME(s). After the plume excess temperature ratio is reduced to the input cut-off ratio, integration stops and a table giving areas within surface isotherms is printed out. For zero surface heat transfer, these isotherms equal lines of constant concentration.

The output for the example case considered above follows along with a complete program listing.

MODAN   SAMPLE OUTPUT

```
1 MOTZ-BENEDICT MODEL      TRIAL RUN OF MOTZ-BANIDICT PROGRAM

  DISCHARGE ANGLE =  60.0 DEGREES
  DISCHARGE EXCESS TEMPERATURE =  1.5 DEGREES C
  VOLUMETRIC DISCHARGE RATE, Q = 24.7 CU.M/S
  DISCHARGE WIDTH = 10.8 METERS
  DISCHARGE DEPTH =  4.2 METERS
  AMBIENT VELOCITY =   .1 METERS/SEC
  AMBIENT TEMPERATURE =  9.2 DEGREES C
  TEMP. CUT-OFF FACTOR = .200 DELTA-T/DELTA-T0
  CONVECTIVE HEAT TRANSFER FACTOR = 2



   ARC(M)     TEMP(C)  EX TEMP(C) U(CM/S)  WIDTH(M)     Q/Q0      QH/Q0      X(M)      Y(M)     BETA     TIME(S)

    11.39      10.70      1.50     54.45     17.28      1.42      1.00      7.47      8.59     48.98     20.91
    11.68      10.69      1.49     54.06     17.56      1.43      1.01      7.67      8.81     48.87     21.46
    11.98      10.67      1.47     53.68     17.83      1.44      1.01      7.86      9.04     48.77     22.00
    12.28      10.66      1.46     53.29     18.12      1.46      1.02      8.06      9.27     48.66     22.57
    12.59      10.65      1.45     52.92     18.41      1.47      1.03      8.26      9.49     48.55     23.15
    12.90      10.64      1.44     52.54     18.70      1.48      1.04      8.47      9.73     48.44     23.75
    13.22      10.62      1.42     52.17     19.00      1.50      1.04      8.68      9.97     48.33     24.35
    13.55      10.61      1.41     51.80     19.30      1.51      1.05      8.90     10.21     48.22     24.98
    13.87      10.60      1.40     51.44     19.60      1.52      1.06      9.12     10.45     48.10     25.61
    14.21      10.59      1.39     51.07     19.92      1.54      1.07      9.35     10.71     47.99     26.27
    14.55      10.57      1.37     50.72     20.23      1.55      1.07      9.57     10.96     47.88     26.94
    14.90      10.56      1.36     50.36     20.55      1.56      1.08      9.81     11.22     47.76     27.63
    15.25      10.55      1.35     50.01     20.88      1.58      1.09     10.04     11.48     47.65     28.33
    15.61      10.54      1.34     49.66     21.21      1.59      1.10     10.29     11.74     47.53     29.06
    15.98      10.53      1.33     49.31     21.54      1.60      1.10     10.53     12.01     47.42     29.79
    16.35      10.52      1.32     48.97     21.88      1.62      1.11     10.79     12.29     47.30     30.56
    16.73      10.50      1.30     48.63     22.23      1.63      1.12     11.04     12.56     47.18     31.33
    17.12      10.49      1.29     48.29     22.58      1.65      1.13     11.31     12.85     47.06     32.13
    17.51      10.48      1.28     47.96     22.93      1.66      1.14     11.57     13.13     46.94     32.94
    17.91      10.47      1.27     47.62     23.30      1.67      1.14     11.85     13.43     46.82     33.78
    18.31      10.46      1.26     47.30     23.66      1.69      1.15     12.13     13.72     46.70     34.63
    18.73      10.45      1.25     46.97     24.04      1.70      1.16     12.41     14.03     46.58     35.52
    19.15      10.44      1.24     46.65     24.41      1.72      1.17     12.70     14.33     46.46     36.41
```

EXAMPLE INPUT, OUTPUT AND MODEL LISTING

Input

Input to the MOBEN model consists of two cards for each case run. Any number of cases can be run back to back by simply stacking input cards. Input consists of an identification card and a card containing the discharge angle, volumetric discharge rate, excess temperature, width and depth, ambient velocity and temperature, a cut-off factor, and a surface heat transfer coefficient factor. As an example, consider the discharge of 24.7 m^3/s of an industrial effluent through a discharge channel 4.72 m deep and 10.8 m wide at an angle of 60° relative to the ambient current and an excess temperature of 1.5°C. The ambient velocity and temperature are 0.1 m/s and 9.2 C, respectively, and surface heat transfer is moderate. The computer punch card format for this input follows.

104.79	9.77	.57	27.62	88.19	3.68	1.97	79.46	67.68	33.22	296.42
106.81	9.76	.56	27.47	89.48	3.71	1.98	81.15	68.78	33.04	303.75
108.91	9.76	.56	27.32	90.82	3.74	1.99	82.92	69.93	32.85	311.42
111.01	9.75	.55	27.18	92.15	3.78	2.00	84.68	71.06	32.66	319.12
113.20	9.74	.54	27.04	93.53	3.82	2.01	86.53	72.24	32.46	327.19
115.38	9.74	.54	26.90	94.90	3.85	2.02	88.37	73.41	32.28	335.30
117.66	9.73	.53	26.75	96.32	3.89	2.04	90.30	74.62	32.08	343.78
119.93	9.73	.53	26.62	97.74	3.93	2.05	92.23	75.83	31.89	352.31
122.30	9.72	.52	26.48	99.20	3.96	2.06	94.25	77.08	31.69	361.24
124.68	9.72	.52	26.34	100.65	4.00	2.07	96.26	78.32	31.50	370.22
127.14	9.71	.51	26.20	102.16	4.04	2.08	98.37	79.60	31.31	379.61
