



**TECHNICAL GUIDANCE FOR ASSESSING  
THE QUALITY OF  
AQUATIC ENVIRONMENTS**

---

91-78  
Revised  
February 1994

*printed on recycled paper*

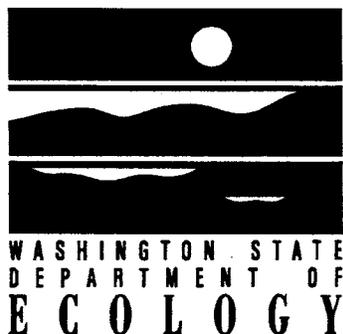


*The Department of Ecology is an Equal Opportunity and Affirmative Action employer and shall not discriminate on the basis of race, creed, color, national origin, sex, marital status, sexual orientation, age, religion, or disability as defined by applicable state and/or federal regulations or statutes.*

*If you have special accommodation needs, please contact the Environmental Investigations and Laboratory Services Program, Watershed Assessments Section, Barbara Tovrea at (206) 407-6696 (voice). Ecology's telecommunications device for the deaf (TDD) number at Ecology Headquarters is (206) 407-6006.*

*For additional copies of this publication,  
please contact:*

*Department of Ecology  
Publications Distributions Office  
at P.O. Box 47600  
Olympia, Washington 98504-7600  
(206) 407-7472  
Refer to Publication Number 91-78 (revised)*



**TECHNICAL GUIDANCE FOR ASSESSING  
THE QUALITY OF  
AQUATIC ENVIRONMENTS**

---

By  
*Robert F. Cusimano*

Contributors  
*Joe Joy, Will Kendra, Greg Pelletier, and Rob Plotnikoff*

Environmental Investigations and Laboratory Services Program  
Watershed Assessments Section  
Olympia, Washington 98504-7710

February 1994  
Revised  
91-78

*printed on recycled paper*



## TABLE OF CONTENTS

ABSTRACT .....	.iv
ACKNOWLEDGEMENTS .....	v
TABLE OF ACRONYMS .....	.vi
GLOSSARY .....	viii
<b>SECTION 1: OVERVIEW</b>	
1.1 Introduction .....	1-1
1.2 Water Quality in Washington State .....	1-1
1.3 Pollution .....	1-2
<b>SECTION 2: WATER QUALITY AND ECOLOGICAL CONCEPTS</b>	
2.1 The Physical Properties of Water .....	2-1
2.2 The Hydrologic Cycle .....	2-1
2.3 The Physical Attributes of Waterbodies .....	2-2
2.4 Surface Water Ecosystems .....	2-3
2.5 Surface Water Quality .....	2-6
<b>SECTION 3: PLANNING AND STUDY DESIGN</b>	
3.1 Planning and Water Quality Assessment Program .....	3-1
3.2 Quality Control/Quality Assurance (QA/QC) .....	3-3
3.3 Designing a Water Quality Assessment Project .....	3-4
3.3.1 Field Survey Design .....	3-5
3.3.2 Lab and Equipment Scheduling and Budget .....	3-9
3.3.3 Reconnaissance Trip .....	3-10
3.3.4 Final Preparations .....	3-10
3.4 Field Survey .....	3-17
<b>SECTION 4: WATER QUALITY ASSESSMENT</b>	
4.1 Pollutant Loading Calculations .....	4-1
4.1.1 Streamflow Measurements .....	4-2
4.2 Rivers and Streams .....	4-2
4.2.1 Mixing Zones .....	4-3
4.2.2 River Segmentation .....	4-5
4.2.3 Dissolved Oxygen and BOD .....	4-6
4.2.4 Nutrients and Eutrophication .....	4-7
4.2.5 Bacterial Indicators .....	4-7
4.2.6 Toxic Substances .....	4-8

## TABLE OF CONTENTS (Continued)

4.3	Lakes and Reservoirs	4-8
4.3.1	Eutrophication	4-8
4.3.2	Dissolved Oxygen	4-9
4.3.3	Toxicant Screening	4-9
4.4	Estuaries	4-10
4.4.1	Mixing Zones	4-10
4.4.2	Flushing Time Calculations	4-11
4.4.3	Far-field Approach to Pollutant Distribution	4-12
4.4.4	Pollutant Distributions from Sewage Outfalls	4-12

### SECTION 5: TMDL ANALYSES

5.1	Chemical Specific vs. Whole Effluent Approach	5-1
5.1.1	Chemical Specific Approach	5-1
5.1.2	Whole Effluent Approach	5-2
5.2	Development of TMDL, WLA, and Permit Limits	5-2
5.2.1	Rivers and Streams	5-3
5.2.2	Lakes and Impoundments	5-5
5.2.3	Estuaries and Coastal Bays	5-6
5.3	Development of TMDL and LA	5.7

### SECTION 6: BIOLOGICAL SURVEYS

6.1	Freshwater Communities	6-1
6.1.1	Periphyton	6-3
6.1.2	Phytoplankton and Zooplankton	6-4
6.1.3	Macrophytes	6-5
6.1.4	Macroinvertebrates	6-5
6.1.5	Fish	6-7
6.2	Fish and Shellfish Tissue	6-7
6.2.1	Conventional Pollutants	6-8
6.2.2	Toxic Pollutants	6-8

### SECTION 7: SEDIMENT CONTAMINATION SURVEYS

7.1	Conventional Pollutants	7-1
7.2	Toxic Pollutants	7-2

### SECTION 8: REPORTING CONSIDERATIONS

8.1	Data Management	8-1
8.2	Data Analysis and Presentation	8-8
8.3	Reporting	8-9

SECTION 9:	ANNOTATED BIBLIOGRAPHY	9-1
------------	------------------------	-----

TABLE OF CONTENTS (Continued)

**SECTION 10: LITERATURE CITED AND ADDITIONAL READING . . . . . 10-1**

**APPENDICES**

A. Planning Checklist . . . . . A-1  
B. Equipment Checklist . . . . . B-1  
C. Methods for Estimating Streamflow . . . . . C-1  
D. Spreadsheets for Water Quality-based Permit Calculations . . . . . D-1  
E. Example Table of Contents for Reports . . . . . E-1

## ABSTRACT

The Watershed Assessments Section of Ecology prepared this guidance manual which discusses developing water quality assessment programs and technical methods for conducting water quality studies. The manual provides a brief overview of water quality and ecological concepts with respect to Washington State regulations. The manual also describes survey planning, study design, report writing, and data management activities, as well as assessment techniques for water, biota, and sediment quality. In addition, the manual provides an annotated bibliography and extensive reference section of water quality-related publications. This manual is written for those interested in improving their understanding of the water quality assessment process, including persons interested in meeting Ecology grant program requirements.

## ACKNOWLEDGEMENTS

We wish to acknowledge the Watershed Assessments Section staff for their contributions to the development of this handbook. We are also grateful to the following reviewers for their helpful comments: Timothy Determan, Stewart Lombard, David Hallock, John Tooley and Pete Striplin. In addition, we would like to thank the Water Quality Financial Assistance Nonpoint Section for their input in developing the handbook. A special thanks to Barbara Tovrea and Kelly Carruth for their work in preparing the handbook.

Table 1. Acronyms used in the present report.