129.61	9.71	.51	26.07	103.66	4.08	2.09	100.48	80.88	31.11	389.06
132.19	9.70	.50	25.94	105.21	4.12	2.10	102.69	82.21	30.91	398.96
134.76	9.70	.50	25.81	106.75	4.16	2.11	104.90	83.53	30.72	408.90
137.44	9.69	.49	25.67	108.35	4.20	2.12	107.21	84.89	30.52	419.32
140.12	9.69	.49	25.55	109.94	4.24	2.13	109.52	86.25	30.32	429.79
142.92	9.68	.48	25.42	111.59	4.28	2.14	111.94	87.66	30.12	440.77
145.72	9.68	.48	25.29	113.23	4.32	2.15	114.36	89.06	29.92	451.80
148.63	9.67	.47	25.16	114.93	4.36	2.16	116.89	90.51	29.72	463.37
151.55	9.67	.47	25.04	116.62	4.41	2.17	119.43	91.95	29.52	474.99
154.60	9.66	.46	24.91	118.37	4.45	2.19	122.08	93.45	29.32	487.18
157.64	9.66	.46	24.79	120.12	4.49	2.20	124.73	94.93	29.11	499.43
160.82	9.65	.45	24.67	121.92	4.54	2.21	127.51	96.47	28.91	512.28
164.00	9.65	.45	24.55	123.72	4.58	2.22	130.30	98.01	28.71	525.19
167.32	9.64	.44	24.43	125.59	4.63	2.23	133.21	99.59	28.50	538.75
170.64	9.64	.44	24.31	127.44	4.68	2.24	136.13	101.17	28.30	552.37
174.11	9.63	.43	24.19	129.37	4.72	2.25	139.19	102.81	28.09	566.67
177.57	9.63	.43	24.08	131.28	4.77	2.26	142.25	104.44	27.88	581.05
181.20	9.62	.42	23.96	133.27	4.82	2.27	145.46	106.13	27.67	596.15
184.83	9.62	.42	23.85	135.24	4.87	2.28	148.68	107.81	27.46	611.32
188.62	9.61	.41	23.73	137.29	4.92	2.29	152.05	109.55	27.25	627.26
192.41	9.61	.41	23.62	139.33	4.97	2.31	155.42	111.28	27.05	643.29
196.38	9.60	.40	23.51	141.46	5.02	2.32	158.96	113.08	26.83	660.13
200.35	9.60	.40	23.40	143.56	5.07	2.33	162.51	114.87	26.62	677.06
204.51	9.59	.39	23.29	145.76	5.12	2.34	166.23	116.72	26.41	694.87
208.67	9.59	.39	23.18	147.93	5.17	2.35	169.95	118.56	26.20	712.77
213.03	9.59	.39	23.07	150.20	5.23	2.36	173.87	120.48	25.98	731.61
217.38	9.58	.38	22.96	152.46	5.28	2.37	177.79	122.38	25.77	750.54
221.95	9.58	.38	22.86	154.80	5.34	2.38	181.90	124.36	25.55	770.48
226.52	9.57	.37	22.75	157.13	5.40	2.39	186.03	126.32	25.34	790.51
231.31	9.57	.37	22.65	159.56	5.45	2.40	190.37	128.36	25.12	811.63
236.11	9.56	.36	22.54	161.90	5.51	2.42	194.71	130.39	24.90	832.84

F-37

19.58	10.43	1.23	46.33	24.80	1.73	1.18	13.00	14.64	46.33	37.34
20.01	10.42	1.22	46.01	25.18	1.75	1.18	13.30	14.95	46.21	38.28
20.46	10.41	1.21	45.69	25.58	1.76	1.19	13.61	15.28	46.08	39.25
20.91	10.40	1.20	45.39	25.98	1.78	1.20	13.92	15.60	45.96	40.24
21.37	10.38	1.18	45.08	26.39	1.80	1.21	14.24	15.93	45.83	41.26
21.84	10.37	1.17	44.77	26.80	1.81	1.22	14.56	16.26	45.71	42.29
22.32	10.36	1.16	44.47	27.22	1.83	1.22	14.90	16.61	45.58	43.37
22.80	10.35	1.15	44.17	27.64	1.84	1.23	15.24	16.95	45.45	44.45
23.29	10.34	1.14	43.87	28.08	1.86	1.24	15.59	17.31	45.32	45.59
23.79	10.33	1.13	43.58	28.51	1.88	1.25	15.94	17.66	45.19	46.72
24.31	10.32	1.12	43.28	28.96	1.89	1.26	16.30	18.02	45.06	47.91
24.82	10.31	1.11	42.99	29.41	1.91	1.27	16.66	18.39	44.93	49.11
25.36	10.30	1.10	42.70	29.87	1.93	1.28	17.04	18.77	44.80	50.35
25.89	10.29	1.09	42.42	30.33	1.94	1.28	17.42	19.14	44.66	51.61
26.45	10.28	1.08	42.14	30.81	1.96	1.29	17.82	19.53	44.53	52.92
27.00	10.28	1.08	41.86	31.28	1.98	1.30	18.21	19.92	44.39	54.23
27.57	10.27	1.07	41.58	31.77	1.99	1.31	18.62	20.32	44.26	55.61
28.15	10.26	1.06	41.31	32.26	2.01	1.32	19.03	20.72	44.12	56.99
28.74	10.25	1.05	41.03	32.76	2.03	1.33	19.46	21.13	43.98	58.43
29.33	10.24	1.04	40.77	33.27	2.05	1.34	19.89	21.54	43.85	59.89
29.95	10.23	1.03	40.50	33.79	2.06	1.34	20.33	21.97	43.71	61.40
30.56	10.22	1.02	40.24	34.30	2.08	1.35	20.78	22.39	43.57	62.93
31.20	10.21	1.01	39.97	34.84	2.10	1.36	21.24	22.83	43.43	64.52
31.84	10.20	1.00	39.71	35.37	2.12	1.37	21.70	23.27	43.29	66.12
32.50	10.19	.99	39.45	35.92	2.14	1.38	22.19	23.72	43.15	67.79
33.16	10.18	.98	39.20	36.47	2.16	1.39	22.67	24.17	43.01	69.47
33.85	10.17	.97	38.95	37.04	2.18	1.40	23.17	24.64	42.86	71.22
34.53	10.17	.97	38.70	37.60	2.20	1.41	23.67	25.11	42.72	72.99
35.24	10.16	.96	38.45	38.18	2.22	1.42	24.20	25.59	42.57	74.83
35.95	10.15	.95	38.20	38.77	2.23	1.43	24.72	26.07	42.43	76.68
36.69	10.14	.94	37.96	39.37	2.25	1.43	25.26	26.56	42.28	78.61
37.42	10.13	.93	37.72	39.96	2.27	1.44	25.81	27.06	42.13	80.56
38.19	10.12	.92	37.48	40.58	2.30	1.45	26.37	27.57	41.98	82.59
38.95	10.12	.92	37.24	41.20	2.32	1.46	26.94	28.08	41.84	84.63
39.74	10.11	.91	37.00	41.84	2.34	1.47	27.53	28.60	41.69	86.76
40.53	10.10	.90	36.77	42.47	2.36	1.48	28.12	29.13	41.54	88.90
41.35	10.09	.89	36.54	43.12	2.38	1.49	28.74	29.67	41.38	91.14
42.17	10.08	.88	36.31	43.78	2.40	1.50	29.35	30.21	41.23	93.39
43.02	10.07	.87	36.08	44.45	2.42	1.51	29.99	30.77	41.08	95.74
43.87	10.07	.87	35.86	45.12	2.44	1.52	30.64	31.33	40.93	98.10
44.75	10.06	.86	35.64	45.81	2.46	1.53	31.30	31.91	40.77	100.57
45.63	10.05	.85	35.42	46.51	2.49	1.54	31.97	32.48	40.62	103.05

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```
    241.14      9.56     .36    22.44   164.49      5.57     2.43   199.28   132.50    24.68   855.22
    246.17      9.55     .35    22.34   166.99      5.63     2.44   203.86   134.60    24.46   877.71
    251.46      9.55     .35    22.24   169.60      5.69     2.45   208.68   136.78    24.24   901.44
    256.75      9.55     .35    22.14   172.19      5.75     2.46   213.51   138.94    24.02   925.29
    262.32      9.54     .34    22.04   174.90      5.82     2.47   218.59   141.19    23.80   950.49
    267.88      9.54     .34    21.94   177.59      5.88     2.48   223.69   143.43    23.58   975.80
    273.74      9.53     .33    21.84   180.40      5.95     2.49   229.07   145.76    23.35  1002.57
    279.60      9.53     .33    21.74   183.19      6.01     2.50   234.45   148.08    23.13  1029.46
    285.70      9.52     .32    21.64   186.11      6.08     2.52   240.13   150.49    22.90  1057.93
    291.96      9.52     .32    21.55   189.01      6.15     2.53   245.83   152.88    22.68  1086.52
    298.47      9.51     .31    21.45   192.05      6.22     2.54   251.84   155.38    22.45  1116.83
    304.99      9.51     .31    21.36   195.06      6.29     2.55   257.87   157.86    22.22  1147.27
    311.87      9.51     .31    21.26   198.23      6.36     2.56   264.25   160.45    21.99  1179.56
    318.75      9.50     .30    21.17   201.37      6.43     2.57   270.64   163.01    21.76  1212.00
    326.03      9.50     .30    21.08   204.66      6.51     2.58   277.40   165.70    21.53  1246.46

 OISOTHERM     AREA(ACRES)   AREA(SQ. KM.)           RATIO    AREA/Q (SEC/M)    AREA*E/(BO*BO)      TIME(SEC)

   1.00000         .0486       .0001966              .6667           7.9596       .68471E+00         66.1183
    .30000        4.7047       .0190393              .2000         770.0224       .66308E+02       1212.0029
     1.550 CP SECONDS EXECUTION TIME
```

46.55	10.04	.84	35.20	47.22	2.51	1.55	32.66	33.08	40.46	105.64
47.46	10.04	.84	34.98	47.93	2.53	1.56	33.36	33.67	40.31	108.24
48.41	10.03	.83	34.77	48.66	2.55	1.57	34.08	34.28	40.15	110.96
49.36	10.02	.82	34.55	49.40	2.58	1.58	34.81	34.89	39.99	113.70
50.34	10.01	.81	34.34	50.15	2.60	1.59	35.56	35.52	39.83	116.55
51.33	10.01	.81	34.14	50.90	2.62	1.60	36.32	36.15	39.67	119.42
52.35	10.00	.80	33.93	51.68	2.65	1.61	37.11	36.80	39.51	122.42
53.36	9.99	.79	33.72	52.46	2.67	1.61	37.89	37.45	39.35	125.43
54.42	9.98	.78	33.52	53.26	2.69	1.62	38.71	38.12	39.19	128.58
55.48	9.98	.78	33.32	54.05	2.72	1.63	39.53	38.79	39.03	131.75
56.58	9.97	.77	33.12	54.88	2.74	1.64	40.39	39.48	38.86	135.05
57.68	9.96	.76	32.92	55.70	2.77	1.65	41.24	40.16	38.70	138.38
58.82	9.96	.76	32.72	56.54	2.79	1.66	42.13	40.87	38.53	141.85
59.95	9.95	.75	32.53	57.39	2.82	1.67	43.03	41.58	38.37	145.34
61.14	9.94	.74	32.34	58.26	2.84	1.68	43.95	42.31	38.20	148.98
62.32	9.93	.73	32.15	59.13	2.87	1.69	44.88	43.04	38.03	152.65
63.55	9.93	.73	31.96	60.02	2.89	1.70	45.85	43.80	37.86	156.48
64.77	9.92	.72	31.77	60.91	2.92	1.71	46.82	44.55	37.70	160.33
66.05	9.91	.71	31.59	61.84	2.95	1.72	47.83	45.33	37.52	164.35
67.32	9.91	.71	31.41	62.76	2.97	1.73	48.84	46.10	37.36	168.39
68.64	9.90	.70	31.22	63.70	3.00	1.74	49.89	46.90	37.18	172.61
69.96	9.89	.69	31.04	64.65	3.03	1.75	50.95	47.70	37.01	176.86
71.34	9.89	.69	30.86	65.63	3.06	1.76	52.05	48.52	36.84	181.29
72.71	9.88	.68	30.69	66.60	3.08	1.77	53.15	49.35	36.67	185.75
74.14	9.88	.68	30.51	67.60	3.11	1.78	54.29	50.20	36.49	190.41
75.56	9.87	.67	30.34	68.60	3.14	1.79	55.44	51.04	36.32	195.10
77.04	9.86	.66	30.17	69.64	3.17	1.81	56.63	51.92	36.14	199.99
78.52	9.86	.66	30.00	70.67	3.20	1.82	57.83	52.79	35.96	204.92
80.06	9.85	.65	29.83	71.73	3.23	1.83	59.08	53.69	35.78	210.06
81.60	9.84	.64	29.66	72.79	3.26	1.84	60.32	54.59	35.61	215.23
83.20	9.84	.64	29.49	73.88	3.29	1.85	61.63	55.52	35.43	220.63
84.79	9.83	.63	29.33	74.97	3.32	1.86	62.93	56.44	35.25	226.07
86.46	9.83	.63	29.17	76.10	3.35	1.87	64.29	57.40	35.07	231.75
88.12	9.82	.62	29.01	77.22	3.38	1.88	65.65	58.35	34.89	237.46
89.84	9.81	.61	28.84	78.38	3.41	1.89	67.07	59.33	34.70	243.42
91.57	9.81	.61	28.69	79.53	3.44	1.90	68.49	60.31	34.52	249.42
93.36	9.80	.60	28.53	80.73	3.48	1.91	69.97	61.33	34.34	255.70
95.16	9.80	.60	28.38	81.91	3.51	1.92	71.45	62.34	34.16	262.00
97.02	9.79	.59	28.22	83.14	3.54	1.93	73.00	63.38	33.97	268.60
98.89	9.78	.58	28.07	84.36	3.57	1.94	74.54	64.42	33.79	275.23
100.83	9.78	.58	27.92	85.63	3.61	1.95	76.16	65.50	33.60	282.16
102.77	9.77	.57	27.77	86.88	3.64	1.96	77.78	66.57	33.41	289.13

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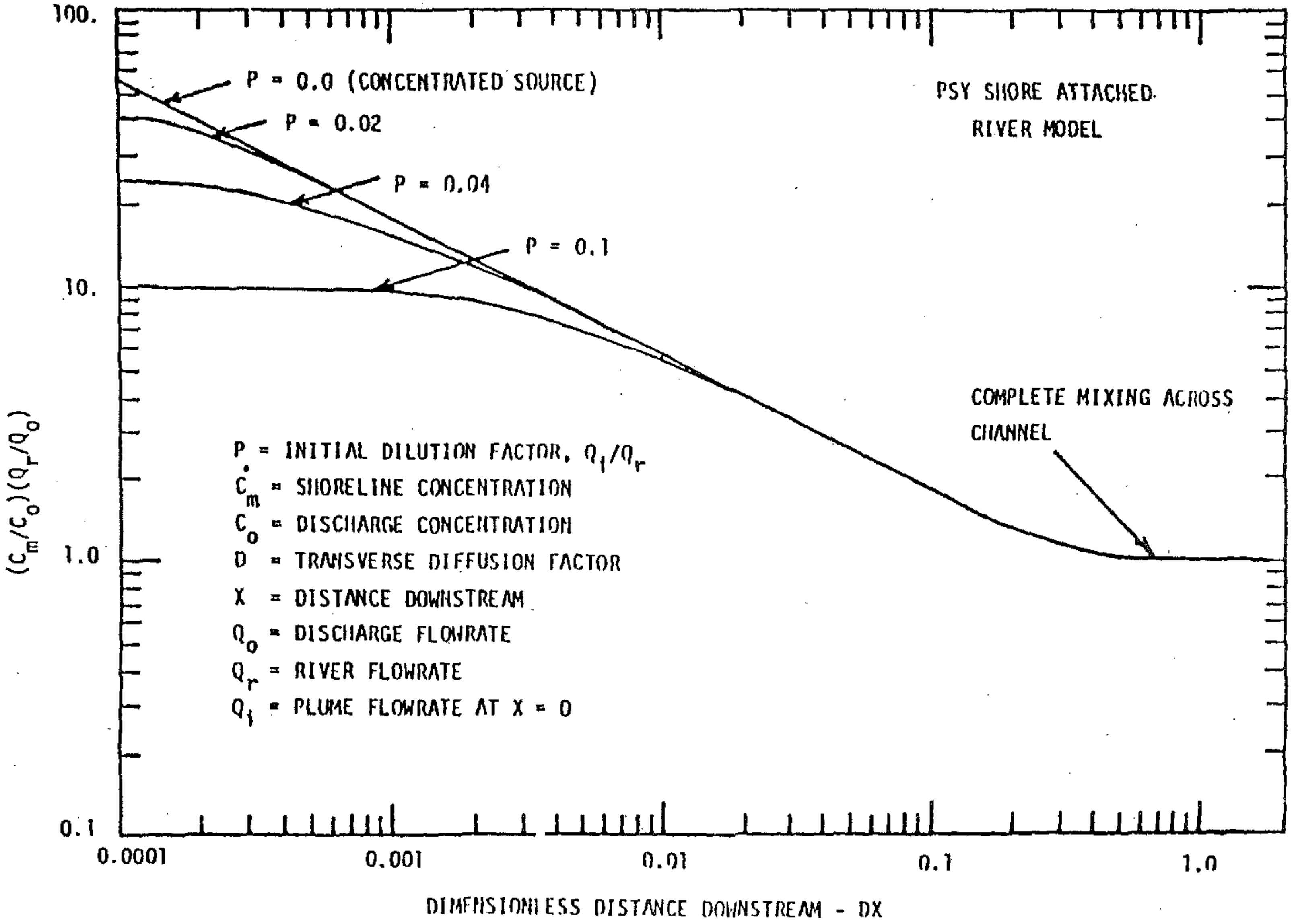

Figure 1. Near Shore Concentrations Using PSY Model

VIII. PSY MODEL

THEORETICAL CONSIDERATIONS

The PSY two-dimensional shore-attached surface plume river model is based on the theoretical solution to the steady-state convective-diffusion equation by Paily and Sayre (13). It does not handle jet induced entrainment. As a result it is a far field model or a model where initial momentum of the discharge is small compared to ambient momentum. In addition, since it is two-dimensional with no vertical diffusion, it should only be used where the receiving water is shallow and the plume is attached to the bottom.