Acronym	Definition
ADAPS	A USGS mainframe computer program for accessing USGS flow data
AKART	All Known, Available, and Reasonable methods of Treatment (technology-based pollution controls)
BMPs	Best Management Practices
BOD	Biochemical Oxygen Demand (BOD <sub>5</sub> = 5-day BOD)
CBOD	Carbonaceous BOD (CBODU = Ultimate CBOD)
CSO	Combined Sewer Overflow (sanitary & storm sewers)
DMR	Discharge Monitoring Report (maintained by NPDES permittees)
DNR	Washington State Department of Natural Resources
D.O.	Dissolved Oxygen
DOT	Washington State Department of Transportation
DSHS	Washington State Department of Social and Health Services
EILS	Ecology's Environmental Investigations and Laboratory Services Program
EPA	U.S. Environmental Protection Agency
FC	Fecal Coliform bacteria
FDA	U.S. Food and Drug Administration
FS	Fecal Streptococci bacteria
GIS	Geographic Information System (computer software)
HQ	Ecology's Headquarters Offices (Olympia)
LA	Load Allocation (portion of TMDL allotted to nonpoint sources)
LC <sub>50</sub>	Concentration of toxicant at which 50% of test organisms die (usually over 96-hrs)
METRO	Municipality of Metropolitan Seattle
MPN	Most Probable Number (estimate of bacteria density using multiple-tube fermentation techniques)
NBOD	Nitrogenous BOD
NMFS	National Marine Fisheries Service
NOEL	No Observed Effect Level (highest toxicant concentration which causes no adverse effect in test organisms)
NPDES	National Pollutant Discharge Elimination System (point source wastewater discharge permits)
PCB	Polychlorinated Biphenyls
PC STORET	Microcomputer-based STORET
PSEP	Puget Sound Estuary Program
PUD	Public Utility District
QA/QC	Quality Assurance/Quality Control
RCW	Revised Code of Washington (state laws)

Table 1. Continued.

Acronym	Definition
SCS	U.S. Soil Conservation Service
SOD	Sediment Oxygen Demand
STORET	EPA database for storage of environmental data
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TOX	Total Organic Halides (chloride, bromide, and iodide)
TSD	EPA Technical Support Documents (guidance manuals)
TSS	Total Suspended Solids
UOD	Ultimate Oxygen Demand
USBR	U.S. Bureau of Reclamation
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WAC	Washington Administrative Code (state regulations)
WAS	Ecology's Watershed Assessments Section
WDIS	Waste Discharge Inventory System
WLA	Wasteload Allocation (portion of TMDL allotted to point sources)
WTP	Wastewater Treatment Plant
7Q10	7-day average low flow expected to occur once every 10 years (1Q10 = 1-day average low flow expected to occur . . .)

## GLOSSARY

### Definitions

Acid neutralizing capacity (ANC): the total capacity of a water sample to neutralize a titrated strong acid. Acid neutralizing capacity includes alkalinity (carbonate species) and other basic species.

Acid deposition: referred to as acid rain, but includes rain, snow, or dry deposition of acids and acidifying compounds from the atmosphere; precipitation with a pH less than 5.0 is usually considered to be unnaturally acidic.

Acidification: any temporary or permanent loss of acid neutralizing capacity.

Acute Conditions: changes in the physical, chemical, or biological environment which are expected or demonstrated to result in injury or death to an organism as a result of short-term exposure to the substance or detrimental environmental condition (Chapter 173-201A-020 WAC).

Accuracy: the nearness of a measurement to the actual value of a variable being measured.

Adsorption: the adhesion of one substance to the surface of another; clays, for example, can adsorb metals, phosphorus, and organic molecules.

Advective Transport: the physical processes of advection and dispersion which transport fluid constituents from location to location.

Aerobic: describes living organisms or biological processes that require oxygen; can be used to describe the presence of oxygen in the physical environment (for example, the hypolimnion is aerobic).

Algae: a large and diverse group of small aquatic plants that may be unicellular or multicellular (filamentous).

Aliquot: part of a sample prepared for the analysis of a single or set of specific analytes, sent in a separate container to the analytical laboratory.

Allochthonous: external sources of organic material transported in a dead or decomposing state to a biological community for use.

Autochthonous: photosynthetic production of organic material within a biological community.

**Autocorrelated Data:** data which have a greater correlation between adjacent values in a series than between more distant values in the same series. For example, data collected on two consecutive days may be more highly correlated than data collected a month apart.

**Autotrophic:** a classification of living organisms which synthesize the organic materials they require from inorganic sources. For example, green plants use light as a source of energy to produce organic material from carbon dioxide and water.

**Background Conditions:** the biological, chemical, and physical conditions of a waterbody, outside the area of influence of the discharge under consideration (Chapter 173-201A-020 WAC).

**Benthic:** bottom of a waterbody.

**Benthos:** flora and fauna living on the bottom of a lake, stream or sea.

**Bias:** the systematic difference between a measured and true value.

**Bioaccumulate:** accumulate within organisms via the food chain.

**Bioconcentrate:** accumulate within organisms directly from the physical environment.

**Biota:** living organisms.

**Chronic conditions:** changes in the physical, chemical, or biologic environment which are expected or demonstrated to result in injury or death to an organism as a result of repeated or constant exposure over an extended period of time to a substance or detrimental environmental condition (Chapter 173-201A-020 WAC).

**Critical Condition:** when the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or characteristic water uses (Chapter 173-201A-020 WAC).

**Correlation Analysis:** determining the relationship between two or more variables (i.e., how the magnitude of one variable changes as the magnitude of the second variable changes).

**Detritus:** decomposing organic matter.

**Dendritic:** branched.

**Epilimnion:** the upper, usually warmer stratum of a waterbody.

**Eutrophic**: a body of water with an abundant supply of nutrients and a high rate of photosynthesis.

**Freshet**: a rise in stage of a stream caused by heavy rain or melted snow, or a stream of fresh water flowing into a body of salt water.

**Hydraulic Residence Time**: the time required to exchange the total volume of water in a waterbody.

**Hydrolysis**: a chemical reaction of a compound with water.

**Hypolimnion**: the lower, usually cooler stratum of a waterbody.

**Kingdoms**: the highest category into which organisms are classified.

**Limnology**: the study of the physical, chemical, and biological properties of lakes and other bodies of fresh water (e.g., reservoirs).

**Macrophytes**: large forms of aquatic plants, including macroalgae, mosses, ferns, and flowering plants adapted to aquatic habitats.

**Metalimnion**: the stratum between the epilimnion and hypolimnion which shows thermal discontinuity (see thermocline).

**Mixing Zone**: that portion of a waterbody adjacent to an effluent outfall where mixing results in the dilution of the effluent with the receiving water (Chapter 173-201A-020 WAC).

**Morphometry**: physical characteristics of a waterbody, such as length, width, area, and volume.

**Natural Conditions**: surface water quality that was present before any human-caused pollution (Chapter 173-201A-020 WAC).

**Permit**: a document issued pursuant to RCW 90.48.160 et seq. or RCW 90.48.260 or both, specifying the waste treatment and control requirements and waste discharge conditions (Chapter 173-201A-020 WAC).

**Periphyton**: microfloral growth upon substrate such as rocks or woody debris.

**Plankton**: very small organisms (microscopic plants and animals) that drift or float passively in a waterbody.

**Photolysis**: chemical reaction produced by exposure to light or ultraviolet radiation.

**Precision**: the closeness of repeated measurements of the same quantity.

Protozoans: unicellular microscopic organisms, usually members of the Kingdom Protista.

Quality Assurance: steps taken to ensure that a project is adequately planned and implemented to provide data which meet data quality objectives.

Quality Control: steps taken during sample collection and analysis to ensure that the data quality objectives are met.

Taxa: groups of organisms (see Taxonomy).

Taxonomy: the naming, description, and classification of organisms into named groups.

Thermocline: the plane of maximum rate of change (usually decrease) of temperature with respect to the depth of a waterbody. It is sometimes defined as a temperature discontinuity layer.

Transpiration: the loss of water vapor by plants to the atmosphere through gas exchange.

Trophic Level: the position that an organism occupies in a food chain.

## SECTION 1 OVERVIEW

### 1.1 Introduction

This guidance manual is designed to provide an overview of water quality issues and direction for developing water quality assessment programs. The manual should enhance the reader's general understanding of water quality information. However, the subject of water quality is very broad and beyond treatment in a single document. This manual should be supplemented with more detailed literature for an in-depth understanding of the topics discussed.

This guidance manual is written for informed citizens, local governments, and Indian Tribes interested in improving their understanding of the water quality assessment process, especially those interested in meeting Ecology's grant requirements. Those interested in developing a monitoring plan for a specific lake, reservoir, stream, river, or estuary will find the guidance presented in this manual helpful in planning and implementing their project.

Ecology published a manual in June 1989 entitled, "Guidance for Conducting Water Quality Assessments" which was developed for watershed management committees designing watershed action plans. That manual was intended to address the nonpoint rule, Chapter 400-12 of the Washington Administrative Code (WAC), and it contains information on water quality monitoring, riparian corridor assessment, and land use assessment. The two manuals may be used together since the guidance presented here does not contain information on riparian corridor assessment or land use assessment.

### 1.2 Water Quality in Washington State

In Washington State, a body of regulations were developed at both the state and federal level to protect, maintain, and enhance the water quality of the state. It is the policy of the state of Washington to:

" . . . maintain the highest possible standards to ensure the purity of all waters of the state consistent with public health and public enjoyment thereof, and propagation and protection of wild life, birds, game, fish and other aquatic life, and the industrial development of the state, and to that end require the use of all known available and reasonable methods by industries and others to prevent and control the pollution of the waters of the state of Washington. Consistent with this policy, the state of Washington will exercise its powers, as fully and as effectively as possible, to retain and secure high quality for all waters of the state."

- Chapter 90.48, Revised Code of Washington

These goals are similar to the Federal Clean Water Act (Public Law 92-500) objective: "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."

All state surface waters have been designated as one of five classes: Lake Class, AA, A, B, and C. Each of these classes is defined by a set of characteristic uses that are protected by specific water quality criteria. The characteristic uses include, but are not limited to:

- domestic, industrial, and agricultural water supply;
- stock watering;
- salmonid and other fish migration, rearing, spawning, and harvesting;
- wildlife habitat;
- primary contact recreation, sport fishing, boating, and aesthetic enjoyment; and
- commerce and navigation.

The specific water quality criteria applied to the different classes include:

- fecal coliform;
- dissolved oxygen;
- total dissolved gas;
- temperature;
- pH;
- turbidity;
- toxic, radioactive, or deleterious material; and
- aesthetic values.

These uses and criteria make up the water quality standards for surface waters. They are listed in Chapter 173-201 of the WAC. In addition to criteria for conventional pollutants, the standards list criteria for many toxic substances and generally provide for protection of water quality against degradation.

Protection of water quality is also afforded by issuance of waste discharge permits for municipal and industrial wastewater treatment plants. The limits on various pollutants in a wastewater discharge are outlined in Chapter 173-221 WAC, and in U.S. Environmental Protection Agency wastewater discharge development documents. Violations of water quality criteria or waste discharge permit limits can lead to penalties.

### **1.3 Pollution**

Many types of pollutants threaten the aquatic environment. Pollutants such as pesticides, oil, industrial effluent, nuclear waste, and metals can be directly toxic to aquatic organisms. Other materials introduced into water, such as sewage, animal waste, and sawmill waste may not be directly toxic, but could overload the capacity of the receiving water to assimilate them, thereby creating toxic conditions (e.g., dissolved oxygen depletion). In addition, sewage and animal wastes present in amounts that produce no visible effect on the estuarine ecosystem may render

marine shellfish unsafe to eat and result in closure of commercial shellfish beds. Another type of pollution is the enrichment of water with nutrients (phosphates and nitrates) contained in detergents and fertilizers. Nutrients often stimulate plant growth, which may lead to reductions in dissolved oxygen or aesthetic impairment. Finally, certain pollutants such as DDT, dioxin, and some metals can bioconcentrate (accumulate within organisms directly from water) and/or bioaccumulate (accumulate within organisms via the food chain), and thus become potentially toxic to humans.

## SECTION 2 WATER QUALITY AND ECOLOGICAL CONCEPTS

### 2.1 The Physical Properties of Water

Webster's II New Riverside University Dictionary concisely defines water as:

Water n. 1. A clear, colorless, nearly odorless and tasteless liquid, H<sub>2</sub>O, the most widely used of all solvents and essential for most plant and animal life.

Wetzel (1983) describes water in chapter two of his book on limnology:

Water is the essence of life on earth, and totally dominates the chemical composition of all organisms. The ubiquity of water in biota as the fulcrum of biochemical metabolism rests on its unique physical and chemical properties.

The solvent properties of water enable it to dissolve minerals, gases, and organic material. The physical properties of water enable it to transport sediments and carry bacterial and viral contaminants. The chemical and physical properties of water naturally change at every stage of the hydrologic cycle. However, humans through activities such as urbanization, agriculture, forestry, mineral exploitation, and other land use can also change water's characteristics.

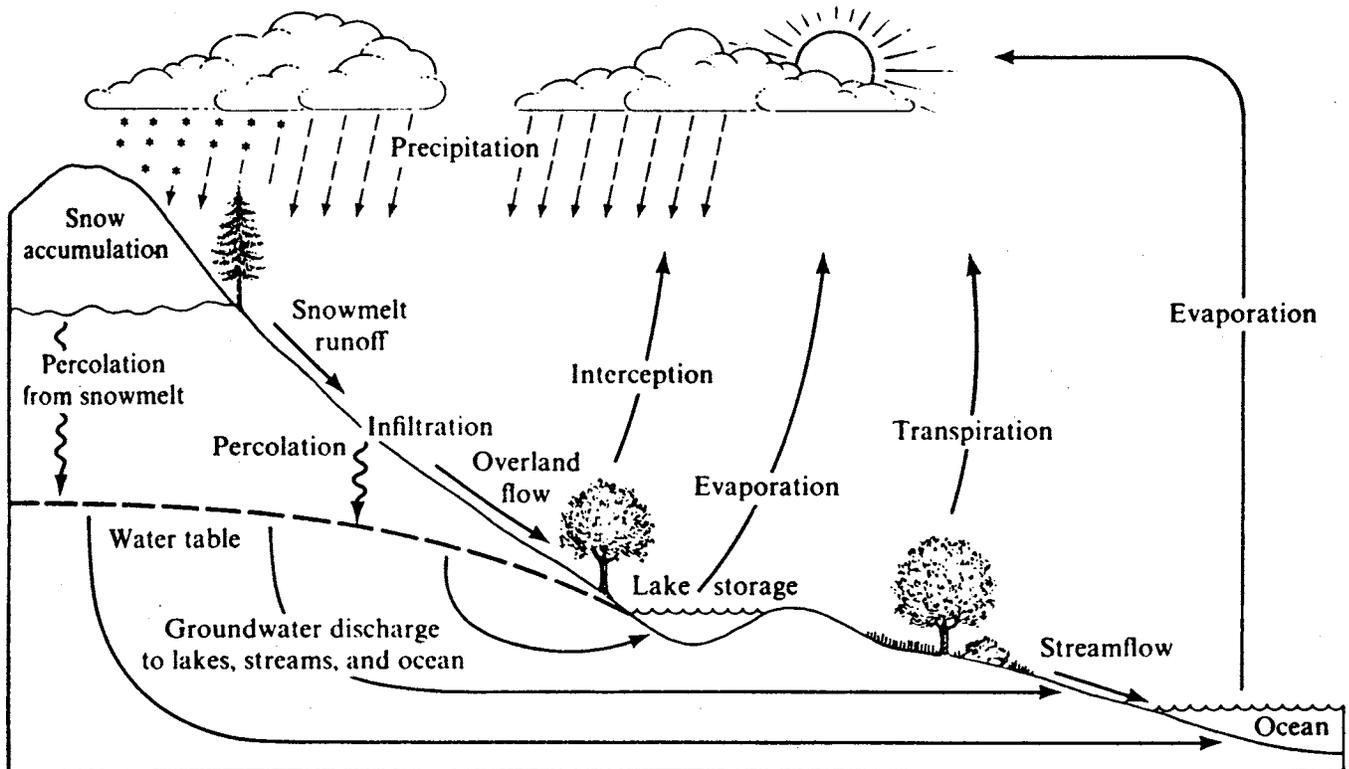
### 2.2 The Hydrologic Cycle

It is important for anyone working on water quality assessment issues to have an understanding of water movements and the processes that affect its physical and chemical characteristics as it moves from mountains to sea. The "hydrologic cycle" provides a conceptual framework for understanding these processes.

The hydrologic cycle (Figure 1) is driven by the sun and is described by Dunne and Leopold (1978) as simply ". . . the ways in which water moves around the earth . . ." They further note that ". . . during its endless circulation from ocean to atmosphere to earth and back to ocean, the water is stored temporarily in streams, lakes, the soil, or groundwater and becomes available for use."