The governing equation for this model is,

$$hU\frac{\partial}{\partial x}(\Delta C) = \frac{\partial}{\partial y}\left[hE_y\frac{\partial}{\partial y}(\Delta C)\right] \qquad (7)$$

where h = local depth of flow; U = depth-averaged velocity in the stream-wise direction; ΔC = depth-average value of concentration in excess of the ambient; E_y = overall transverse mixing coefficient generated by ambient turbulence and bend induced secondary motion; and x and y = distances in the stream-wise and transverse directions respectively. This equation can be simplified by introducing a new transverse coordinate defined as,

$$p = \frac{1}{Q_r}\int_0^y hU\,dy \qquad (8)$$

where Q_r = total river discharge. If river depth and velocity are constant, p is simply the fractional distance to the point in question from the near shore, y/W, where W is the river width. Substituting (8) into (7) and rearranging, the convective-diffusion equation becomes,

$$\frac{\partial}{\partial x}(\Delta C) = D\frac{\partial^2}{\partial y^2}(\Delta C) \qquad (9)$$

where $\bar{h}$ is the average river depth, W is the average width of the river (both in meters), n is Manning's coefficient, α is the dimensionless transverse mixing coefficient defined as $\alpha = E_y/\bar{h}U_*$. The shear velocity, U_* is defined as $U_* = (g\bar{h}S)^{1/2}$ where S is the slope of the river energy gradient. For most rivers, S is the river slope. Manning's coefficient is an empirical constant having dimensions of $(\text{length})^{1/6}$. Recommended values are given below,

Type of Surface	Manning's Coefficient, n
Smooth rivers, no boulders or brush	0.025
Moderately rough with medium sized rocks	0.05
Irregular with large boulders	0.10

Unfortunately the value of α can vary considerably from river to river. In relatively straight uniform sections of a river, the following expression has been found to be reasonable, $\alpha = 0.1 + 0.0019(W/\bar{h})$. A correlation for sinuous rivers obtained from several sources using primarily Missouri River data (13) is,

$$\alpha = 0.4(W/\bar{h})^2(U/U_*)^2(\bar{h}/R_c)^2 \qquad (13)$$

where R_c is the radius of curvature of the river. The numerical coefficients in these equations can be used if nothing better is available for the particular river in question but should be modified when better information can be found. When the stretch of the river where dilution values are desired is large, the value of D may change. In this case, the river should be divided into sections with D assumed to be constant but different in each section.

where D is the Transverse diffusion factor defined as

$$D = h^2UE_y/Q_T^2 \tag{10}$$

Equation (9) can be solved with appropriate initial conditions in terms of the probability density function. See (13) for details. The solution for the maximum concentration at the near shore for a concentrated source at the origin is given by the following expression which includes the effects of reflections from the far shore,

$$\frac{C_m}{C_o} = \frac{Q_o}{Q_r\sigma_p}\left(\frac{2}{\pi}\right)^{1/2}\left[1 + 2\sum_{n=1}^{\infty} \exp\left(-\frac{n^2}{\sigma_p^2}\right)\right] \tag{11}$$

where Q_o is the discharge flow rate, and σ_p is the standard deviation given by $\sigma_p = (2Dx)^{1/2}$. This solution is plotted on Figure 1 labeled "concentrated source". The other curves on this figure are for discharges with a finite sized source.

This is given as $P = Q_i/Q_T$ where Q_i is the average flow within the plume at x equal to zero. For most industrial discharges, setting P = 0 has little effect on the far field dilution.

The accuracy of the PSY model is highly dependent on the ability of the user to determine the appropriate value of D. Paily and Sayre (13) recommend that D be calculated from an equation of the form,

$$D = n\,3.13\,a\,(\bar{h})^{5/6}/W^2 \tag{12}$$

If a uniform depth and velocity are assumed, the solution to equation (9) can be integrated to yield surface areas within given lines of constant concentration. A computer program has been written to perform this integration and is given in this report as the "PSY" model. When the transverse diffusion factor, river depth, and width are given as a function distance downstream and with river and discharge flow rates given, this program prints out the lateral distance from shore to selected lines of constant concentration and the surface area within them as a function of distance downstream. This is shown on Fig. 2 for the sample case considered later. As an example, the area printed out for x = 405 m and C/CO = 0.1 is 3020 m^2 and represents the area between the near shore, the concentration line C/CO = 0.1 and x = 405 m. It is shown on the figure as the crosshatched area. The lateral distance to this line is yp = 6.29 m at this value of x. Therefore, when yp goes to zero, the concentration line reaches the shore and the area is complete. Up until then, the areas printed out are only partial areas.