A water "balance" can be determined for a waterbody by the equation: water input = water output  $\pm$  the amount stored. Inputs and outputs depend on the waterbody of interest. For example, if the waterbody is a lake, then inputs could be from direct precipitation, groundwater flow, and surface influents (including tributary streams and surface runoff); while outputs may be surface effluents (usually outlet streams), evaporation and seepage to groundwater.

Figure 1. Hydrologic Cycle (taken from Dunne and Leopold, 1978)



The water balance is an important tool in water quality assessment projects. It can be used to predict streamflow, water-table elevations, and lake water flux, and to phrase explicit questions about the environmental impact of proposed changes in land use (Dunne and Leopold, 1978).

During its circulation, water makes contact with soil and rock, is heated and cooled, and is used by flora and fauna. These processes change the chemical properties of water and thereby influence its suitability for different uses by humans (e.g., irrigation, drinking, industrial).

### 2.3 The Physical Attributes of Waterbodies

To a large extent, the physical attributes of a waterbody will determine the chemical and biological characteristics associated with it. For example, a shallow lake with a mud bottom will be warmer than a deeper one in the same area, and if sunlight can reach the bottom, it may have extensive growths of algae and macrophytes and support a variety of other organisms. In contrast, a deep lake which has steep sides and a rocky bottom may be relatively devoid of biota.

The following physical characteristics of waterbodies are important for understanding aquatic ecology and general water quality issues:

### Lakes and Reservoirs

Maximum length, maximum width or breadth, surface area, depth (maximum and mean), volume, shore line length, and elevation (Wetzel, 1983).

### Streams and Rivers

Width, depth, gradient (slope), bed materials, velocity, discharge (velocity x area of a cross section), and elevation (Resh and Rosenberg, 1984).

### Estuaries

Waves, tides, currents, intertidal substrate composition, shoreline slope, freshwater inputs, and sediment movements (Carefoot, 1977).

Each of these waterbodies are also affected by characteristics of the surrounding watershed. Therefore, in addition to watershed area it is important to understand local geology and its potential influence on water quality.

## **2.4 Surface Water Ecosystems**

Surface waters are complex and dynamic ecosystems. Surface waters include lakes, reservoirs, streams, rivers, and estuaries. Each type of surface water is different in hydrologic conditions and watershed influences, yet all have the ability to support aquatic life and generally share some common biological characteristics.

Surface water ecosystems support a variety of biological organisms with representatives from all five kingdoms (Monera, Protozoa, Fungi, Plantae, Animalia). Aquatic biota are influenced by habitable substrate, available food resources, competition with other organisms, presence of parasitism, and incidence of disease. Physical and chemical characteristics of a waterbody are also determinants of population presence or absence. The absence of a population may indicate that environmental conditions were unsuitable in a particular aquatic ecosystem.

The "ecosystem" defines all organisms living in a community and the associated environmental factors (Pennak, 1964; Ricklefs, 1979; Krebs, 1985). Freshwater ecosystems may be whole lakes or small unique sloughs on large reservoirs. The size of an aquatic ecosystem is defined by the extent of interrelatedness among organisms and environmental conditions that influence the biological community.

Each biological population maintains a function within the ecosystem in one of four trophic levels; either as a primary producer, primary consumer, secondary consumer, or tertiary

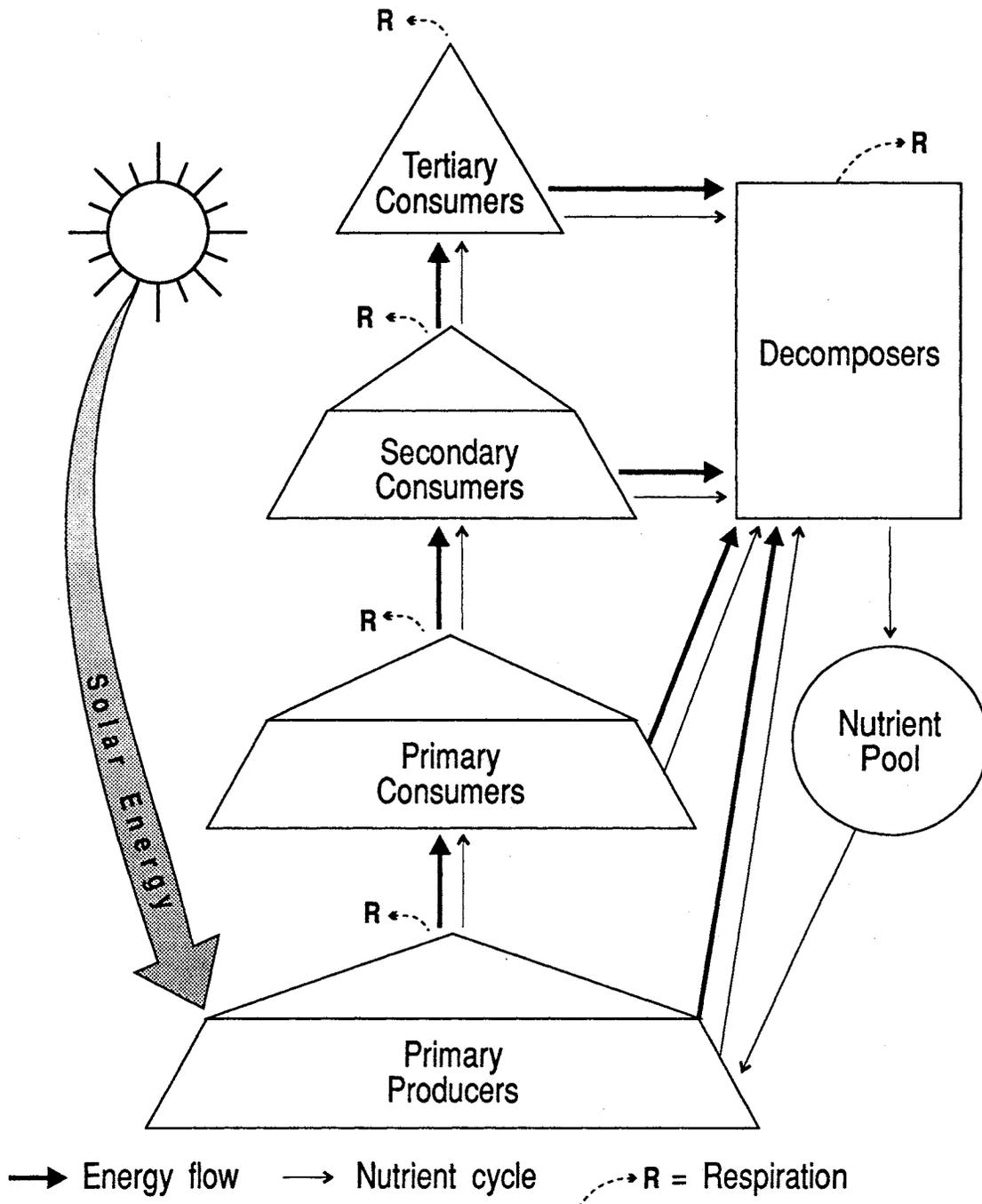
consumer (Mitchell *et al.*, 1988) (Figure 2). The primary producers provide most of the autochthonous input to a waterbody; meaning that organisms such as aquatic macrophytes, periphyton, and phytoplankton are sustained by solar energy and dissolved nutrients and which in turn provide a food base to other functional levels such as the primary consumers and decomposers. Allochthonous inputs to a waterbody are both living and dead organic material that enter the aquatic system from outside sources. The most common examples of allochthonous input are leaves and woody fragments from riparian vegetation. All four trophic levels described in Figure 2 contribute directly to the food base for the decomposers. The decomposers process all detrital material (organic matter) and contribute to a nutrient pool that is used by the primary producers. The four trophic levels directly contribute energy and nutrients to the decomposers who consequently process useable nutrients to complete the nutrient cycle. Energy flow, however, is non-cyclic and originates solely from organisms representing the primary producer trophic level.