EXAMPLE INPUT, OUTPUT AND MODEL LISTING

Example

Consider the discharge of 1.07 m^3/s into a moderately rough river whose flow rate is 72.28 m^3/s. The average river width and depth are 109 m and 1.0 m, respectively. The river slope is 13/1000. Discharge is on a bend in the river where the bend radius is 1000 m. About 1000 m below the discharge the river straightens out and remains uniform for

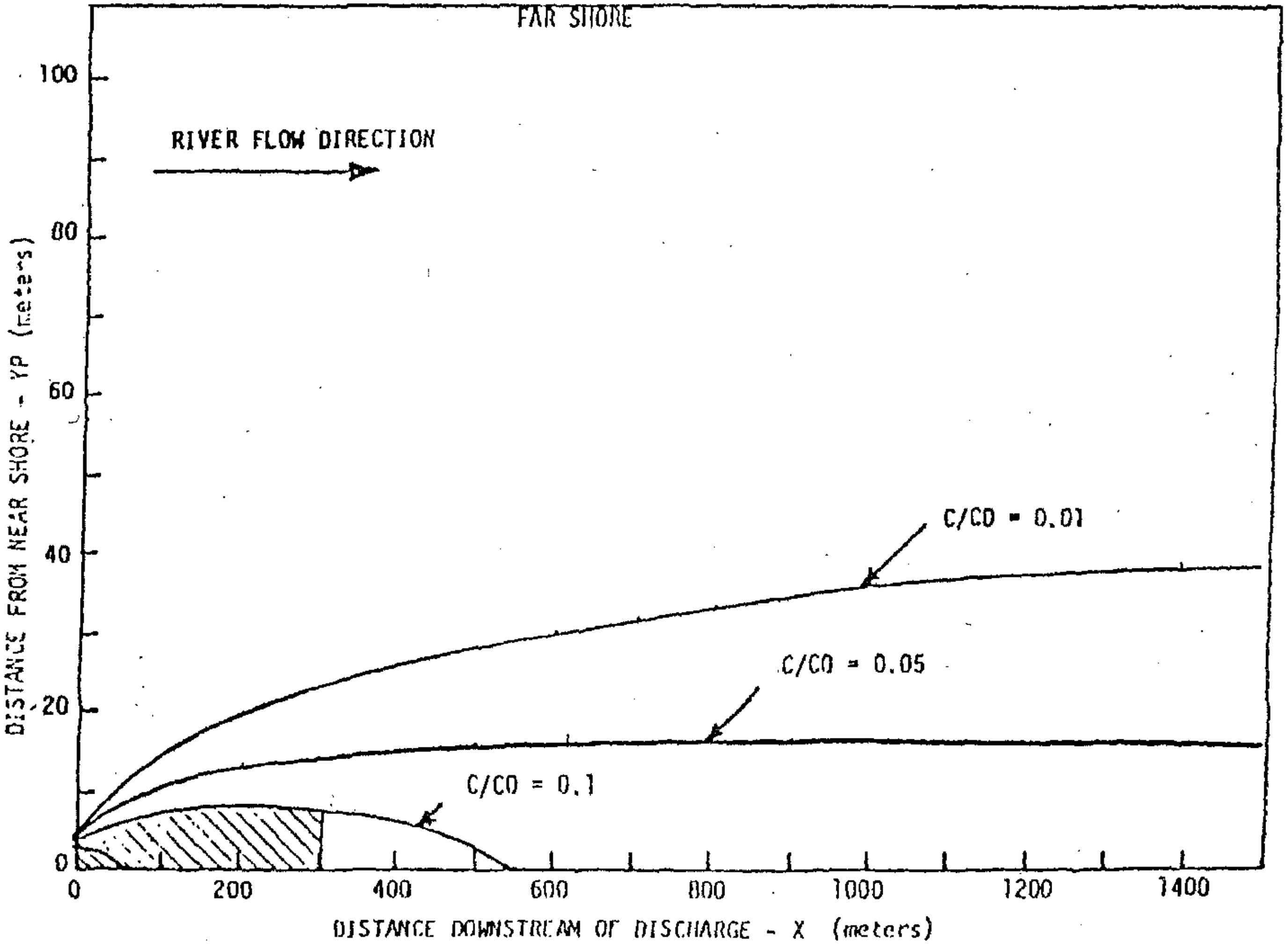

Figure 2. Sketch Defining Variables in PSY Model Printout

several thousand meters. The problem is to find the shoreline dilution as a function of distance downstream and the surface area that has a dilution of 10 or less.

The procedure is to find α and then D for each section of the river. From these and the distance downstream, the appropriate Dx can be found for use with Figure 1. In this case Q_o/Q_r is used for $Q_i/Q_o = 0.014$.

From the data given, the following are determined for the curved section,

$$U = Q_r/\bar{h}W = 72.28/(109 \times 1.0) = 0.663 \text{ m/s}$$

$$U_* = (g\bar{h}S)^{1.2} = (9.8 \times 1.0 \times 15/1000)^{1/2} = 0.361 \text{ m/s}$$

$$\alpha = 0.4(109/1.0)^2(0.663/0.361)^2(1.0/1000)^2 \cong 1.0$$

a value of n - 0.05 is selected, which gives,

$$D_1 = 0.05 \times 3.13 \times 1.0 \times (1.0^{5/6}/109)^2 = 1.32 \times 10^{-5} (1/\text{m})$$

For the straight section,

$$\alpha = 0.1 + 0.0019(109/1.0) = 0.31$$

which yields,

$$D_2 = 0.05 \times 3.13 \times 0.31 \times (1.0)^{5/6}/(109)^2 = 4.3 \times 10^{-6} (1/\text{m})$$

For the curved portion, Dx is simply D_1x. Since the straight section is below this, Dx there is given by $Dx = D_1x_1 + D_2(x - x_1)$ where x_1 is the distance to the beginning of the straight section from the discharge. Using the flow rates given and the values of D determined above, the following table was generated using Figure 1 with P = 0.014.

Distance Downstream from Source (m)	Minimum Dilution Along Near Shore (inverse of concentration
100	4.34
500	9.72
1000	13.2
1500	14.6
2000	15.5
2500	16.5

The areas within the concentration lines was found by running program PSY. The computer punched card format with values for this example along with the output and a complete Fortran listing follow. From the output listing, it is seen that a dilution of 10 or less (C/CO = 0.1 or greater) is contained within an area of 3560 m^2 with the contour line closing at the shore 565 m downstream of the discharge.

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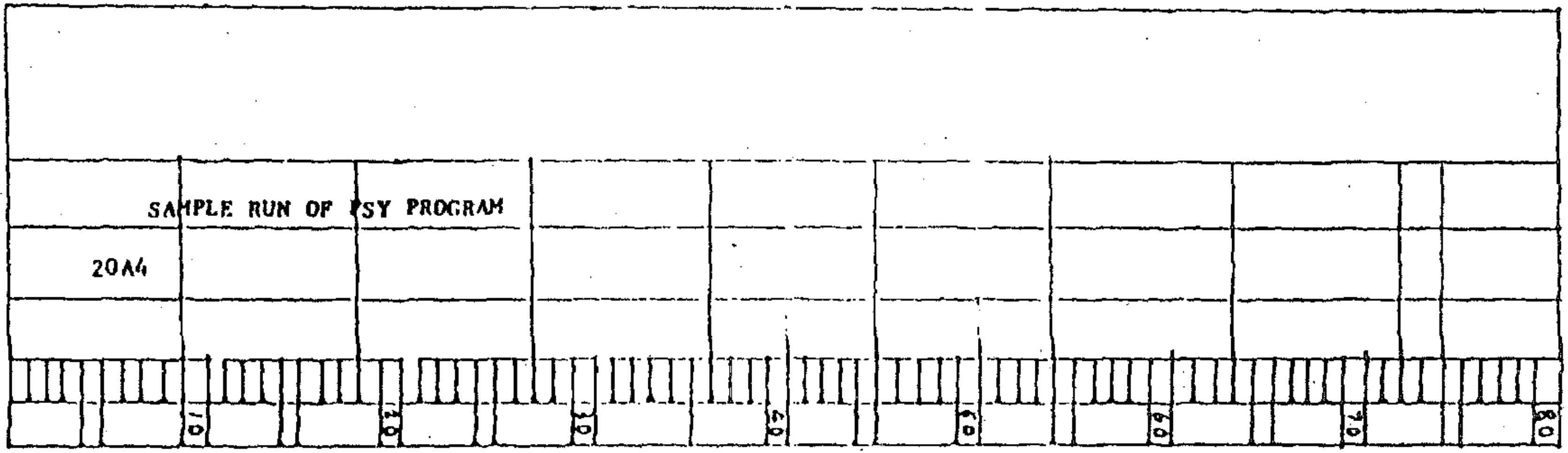
PSY
SAMPLE INPUT
CARD #1



SAMPLE RUN OF PSY PROGRAM

20A4

Anything on this card is printed out at the top of the output listing

NSL	QO	QR	SLIM
2	1.07	72.28	2000.
I10	F10.2	F10.2	F10.2

NSL = Number of Survey Locations on River (At least one and a maximum of 20)

QO = Discharge flow rate (m^3/s)

QR = River flow rate (m^3/s)

SLIM = Distance downstream where calculations are to stop (meters)

PSY
SAMPLE INPUT
CARD 02

F-49

SX	SB	SD	D				
0.0	109.	1.0	1.32E-5	(First card of set)			
1000.	109.	1.0	4.3E-6	(Second card since NSL = 2)			
F10.3	F10.3	F10.3	E10.4				
10	20	30	40	50	60	70	80

SX = Distance downstream of discharge where river data are given

SB = Width of river at this point. Used until a different value is given on next card. (meters)

SD = Depth of river at this point.

D = Transverse diffusion factor (1/meters)

F-50

PSY
SAMPLE INPUT
CARD SET #3

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                              PSY   SAMPLE OUTPUT

SOLUTION TO SURFACE DISCHARGE PROBLEM WITH SHORE-  ATTACHED  PLUME

CASE   1        SAMPLE RUN OF PSY PROGRAM

** DISCHARGE FLOW RATE =      1.070 CUBIC METER/SECOND   **
** RIVER FLOW RATE     =     72.280 CUBIC METER/SECOND   **

               AREA (A) --METER**2      LATERAL  DISTANCE (YP) --METER  FROM DISCHARGE BANK

                                    CONCENTRATION RATIO    C/CO
                                                                        .30                 .50
             .01                   .05                    .10                                                 
DISTANCE     A           YP         A          YP          A          YP       A          YP        A          YP        TIME (SEC
     .10   .107E+01     3.18     .985E+00     2.77      .950E+00     2.67    .885E+00    2.41    .812E+00     2.15       .594E+0
    1.20   .382E+01     3.70     .338E+01     3.21      .323E+01     3.02    .285E+01    2.51    .253E+01     2.16       .178E+0
    2.80   .103E+02     4.35     .894E+01     3.74      .837E+01     3.39    .698E+01    2.66    .590E+01     2.16       .416E+0
    6.00   .258E+02     5.38     .220E+02     4.43      .201E+02     3.94    .158E+02    2.88    .128E+02     2.12       .892E+0
   12.40   .648E+02     6.79     .535E+02     5.40      .477E+02     4.69    .350E+02    3.10    .253E+02     1.78       .184E+0
   25.20   .164E+03     8.68     .131E+03     6.72      .114E+03     5.64    .746E+02    3.09    .367E+02     0.00       .374E+0
   45.20   .359E+03    10.82     .279E+03     8.10      .236E+03     6.56    .128E+03    2.28  ATTACHED TO SHORE        .672E+0
   65.20   .592E+03    12.46     .452E+03     9.11      .373E+03     7.16    .151E+03    0.00                           .969E+02
   85.20   .855E+03    13.85     .642E+03     9.92      .520E+03     7.58  ATTACHED TO SHORE                            .127E+03
  105.20   .114E+04    15.04     .847E+03    10,59      .675E+03     7.88                                                .156E+03
  125.20   .145E+04    16.11     .106E+04    11.16      .835E+03     8.09                                                .186E+03
  145.20   .179E+04    17.07     .129E+04    11.66      .998E+03     8.23                                                .216E+03
  165.20   .214E+04    17.95     .153E+04    12.10      .116E+04     8.32                                                .245E+03
  185.20   .250E+04    18.79     .178E+04    12.49      .133E+04     8.35                                                .275E+03
  205.20   .289E+04    19.55     .203E+04    12.85      .150E+04     8.34                                                .305E+03
  225.20   .329E+04    20.28     .229E+04    13.17      .166E+04     8.30                                                .335E+03
  245.20   .370E+04    20.97     .256E+04    13.46      .183E+04     8.22                                                .364E+03
  265.20   .412E+04    21.63     .283E+04    13.72      .199E+04     8.10                                                .394E+03
  285.20   .456E+04    22.25     .310E+04    13.97      .215E+04     7.95                                                .424E+03
  305.20   .501E+04    22.84     .339E+04    14.19      .231E+04     7.77                                                .454E+03
  325.20   .540E+04    23.41     .367E+04    14.39      .246E+04     7.55                                                .483E+03
  345.20   .595E+04    23.96     .396E+04    14.50      .261E+04     7.30                                                .513E+03
  365.20   .644E+04    24.49     .425E+04    14.75      .275E+04     7.01                                                .543E+03
  385.20   .693E+04    25.00     .455E+04    14.91      .289E+04     6.67                                                .572E+03
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 405.20    .744E+04  25.50    .485E+04  15.06    .302E+04   6.29                  .602E+0
 425.20    .795E+04  25.98    .515E+04  15.19    .314E+04   5.86                  .632E+0
 445.20    .847E+04  26.44    .546E+04  15.31    .325E+04   5.36                  .662E+0
 465.20    .901E+04  26.89    .577E+04  15.42    .336E+04   4.76                  .691E+0
 485.20    .955E+04  27.33    .608E+04  15.53    .344E+04   4.03                  .721E+0
 505.20    .101E+05  27.75    .639E+04  15.62    .351E+04   3.04                  .751E+0
 525.20    .107E+05  28.17    .670E+04  15.70    .355E+04    .82                  .780E+0
 545.20    .112E+05  28.57    .701E+04  15.78    .356E+04   0.00                  .810E+0
 565.20    .118E+05  28.96    .733E+04  15.85   ATTACHED TO SHORE                .840E+0
 585.20    .124E+05  29.35    .765E+04  15.91                                    .870E+0.
 605.20    .130E+85  29.73    .797E+04  15.96                                    .899E+0.
 625.20    .136E+05  30.10    .829E+04  16.01                                    .929E+0
 645.20    .142E+05  30.46    .861E+04  16.05                                    .959E+0
 665.20    .148E+05  30.81    .893E+04  16.08                                    .989E+0
 685.20    .154E+05  31.15    .925E+04  16.11                                    .102E+04
 705.20    .160E+05  31.49    .957E+04  16.13                                    .105E+04
 725.20    .167E+05  31.83    .990E+04  16.15                                    .108E+04
 745.20    .173E+05  32.15    .102E+05  16.16                                    .111E+04
 765.20    .180E+05  32.47    .105E+05  16.16                                    .114E+04
 785.20    .186E+05  32.79    .109E+05  16.16                                    .117E+04
 805.20    .193E+05  33.10    .112E+05  16.16                                    .120E+04
 825.20    .199E+05  33.40    .115E+05  16.15                                    .123E+04
 845.20    .206E+05  33.70    .118E+05  16.13                                    .126E+04
 865.20    .213E+05  33.99    .122E+05  16.11                                    .129E+04
 885.20    .220E+05  34.28    .125E+05  16.09                                    .132E+04
 905.20    .227E+05  34.57    .128E+05  16.06                                    .135E+04
 925.20    .233E+05  34.85    .131E+05  16.02                                    .137E+04
 945.20    .240E+05  35.12    .134E+05  15.99                                    .140E+04
 965.20    .248E+05  35.39    .138E+05  15.94                                    .143E+04
 985.20    .255E+05  35.66    .141E+05  15.90                                    .146E+04
1005.20    .262E+05  35.88    .144E+05  15.86                                    .149E+04
1045.20    .276E+05  36.05    .150E+05  15.82                                    .155E+04
1085.20    .291E+05  36.22    .157E+05  15.78                                    .161E+04
1125.20    .305E+05  36.39    .163E+05  15.74                                    .167E+04
1165.20    .320E+05  36.55    .169E+05  15.70                                    .173E+04
1205.20    .334E+05  36.72    .175E+05  15.36                                    .179E+04
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1245.20     .349E+05  36.88     .182E+05  15.62                                                        .185E+0
1285.20     .364E+05  37.04     .188E+05  15.57                                                        .191E+0
1325.20     .379E+05  37.20     .194E+05  15.52                                                        .197E+0
1365.20     .394E+05  37.36     .200E+05  15.48                                                        .203E+04
1405.20     .409E+05  37.52     .207E+05  15.42                                                        .209E+04
1445.20     .424E+05  37.68     .213E+05  15.37                                                        .215E+04
1485.20     .439E+05  37.83     .219E+05  15.32                                                        .221E+04
1525.20     .454E+05  37.99     .225E+05  15.26                                                        .227E+04
1565.20     .469E+05  38.14     .231E+05  15.20                                                        .233E+04
1605.20     .484E+05  38.29     .237E+05  15.14                                                        .239E+04
1645.20     .500E+05  38.44     .243E+05  15.08                                                        .244E+04
1685.20     .515E+05  38.59     .249E+05  15.02                                                        .250E+04
1725.20     .531E+05  38.74     .255E+05  14.95                                                        .256E+04
1765.20     .546E+05  38.88     .261E+05  14.89                                                        .262E+04
1805.20     .562E+05  39.03     .267E+05  14.82                                                        .268E+04
1845.20     .577E+05  39.17     .273E+05  14.75                                                        .274E+04
1885.20     .593E+05  39.32     .279E+05  14.67                                                        .280E+04
1925.20     .609E+05  39.46     .285E+05  14.60                                                        .286E+04
1965.20     .625E+05  39.60     .291E+05  14.52                                                        .292E+04
2000.00     .641E+05  39.72     .296E+05  14.45                                                        .298E+04
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IX NOMENCLATURE

C	Concentration
C/C_o	Dimensionless concentration ratio - inverse of dilution
D	Transverse diffusion factor, equation (10)
E_y	Overall transverse mixing coefficient
F_o	Discharge densimetric Froude number
h	River depth in PSY model. $\bar{h}$ is average value.