Surface water biological communities are comprised of planktonic organisms, microbial communities (including fungi), macrophytes, protozoans, benthic invertebrates, periphyton, and vertebrates (i.e., fishes, amphibians, reptiles). Amphibians and reptiles are not always traditionally studied as components of aquatic systems possibly due to their partial residence in the terrestrial environment. Each of the aquatic groups are comprised of numerous taxa that maintain their own communities as well as sustain higher trophic level taxa.

Biological information from the aquatic environment is an important component to survey while conducting environmental investigations. Diversity is a key attribute of any aquatic system and an indication of a waterbody's health. In a polluted system, diversity will decrease (fewer taxa) and one or just a few taxa will dominate the ecosystem. Another indication of aquatic health is the mixture of partilular genera; in an unhealthy system some genera will become rare or even disappear while others become more common. However, one should be aware that there are many factors which influence biological community structure and only rigorous data collection and analysis can discern differences due to pollution and those due to natural variability.

The sensitive components of an ecosystem can be determined by examining water chemistry, physical habitat, and biological information. Each ecosystem is different and may best be protected from anthropogenic sources of pollution by identifying those indicators (chemical, physical, biological) that are most sensitive to a particular introduced pollutant. This method allows for efficient protection of an ecosystem and provides for adequate preservation of a waterbody's beneficial uses.

Figure 2. The relationship between energy flow and nutrient cycling (adapted from Mitchell *et al.*, 1988)



## 2.5 Surface Water Quality

In this section, a list of major water quality parameters which may be encountered in the aquatic environment and affected by human activity are presented in very general terms. General classes of toxic substances found in aquatic environments are also presented (e.g., metals, pesticides). The constituents and physical attributes of water presented here affect its use for drinking, irrigation, industry, and recreation, and its suitability for aquatic organisms. The following texts were used as references in preparing this section:

- Standard Methods of Water and Wastewater (APHA *et al.*, 1989)
- Water Chemistry (Snoeyink and Jenkins, 1980)
- Aquatic Chemistry (Stumm and Morgan, 1981)
- Limnology (Wetzel, 1983)

### Alkalinity

Alkalinity is a measure of a water's capacity to neutralize an acid; that is, the ability of the water to resist changes in pH by neutralizing acidic inputs. It indicates the presence of carbonates, bicarbonates, hydroxides, and other less significant substances. The higher the alkalinity, the greater the ability of the water to neutralize acids and maintain its pH.

Alkalinity is measured by adding a known concentration of acid to a volume of water and monitoring pH change. It is usually expressed as an equivalent of calcium carbonate ( $\text{CaCO}_3$ ). Alkalinity rarely exceeds 500 mg/L in natural surface waters. In Washington State, lakes and streams on the west side of the Cascades rarely exceed 50 mg/L, and levels on the east side usually don't exceed 150 mg/L. Waters with high alkalinity are undesirable because of the associated excessive hardness (see hardness) or high levels of sodium salts. When waters with high alkalinity are boiled, deposits may be formed or unpleasant tastes created. Waters with very low alkalinity corrode pipes. Lakes and streams with low alkalinity are susceptible to acid deposition (acid rain) because they are unable to neutralize acid inputs.

### Bacteria

Bacteria, viruses, protozoa, and worms are present in the aquatic environment. Water-borne and water-associated diseases can be caused by these organisms. Because of technical difficulty and expense of directly measuring the presence of pathogens, the safety of water is usually determined indirectly by monitoring the presence of fecal coliform bacteria. Fecal coliform bacteria are intestinal bacteria found in warm blooded animals and thus serve as indicators of enteric wastes. In water quality monitoring they act as a surrogate for measuring the potential presence of entero-bacterial pathogens.

Fecal coliform concentrations are expressed as the number of bacteria colonies per 100 mL of water. High counts of fecal coliform bacteria indicate the presence of animal waste, which may contain pathogenic organisms. Such waters are unsuitable for human consumption, recreation,

and some industrial processes. Filter feeding organisms, such as shellfish, concentrate bacteria in their digestive tracts. Thus, fecal coliform standards for marine water are stricter than those for freshwater. Excessive fecal coliform levels in marine waters may mean contamination of shellfish beds and resultant closure of this important resource-based industry.

## **Carbon**

The major buffer system in natural waters is the carbonate-bicarbonate system (reference alkalinity). As a buffer, the carbonate system helps maintain a constant pH by binding acids or bases that might enter the water (e.g., through acid rain). The bicarbonate ions also provide carbon dioxide for the photosynthetic process by which plants synthesize organic compounds from carbon and water in the presence of sunlight. During photosynthesis carbon dioxide is combined or fixed with other elements to form six-carbon sugars. These fixed carbons (organic carbon) are the backbone of life and constitute a large percentage of organic material.

There are two important water quality measures of carbon: total inorganic carbon and total organic carbon. Total inorganic carbon is a measure of the sum of carbonates, bicarbonates, and carbonic acid. Total organic carbon provides a measure of both dissolved and particulate organic carbon. Both inorganic and organic carbon are usually expressed as mg/L.

The decomposition of organic material removes oxygen from the water. Excessive amounts of organic carbon can lower dissolved oxygen to concentrations below that required by aquatic organisms. The presence of high concentrations of inorganic carbon is also undesirable because carbonates can combine with hardness components to form scale on metal surfaces.

## **Color**

The color of water is attributed to the presence of organic and inorganic material. Different materials absorb and reflect various light frequencies and impart color. Color is measured according to a scale which compares the color of the water sample with a series of standard chemical solutions. Results are expressed as color units (e.g., platinum-cobalt units). Any visible color in water is usually objectionable. Strongly colored waters are usually undesirable for aesthetic reasons. In addition, the production of paper and other goods may be affected by a highly colored water supply.

## **Conductivity**

Conductivity is a measure of the ability of water to conduct electricity. The passage of current through water is a function of the total number of ions present. As ions increase, conductivity increases. Conductivity reflects the total concentration of ions dissolved in the water and can be used to indicate hardness (reference hardness). Conductance is measured as the inverse of resistance by using a conductivity meter and correcting for temperature. Results are reported as microsiemens per centimeter ( $\mu\text{S}$ ) or micromhos per centimeter ( $\mu\text{mhos/cm}$ ). Distilled water generally has a specific conductance of 0.5 to 4  $\mu\text{mhos/cm}$ . Most surface waters in the U.S.

are between 50 and 1,500  $\mu\text{mhos/cm}$  (Snoeyink and Jenkins, 1980). The conductivity of seawater is usually expressed in terms of salinity (see salinity).

### Hardness

Hardness is a measure of dissolved minerals such as aluminum, calcium, iron, and magnesium, although it is mostly determined by the sum of only calcium and magnesium. Water hardness was historically a measure of the capacity of water to precipitate soap (APHA *et al.*, 1989). Water hardness still can be related to soap because the harder the water, the more difficult it is to get lather from soap.

The constituents of hardness (e.g., calcium) are usually measured by Atomic Absorption (AA) spectroscopy or the EDTA titrimetric method, and expressed in mg/L. Water with a high hardness may be undesirable for both industrial and domestic uses. Hard water promotes the formation of scale on boilers and pipes, which can adversely affect its use by industry. Hard water also necessitates increased use of soaps and detergents.

### Metals

Metals and metalloids (e.g., silicon, arsenic) are elements that are distributed naturally in the environment by both geologic and biologic processes. However, anthropogenic activity since the beginning of the industrial age has had the undesirable effect of increasing the concentration of metals in the environment. Metals in water can be toxic to aquatic life and may make water unfit for human consumption. Metals may also enter the food chain through bioconcentration and bioaccumulation and thereby become deleterious to humans.

The Environmental Protection Agency (EPA, 1986) has established aquatic life criteria for the following metals and metalloids: antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, and zinc. These metals are usually measured by Atomic Absorption (AA) spectroscopy as total recoverable or dissolved metal and reported as mg/L or  $\mu\text{g/L}$ . The toxicity and corresponding concern for these metals in aquatic systems is variable. Some, like cadmium, are highly toxic while others, like iron, usually only has "nuisance" effects (e.g., discolor clothes). In the aquatic environment, sediments may also contain elevated concentrations of metals. For a more in-depth discussion of the toxicity of individual metals, see EPA (1986), Quality Criteria for Water.

### Nitrogen

Nitrogen is an element that is ubiquitous in the biosphere. There are a number of important chemical forms of nitrogen in water including dissolved atmospheric molecular nitrogen ( $\text{N}_2$ ), organic compounds (e.g., amino acids, proteins, and humic compounds), ammonia ( $\text{NH}_3$ ) and ammonium ( $\text{NH}_4^+$ ), nitrite ( $\text{NO}_2^-$ ), and nitrate ( $\text{NO}_3^-$ ). A biological process called nitrogen fixation is carried out by plant-bacteria symbiosis. Nitrogen fixation transforms molecular nitrogen into ammonia and ammonium ions. Other bacteria convert ammonia to nitrite and

nitrite to nitrate in a process known as nitrification. Still other bacteria process nitrates into molecular nitrogen, which is released to the atmosphere in a process known as denitrification.

Nitrogen and its compounds are present in most plant and animal materials and consequently are present in decaying matter (organic detritus, sewage). The nitrogen bound in organic material is referred to as organic nitrogen and can be provided to a waterbody by both autochthonous and allochthonous inputs. In addition to the inorganic nitrogen compounds produced during nitrogen fixation, another source of inorganic nitrogen to the aquatic environment can be from nitrogen fertilizers which are used in agriculture to stimulate plant growth. Waters draining from agricultural areas using fertilizers may contain high levels of nitrate.

Since nitrogen is an essential plant nutrient, it contributes to the fertility of water. As an essential component of amino acids, proteins, nucleotides, nucleic acids, chlorophyll, and coenzymes, nitrogen has been found to be a growth-limiting factor in some waters (usually marine). Ammonia, nitrate and nitrite can promote the growth of unwanted algae and plants.

Nitrogen is usually measured colorimetrically in water as: Total Persulfate Nitrogen (TPN), which measures all organic and inorganic nitrogen; Nitrate-Nitrite Nitrogen, which measures total oxidized nitrogen; and Ammonia Nitrogen, which measures the nitrogen produced largely by breakdown of organic material and hydrolysis of urea. Total Kjeldahl Nitrogen (TKN) is also often measured, but only measures ammonia and organic nitrogen. Ecology recommends using TPN and not TKN for total nitrogen, because TPN has been shown to be a more precise and accurate measure of total nitrogen (Smartt *et al.*, 1981). These forms of nitrogen are usually reported in mg/L. The consumption of waters with high nitrate concentrations (10 mg/L) can be detrimental to humans by decreasing the oxygen-carrying capacity of the blood (Klaassen *et al.*, 1986). Ammonia in large quantities is toxic to aquatic life and levels should generally not exceed 0.02 mg/L in freshwater.

## **Nutrients**

(see Nitrogen and Phosphorus)

Plants require mineral elements for many different biological functions. Some minerals are indispensable components of enzyme systems, cell membrane structure and function, and essential biological molecules. These minerals are usually listed as macronutrients or micronutrients which simply refers to the amount required. Macronutrients include nitrogen, phosphorus, potassium, calcium, magnesium or sulfur and micronutrients include iron, chlorine, copper manganese, zinc, molybdenum, boron, cobalt and sodium (Curtis, 1979). Carbon, hydrogen, and oxygen are also important elements in the biosphere, but they are not usually considered as nutrients.

Most nutrients are in adequate supply in the aquatic environment, however, it has been found that some nutrients can be the limiting factor in phytoplankton growth. Nitrogen and phosphorus are of major importance in primary production and are most often cited as limiting factors for growth.

## **Odor**

Odor and taste of water are closely associated. Neither aspect assesses the safety of drinking water, but both affect its use. Odor can be measured; however, in water quality it is usually only considered an attribute which should not be offensive to the consumer or user. Waters with a strong odor are not considered usable for public drinking.

## **Oxygen**

Oxygen is one of the most important gases dissolved in water. The amount of oxygen dissolved in water varies with atmospheric pressure, reaeration rate, photosynthesis, plant and animal respiration, sediment oxygen demand, biochemical oxygen demand, nitrification, salinity, and temperature. The concentration of dissolved oxygen often fluctuates from day to night (diurnally), as well as seasonally. These fluctuations are usually due to changes in water temperature and photosynthesis-respiration activity. The decomposition of organic material can also reduce dissolved oxygen levels.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are measures of the amount of oxygen required to oxidize organic matter by aerobic microbial decomposition and chemical means, respectively. BOD tests include the oxygen demand of nitrogenous as well as carbonaceous compounds. BOD and COD are not pollutants, but measures of the relative potential pollution of organic and inorganic material in the water. Although both BOD and COD indicate a potential for reducing the dissolved oxygen content in water, there is not necessarily a correlation between these two measures.

Dissolved Oxygen (D.O.) is measured by two common methods: the Winkler (chemical) method and the D.O. probe (electrometric) method. Results are reported as mg/L. Adequate D.O. levels are essential to support respiration of aquatic organisms. D.O. requirements vary greatly between species and are dependent on temperature.

## **Pesticides**

Pesticides are chemical compounds formulated to control pests (usually insects, weeds, or fungi). The term pesticide includes insecticides, herbicides and fungicides. Pesticides have both beneficial and detrimental characteristics and are considered environmental contaminants. Ideally their action would be injurious only to specific target organisms. Unfortunately, most of the chemicals used in pesticides are generally toxic to many nontarget organisms, including humans. Pesticides like DDT accumulate in the food web, thereby possibly increasing the deleterious effects on higher organisms, including humans. Water quality assessment of pesticide concentrations should not be based solely on concentrations found in the water, because in an aquatic environment substantial amounts also may be present in sediments and animal tissue.

The Environmental Protection Agency (EPA, 1986) has established aquatic life criteria for some pesticides or compounds used in pesticides. Pesticides are measured by Gas Chromatography (GC) and reported as  $\mu\text{g/L}$  or ppb (parts per billion).

## **pH**

The expression "pH" stands for "potential of hydrogen" and is a measure of hydrogen ion concentration. pH indicates the balance between acids and bases in water. Degrees of acidity are defined by the logarithmic pH scale which has values from 0 to 14. At a neutral pH (7), the concentration of hydrogen (acid) ions equals the hydroxide (base) ions. Values less than 7 are considered acidic and more than 7 basic. Natural fresh waters can range in pH from 4 to 9, but most are between 6 and 8. In seawater, pH ranges from 8.0 to 8.3. pH is controlled by alkalinity, which is usually dominated by the inorganic carbon system (bicarbonate-carbonate) (reference alkalinity). pH is measured electrically with a pH meter, glass electrode, and reference electrode, and reported in standard units of the pH scale.

The pH of water is important in determining chemical and biological characteristics. It affects chemical equilibria, which in turn affect the solubility of trace elements and availability of nutrients. The solubility and resultant toxicity of metals such as cadmium, lead, copper, and zinc are dramatically affected by pH. The pH of drinking water supplies is adjusted to control corrosion in pipes. Industrial users such as paper bleaching, brewing, and electro-plating also need to control their water pH.

## **Phosphorus**

Phosphorus is an essential plant nutrient and may be a limiting factor for plant growth in freshwater. In comparison to other major nutritional and structural components for biota, phosphorus is rarely found in significant concentrations in surface waters for two reasons: (1) there is only a relatively small amount available in the hydrosphere, and (2) what is available is actively taken up by plants. Phosphorus can occur in numerous organic or inorganic forms, and can be present in water as a dissolved or particulate species. In water, phosphorus is continually changing between organically bound forms and oxidized inorganic forms due to the processes of decomposition and synthesis.

Phosphorus is usually measured colorimetrically in water as Total Phosphorus (TP), which measures both suspended and dissolved inorganic and organic phosphorus, and Ortho-phosphate or Soluble Reactive Phosphorus (SRP), which measures only dissolved phosphorus. Phosphorus is usually reported as mg/L. The phosphorus content of detergents and phosphorus concentrations in sewage plant discharges are regulated to reduce eutrophication of waterbodies. Phosphorus concentrations  $>0.10$  mg/L in flowing water and 0.025 mg/L in lakes and reservoirs may stimulate algal growth (EPA, 1986).