H	Plume depth in PDS and PDSM models
n	Manning's coefficient
p	Transverse coordinate in PSY model
P	Initial dilution factor, PSY model
Q	Volumetric flow rate
Q/Q_o	Dilution
r	Radial coordinate in DKHPLM model
R_c	Radius of river bend
s	Streamline coordinate in DKHPLM model
S	Slope of river energy line
u	Plume streamwise velocity
v	transverse velocity
U	Velocity
U_*	Shear velocity = $(g\bar{h}S)^{1/2}$
x,y	Coordinates
yp	Transverse coordinate in PSY output
W	River width
α	Diffusion coefficient, PSY model
θ	Flow angle
ρ	Fluid density
σ	Standard deviation of distribution function

Subscripts and Superscripts

a	Ambient
m	Maximum or plume centerline
o	Discharge
r	River
∞	Free stream
$'$	Turbulent quantity

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Section 301(g) Checklist

State and Regional personnel should use this checklist when reviewing section 301(g) variance request. Section 301(g) applicants may also use this checklist to ensure their application addresses and documents all necessary items. The checklist covers all the factors EPA has identified as important in considering a section 301(g) request. As the importance of each item will vary from site to site, a careful review of the checklist by the permit writer and the applicant, during the early consultation period, can help the applicant determine the degree to which each of these factors must be addressed.

How To Use This Checklist

EPA recommends that Regional and State personnel use this checklist first to determine what the applicant should submit in its completed request and secondly, to review the submitted completed section 301(g) variance request.

The checklist consists of a series of questions addressing the statutory factors listed in section 301(g) of the CWA. State and Regional personnel will determine whether to grant a variance based upon the information furnished in response to the various factors outlined in the checklist.

I. Preliminary Information

Did the applicant provide the following:

1. Legal name and mailing address?
2. Name and address of the point source for which the variance is being sought if it is different from Number 1?
3. Facility ID Number (EPA ID Number)?
4. Name, title, telephone number and address of person in the firm to contact about the section 301(g) completed request?
5. Identification of the nonconventional pollutant(s) or pollutant parameter for which a section 301(g) variance is sought?
6. The 40 CFR citation for the specific effluent guideline containing the limitation from which the section 301(g) variance is sought?
7. The date the initial request (in accordance with 40 CFR 122.21) for the section 301(g) variance was submitted to EPA? (Was a postcard submitted by September 1978, or was an initial request submitted 270 days after the promulgation of the applicable guideline?)
8. The date the applicable BAT effluent guideline(s) was promulgated? (If no BAT effluent guidelines were promulgated, the date the notice of preparation of the draft BPJ/BAT permit was published.)
9. The proposed modified effluent limitation (PMEL) for the nonconventional pollutant?
10. The promulgated BPT effluent guideline limitations? (If no BPT guideline exists, the limitation derived by the State/Region.)
11. The permit compliance schedule?
12. A list or description of State water quality standards applicable to the nonconventional pollutant(s)?

II. Environmental Quality Information

A. IMPACT TO POINT AND NONPOINT SOURCES

Did the applicant provide:

1. an analysis of the potential impact of the applicant's PMEL on other point and nonpoint sources in the vicinity of the point of discharge?

SPECIFICALLY, DID THE APPLICANT:

a. Identify all the point and nonpoint sources in the vicinity of its discharge (with assistance of State permitting authority)?

b. obtain a determination from the State or interstate agency(s) having authority to establish wasteload allocations indicating whether the discharge of the PMEL would result in an additional treatment, pollution control, or other requirements on any point or nonpoint sources? (The State must include a discussion of the basis for its conclusion.)

If neither a or b were addressed:

c. Confer with nearby point sources to determine the possible impact on those sources if the PMEL were approved in a section 301(g) variance?

B. IMPACT TO RECREATIONAL ACTIVITIES

Did the applicant provide:

1. An analysis of the potential impact the PMEL would have on recreational activities in and on the water in the vicinity of the discharge?

SPECIFICALLY, DID THE APPLICANT:

a. Identify recreational activities in and on the water in the vicinity of its discharge?

b. Provide an analysis which determined whether the PMEL would interfere with recreational activities beyond the mixing zone including without limitation swimming, diving, boating, fishing and picnicking and sports activities along shorelines and beaches?

C. IMPACT TO PUBLIC WATER SUPPLIES

Did the applicant provide:

1. an analysis of the potential impact of the PMEL to public water supplies in the vicinity of its discharge?

SPECIFICALLY, DID THE APPLICANT:

a. Identify the public water supplies in the vicinity of its discharge?

b. Provide an analysis which demonstrated that the PMEL would not prevent a planned or existing public water supply from being used, or from continuing to be used as a public water supply, or have the effect of requiring any public water supply to provide additional treatment?

D. IMPACT TO AQUATIC LIFE AND HUMAN HEALTH

Did the applicant provide:

1. a demonstration that the PMEL would still maintain water quality which protects the propogation of a balanced population of shellfish, fish, and wildlife and that the PMEL would not pose an unacceptable risk to human health and the environment because of bioaccumulation, persistency, acute toxicity, chronic toxicity (including carcinogenicity, teratogenicity, mutagenicity) or synergistic effects?

SPECIFICALLY, DID THE APPLICANT:

a. identify a State water quality standard or an EPA water quality criterion (most recently published or Red Book) for the nonconventional pollutant which protects both aquatic life and human health at the edge of the mixing zone?

or b. derive a site-specific criterion number for the nonconventional pollutant using an EPA-approved criterion derivation methodology, and if so, were local species used in the criterion derivation approved by the Regional Administrator?

or c. derive a criterion for the nonconventional pollutant using another method which was approved by OWRS?

or d. derive a safe concentration for the nonconventional pollutant by some other approved means such as field testing, literature search, biomonitoring?