## **Pollutants, Conventional vs. Toxic (Priority Pollutants)**

Many of the parameters which determine water's chemical characteristics are classified as "conventional" pollutants. These parameters, such as nutrients, temperature, and total suspended solids, are present even in pristine waters and are important for biological processes. However, through the activities of humans (e.g., agriculture, industry), they can increase to a point beyond the capacity of a waterbody to assimilate them, and thus become detrimental to aquatic life. In contrast, "toxic" pollutants are usually not found in appreciable amounts in nonpolluted surface waters. Toxic substances include both synthetic chemicals (e.g., pesticides, polychlorinated biphenyls) and natural substances (e.g., metals, petroleum).

The term "priority pollutants" refers to a subset of toxic pollutants that includes the following categories and number of individual compounds (in parentheses): organic acid extractable compounds (15), organic base-neutral extractable compounds (45), organochlorine pesticides (18), polychlorinated biphenyls (PCBs) (7), volatile organic compounds (38), metals (13), and cyanide (1). The 137 compounds in these categories are classified by EPA as hazardous substances in either water, sediment, sludge, soil, or tissue samples and are listed in Ecology's Laboratory Users Manual (Huntamer and Hyre, 1991) under "priority pollutant scan."

## **Salinity**

Salinity is a measure of the dissolved salt content in a volume of water. Salinity is important in determining the density of sea water which drives ocean currents. It also determines osmotic pressure, which affects the geographic range of particular marine organisms. Theoretically, salinity is defined as the total amount of salts in grams per kilogram (g/kg) of seawater, or parts per thousand (ppt or o/oo), when all the carbonate has been converted to oxide, all the iodine and bromine have been replaced by chlorine, and all organic matter has been completely oxidized (Duxbury, 1971).

Salinity is never routinely measured according to the definition. Since 1960, most oceanic salinity measurements have been made by measuring temperature compensated conductivity (Knauss, 1978). Normally, salinity is measured in o/oo with a salinometer (modified conductivity meter). The normal salinity of sea water is 35 o/oo, but because of freshwater inputs in estuaries the surface salinities are usually less than this value. Salinity can be used in estuaries to trace the horizontal and vertical mixing of freshwater inputs.

## **Solids, Total Suspended (TSS)**

Total Suspended Solids are the portion of solid organic and inorganic material that is retained by a filter. Total Dissolved Solids are the portion in water that passes through a filter. TSS is simply a relative measure of how much suspended material is carried in water.

TSS is measured by filtering a known volume of water through a filter. The residue retained on the filter is evaporated to dryness, weighed and reported as mg/L. High TSS levels can decrease the aesthetic value of water for drinking, swimming, or bathing, and reduce light transmission, which can lead to reduced primary production. In addition, high TSS may cause stress to benthic filter-feeding organisms and fish eggs in streams, and reduce available habitat. Contaminants can adsorb to solids that are washed into a receiving water, thus increasing their concentration in the water. High silt concentrations may also reduce fecal coliform die off partly because of adsorption to particles. Sediments can fill lakes and reservoirs and other water impoundments.

### **Temperature**

Temperature may be one of the most important variables of water. Since most aquatic organisms are "cold-blooded," their metabolism is controlled by water temperature. The temperature of water regulates the respiration, distribution, behavior, movement, feeding rate, growth, and reproduction of aquatic organisms.

Temperature is usually measured with a mercury thermometer and reported as degrees Celsius ( $^{\circ}\text{C}$ ). Changes in water temperature can change the rate of biodegradation of organic matter; increased temperature accelerates biodegradation, which increases the demand for dissolved oxygen. As temperature increases, oxygen also becomes less soluble in water, which can lead to oxygen depression. This attribute of water can lead to problems for aquatic organisms, because while warmer water holds less oxygen, respiration (metabolic) demand for oxygen increases with temperature. Changes in temperature can also change biological community composition and diminish the ability of organisms to withstand pathogens and toxic substances.

### **Turbidity**

Turbidity is a measure of the clarity of water. It is a result of light being scattered and absorbed rather than transmitted through water. Turbidity is caused by suspended material in the water such as clay, silt, organic matter, and small biological organisms.

Turbidity is measured in a nephelometer relative to standard samples composed of formazin suspensions. Turbidity is reported in nephelometric turbidity units (NTU) which are based on the amount of light that is scattered by the standard formazin samples. Turbidity is an important index of water quality for food and beverage industries. Turbid waters interfere with disinfection in water treatment plants. High turbidity can reduce photosynthetic activity, which can lead to reduction in a water's ability to support all trophic levels. Some studies suggest that die off of fecal coliform is reduced in highly turbid waters because of the attenuation of ultraviolet radiation.

SECTION 3  
PLANNING AND STUDY DESIGN

**3.1 Planning a Water Quality Assessment Program**

Data may be collected to monitor or to characterize ambient conditions in aquatic systems. The purpose for collecting data may be to assess the impact of controls on the containment of pollutants, to detect long-term trends, to measure compliance with ambient standards, to provide a summary of average or extreme conditions, or to establish baseline data for future reference.

When planning a water quality monitoring study, one must plan the major tasks required to conduct and complete a successful study. The following is a list of major steps, modified from those presented by Gilbert (1987), that should be addressed when undertaking a monitoring program:

1. Develop a problem statement for the general area of concern. Example:

Statement of Problem

High levels of fecal coliform and nutrients are routinely found in streams draining the Anywhere Creek watershed. The major contributor to the elevated concentrations is suspected to be poor dairy farming practices.

Note: Information on the background or history of the problem is also helpful in providing focus for a project. For this example, what are the traditional farming practices, what health issues have been raised, what other pollution sources are suspect, etc.

2. Clearly define study objectives, including all assumptions and hypotheses. Example:

Specific Objectives of the Project

- a. Determine fecal coliform, nutrients, TSS, temperature, and conductivity values on stream reaches above and below the major impact areas of the dairy farms.
- b. Determine loads to the stream for each parameter and analyze for relationships between variables.
- c. Determine the number of water quality criteria exceedances for each variable from dairy farm impact areas.
- d. Relate the exceedances to impairment of water usage under state water quality standards.

3. Define areas of interest, (e.g., stream reach, lake, estuary, watershed).
4. Collect available background information on the physical characteristics of the study area, weather patterns, groundwater influences, and any other information that might help in the sampling design or interpretation of collected data.
5. Conduct a reconnaissance visit to the study site. Bring a USGS topographic (topo) map of the area and note major features and possible study influences (e.g., manure spreader used within the watershed). We recommend a 7-1/2 minute quad map (1:24,000 scale). Topo's are available at most outdoor sporting goods stores.
6. Examine any existing data or conduct a pilot study to obtain information on possible concentration ranges and variability to be encountered.
7. Develop a sampling design that will provide representative data from the study area. Define (a) the types and number of samples to be collected, (b) the sampling frequency and station locations, and (c) the field measurements and collection procedures needed to meet objectives and hypotheses of study.
8. Develop a quality assurance and quality control program for all aspects of the study including: field sample collection, sample processing, laboratory analysis, data validation, data entry and management, statistical analyses, and data interpretation and reporting (see QA/QC section).
9. Develop a data management plan, including field and laboratory data forms and a data management system (Reference Section 8 - Reporting Considerations).
10. Conduct the study according to the established protocols and quality assurance/quality control plans.
11. Summarize relevant information and evaluate hypotheses.
12. Prepare a report summarizing steps 1-11 above, including an evaluation of whether study objectives have been met.

If a consultant is going to be selected to develop and implement the monitoring plan, the following criteria should be considered before awarding a contract to any candidate: experience in conducting water quality programs; expertise in the areas of environmental science (environmental engineering, limnology, biology, hydrology, statistics); and management and logistic capabilities.