e. demonstrate that the PMEL, after dilution in the mixing zone, would meet that water quality standard or criterion?

f. demonstrate that all other factors such as bioaccumulation, persistency, and synergistic propensities have been adequately addressed? (See questions on persistency and synergism in Section III of the checklist)

E. MODELLING AND FATE AS RELATED TO SECTION 301(g) VARIANCES

Did the applicant:

1. Provide an aerial-view map of the facility and the surrounding area illustrating the boundary of the State mixing zone and the concentration isopleth of the nonconventional pollutant from point of discharge to the mixing zone boundary?

2. Identify which model was used to determine the dilution pattern of the nonconventional pollutant and provide a basis for using that particular model?

3. Provide any field data to calibrate and validate the model of choice?

4. State how the mixing zone was determined if it was not an approved State water quality standard mixing zone (case-by-case basis)?

5. Provide basis for the design flow used in making dilution calculations?

III. Special Considerations

A. POLLUTANT PARAMETERS (COD, TOC, TKN, Total phenols)

Did the applicant:

1. Identify the chemical constituents of the pollutant parameter and rule out the existence of toxics in the pollutant parameter? (Toxics may be found in trace amounts or at levels equivalent to BAT.)

2. Identify the means by which the constituents were identified? (e.g., GC/MS)

3. Derive a criterion number for the pollutant parameter by applying the EPA criterion derivation methodology of November 1980 to the whole effluent and expressing the resulting criterion in percent effluent?

4. Determine that the pollutant parameter was not a source of toxicity after conducting a bench scale treatment study?

5. Determine a safe level of the pollutant parameter by conducting a literature search?

6. Assess the potential for human health impact of the nonconventional pollutant parameter?

B. SYNERGISTIC PROPENSITIES

Did the applicant:

1. Identify potential synergistic propensities in the effluent and receiving water?

   SPECIFICALLY, DID THE APPLICANT:

a. identify possible chemical reactions between compounds producing more toxic pollutants?

b. identify possible reactions dependent upon physical parameters such as increased toxicity related to increasing or decreasing temperature, pH, alkalinity, conductivity, flow (turbulence), or suspended solids.

c. identify possible joint effects where two compounds affect an organism in two different ways simultaneously? (E.g. one pollutant affecting respiration, another the central nervous system.)

d. apply biomonitoring techniques to determine whether synergism is occurring in applicant's effluent. (Were toxicity tests conducted on separate toxic, conventional, or nonconventional fractions and then on the whole effluent to determine differences between the toxicity of the whole effluent and the different fractions?)

e. examine the potential for additivity in the effluent?

C. PERSISTENCY

Did the applicant:

1. Identify pollutants which could impact aquatic life or human health due to persistency?

SPECIFICALLY, DID THE APPLICANT:

a. examine chemical or physical reactions such as volatilization, photolysis, adsorption, absorption, oxidation and hydrolysis to determine the fate of the nonconventional pollutant?

b. apply direct analytical methods or conduct a literature search to determine the persistency of the nonconventional pollutant?

c. conduct structural analysis of the principal components in the effluent to determine whether the compounds are of a persistent nature?

APPENDIX H

The following lists provide the current status of the Technical Guidance Manuals for Performing Wasteload Alloacations. These have been developed by the Office of Water Regulations and Standards, Monitoring and Data Support Division. If you have any questions about any of these documents or would like a copy of one of these documents please call (202) 382-7056.

WASTELOAD ALLOCATION GUIDANCE BOOKS AND CHAPTERS

GENERAL GUIDANCE

STREAMS AND RIVERS

1. BOD/DO Impacts
2. Nutrient/Eutrophication Impacts
3. Toxic Substances Impacts

ESTUARIES

1. BOD/DO Impacts
2. Nutrient/Eutrophication Impacts
3. Toxic Substances Impacts

LAKES AND IMPOUNDMENTS

1. BOD/DO Impacts
2. Nutrient/Eutrophication Impacts
3. Toxic Substances Impacts

DESIGN CONDITIONS

1. Design Flow
2. Design Temperature
3. Design pH
4. Design Effluent Flow
5. Design Rate Constants

PERMIT AVERAGING

SCREENING MANUAL

1. Toxic Organic and Conventional Pollutants
2. Toxic Metals

INNOVATIVE PERMITS

BIOMONITORING

1. Design Conditions
2. Permit Averaging
3. Modeling Toxicity
4. Mixing Zone

FINAL NATIONAL GUIDANCE

o To date the following final national guidance has been issued:

- A Screening Procedure for Toxic and Conventional Pollutants
  (August 29, 1983)

- Lakes and Impoundments, Chapter 2, Eutrophication
  (August 29, 1983)

- Streams and Rivers, Chapter 1, BOD/DO Impacts
  (October 3, 1983)

- Streams and Rivers, Chapter 2, Eutrophication
  (scheduled December 1983)

o The following final national guidance is planned for release in the coming year:

- Streams and Rivers, Chapter 3, Toxic Substances
  (scheduled September 1984)

- Permit Averaging Periods
  (scheduled September 1984)

DRAFT MANUALS FOR HEADQUARTERS AND REGIONAL REVIEW AND COMMENT

o Within the past year, the following draft guidance manuals were sent to the Headquarters and Regions for review and comment:

- Streams and Rivers, Chapter 2, Eutrophication
- Permit Averaging
- Streams and Rivers, Chapter 3, Toxic Substances
- Design Conditions, Chapter 1, Design Flow
- Innovative Permits

o Drafts of the following WLA guidance manuals are under development and scheduled for release to the Headquarters and Regions for review and comment during FY84:

- Design Conditions, Chapter 2, Design Temperature
- Design Conditions, Chapter 3, Design pH
- A Screening Procedure for Toxic Metals
- Estuaries, Chapter 1, BOD/DO Impacts
- Estuaries, Chapter 2, Eutrophication
- Lakes and Impoundments, Chapter 3, Toxic Substances

GUIDANCE MANUALS PLANNED FOR FY84

- PREPARATION OF THE FOLLOWING DRAFT WASTELOAD ALLOCATION GUIDANCE MANUALS IS SCHEDULED FOR INITIATION DURING FY84:
  - GENERAL GUIDANCE (NOVEMBER 1983)
  - ESTUARIES, CHAPTER 3, TOXIC SUBSTANCES (MARCH 1984)
  - DESIGN CONDITIONS, CHAPTER 4, EFFLUENT FLOW (OCTOBER 1983)
  - DESIGN CONDITIONS, CHAPTER 5, RATE CONSTANTS (TO BE DETERMINED)
  - LAKES AND IMPOUNDMENTS, CHAPTER 1, BOD/DO IMPACTS (TO BE DETERMINED)
- DEVELOPMENT OF THE FOLLOWING GUIDANCE MANUALS ON THE BIOMONITORING APPROACH IS ALSO PLANNED FOR INITIATION IN FY84:
  - PERMIT AVERAGING FOR GENERIC TOXICITY (NOVEMBER 1983)
  - DESIGN CONDITIONS FOR GENERIC TOXICITY (NOVEMBER 1983)
  - MODELING GENERIC TOXICITY (DECEMBER 1983)
  - MIXING ZONE (TO BE DETERMINED)

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TECHNICAL TRAINING SEMINARS

- Technical training seminars planned for FY84 are:
  - BOD/DO Modeling in Dallas, January 1984
  - Toxic Substances in Atlanta, March 1984
  - Toxic Substances in San Francisco, May 1984
  - Design Conditions/Permit Averaging, August 1984 (Location to be Determined)
  - Innovative Permits, August 1984 (Location to be Determined)