### 3.2 Quality Assurance/Quality Control (QA/QC)

Data used for making decisions that may affect individuals, communities, industry, or governments must be of sufficient accuracy and precision to minimize the possibility of misinterpretation. Although measurement data are only estimates of the true value, QC procedures can be incorporated into the sampling, analysis, and reporting elements of a project to provide an estimate of the accuracy of the data. A QA program is used in environmental studies to ensure that reliable data are collected and appropriately maintained in a database.

Quality Control activities are designed to ensure that the measurement process is capable of meeting data quality objectives for accuracy (i.e., precision and bias). Quality control procedures are applied to maintain statistical control of the measurement process which includes sample collection and instrument calibration and analysis. Quality control procedures include the use of blanks, replicates, spikes, and check standards (e.g., reference materials).

Whereas QC is specific to the measurement process, QA is the overall integrated program for assuring the reliability of data. Quality assurance involves all aspects of sample collection, analysis, data management, and reporting. Quality assurance is achieved by developing a specific QA project plan. Other QA activities include:

1. Selection of an accredited analytical laboratory.
2. Developing Standard Operating Procedures (SOP).
3. Training field sampling crews.
4. Establishing a communication scheme between management, sampling, and analytical personnel.
5. Conducting on-site field and laboratory inspections.
6. Collecting and analyzing different types of QC samples to quantify data quality.
7. Defining data management procedures (Reference Section 8 - Reporting Considerations).

A QA plan must be completed before sampling. Anyone interested in developing an appropriate QA plan should reference Ecology (1991) Guidelines and Specifications for Preparing Quality Assurance Project Plans. This document discusses the following major plan elements:

1. Title Page.
2. Table of Contents.
3. Project Description.
4. Project Organization and Responsibility.
5. Data Quality Objectives.
6. Sampling Procedures.
7. Analytical Procedures.
8. Data Reduction, Review and Reporting.
9. Quality Control Procedures.
10. Performance and Systems Audits.
11. Preventive Maintenance.

12. Data Assessment Procedures.
13. Corrective Action.
14. Quality Assurance Reports.

### **3.3 Designing a Water Quality Assessment Project**

Numerous problems must be faced when developing an appropriate water quality assessment design. The major problem is to define the environmental "population" of interest. The first three steps listed in Section 3.1 (Planning a Water Quality Assessment Program) must be completed before committing to the monitoring aspects of the study. Completion of these steps will assist in defining the population of interest. Unless the population is clearly defined and related to the study objectives, the collected data may not be useful in addressing the issues of concern.

The identification of any existing water quality problems is the first step in developing a sampling design. Once a problem is identified, a set of explicit objectives should be developed for the sampling program. These objectives can then be prioritized based on the resources available. Afterwards, the sampling design can be developed.

According to Gaugush (1987) a sampling design must provide answers to four fundamental questions:

- a. What to sample?
- b. How many samples?
- c. Where to sample?
- d. When to sample?

The answer to the first question is the list of parameters to be measured based on the problem statement and specific objectives. If the problem statement and objectives are properly developed, then the parameters of interest will be fairly obvious. (The planning check-list shown in Appendix A may be helpful in asking the right questions about parameters of interest.) Ideally, the temporal and spatial allocation of samples would only be based on the desire to meet the stated program objectives. However, the number, area, and frequency of sampling are often affected by the size of budget, personnel availability, and other logistic considerations.

In order to determine the best allocation of samples, it is advisable to seek the technical services of one who understands complex water quality assessment issues. There are a number of points that must be considered in this aspect of a project: spatial and temporal variability of the parameters of interest, hydrologic conditions, and other physical variables that might affect the results. An in-depth discussion of these issues is beyond the scope of this manual, however, the following subsection lists some of the major considerations for designing a water quality assessment project.

### **3.3.1 Field Survey Design**

Once the goals and objectives of the project have been set, designing an appropriate survey can begin. The goal of any survey design is to efficiently use resources to get the necessary data at the lowest cost and effort. The more information gathered, and greater level of understanding obtained about the parameters and survey area during the proposal phase, the more efficient the survey design will be.

General guidelines for designing a survey are as follows:

1. Establish what limits you have on resources:
  - Budget.
  - Equipment.
  - Staff (who can help? what are their levels of experience? when are they available?).
  - Field time.
  - Data evaluation deadlines.
  
2. Set the physical boundaries of the study area if these were not firmly set when the scope was agreed to, and try to clearly isolate as many sources as possible. Try to keep the residual, or "unknown source" category as small as possible.
  - Define the upstream limit of the study area or a control station. Establish a site with homogenous water quality outside the influence of any of the target discharges.
  - Define the limits on source identification depending on the objectives. For tributaries either put a site at the mouth, or one at the mouth and one upstream at a control station above the area of concern. For point sources, establish a site at the final effluent unless efficiency data or data on a source of contaminants within the point source collection system are needed. Nonpoint sources can be defined by careful station placement or can be included in residual terms. Ground water inputs can be estimated by difference, measured by well sampling, or included in a residual term. Precipitation inputs can be estimated from local weather station data, measured on site, or included in a residual term. Instream or autochthonous inputs (like sediments, algae, macrophytes, bacteria and aquatic biota) which cause changes in water quality can be measured, estimated, or included in a residual term.
  - Define the downstream limit where your measurements and data analyses/evaluations end.
  
3. Set the survey confidence limits:
  - Will an estimate based on a few samples meet the objectives and be defensible?

- What level of confidence in the data and your interpretation of the conditions will be gained from adding stations, samples, parameters, or better detection limits; or increasing the duration of survey?
  - Which element of your analysis has the greatest degree of error? Does the level of precision you want for other elements make sense relative to this margin of error? For example, if you are determining phosphorus loading, it doesn't make sense to measure discharge by timing a stick floating downstream, and then require high precision in the analytical data.
4. Mass balance calculations are an important tool for evaluating contaminant sources, transport mechanisms, and sinks (e.g., a water balance equation):

$$Q_{\text{inflow}} + Q_{\text{tributary}} - Q_{\text{evaporation}} - Q_{\text{diversion}} \pm Q_{\text{groundwater}} = Q_{\text{outflow}}$$

The design of the survey should ensure mass balance data are available and are collected where they will accurately represent the element of the equation. Sometimes lateral or vertical stratification of sampling will be necessary to achieve the desired accuracy (see 7, below). Other situations call for temporal stratification at a single site, or good understanding of time of travel within a survey area (see 6, below).

Usually mass balance calculations are set up for several parameters. Calculation proceeds from doing the water balance, to a conservative parameter balance (e.g., chlorides or solids), to a more complex parameter (e.g., metals or nutrients) balance. The investigator must take these interactions into consideration during the design phase, and account for each higher level of complexity in the calculation.

5. The investigator must have a clear understanding of potential transport mechanisms and sinks for a particular contaminant to place sampling stations, make parameter lists, decide which media to collect, and arrange proper collection schedules. For example, for several toxic substances it is important to sample suspended sediment and organic carbon concentrations to accurately estimate the fate of the toxic material. In addition, sediments are often the only medium where some toxicants can be detected; if so, the sediments should be sampled.

The investigator must also be knowledgeable about ancillary parameters necessary to evaluate a contaminant of interest against a criterion or standard. For example, to evaluate ammonia concentrations against water quality criteria, temperature and pH values are needed; hardness values are required for evaluation of some metals; sediment analyses need grain size, TOC, and percent solids, etc.

There are several general references, case studies, and journal articles that can be used as examples of successful design strategies. These are listed in the Annotated Bibliography and Literature Cited sections.

6. The general schedule of the field work and the specific spatial and temporal layout of sampling stations within the study area are important elements to address. The reader can consult texts discussing sampling design if he/she is unfamiliar with the concepts outlined below (Gilbert, 1987; Reckhow and Chapra, 1983; Hammer and MacKichan, 1981; and Sanders *et al.*, 1983).

The timing of sample collection should be scheduled to best characterize the water quality problem. Specifically, the critical period needs to be defined. Water quality impacts from municipal point sources are often most severe while the receiving water is at low flow (e.g., the 7-day, ten year (7Q10) low flow event). Some industrial point sources or municipal point sources with a large industrial input may have a greater impact on receiving waters at another time of the year. For instance, food processors discharge at harvest time when flows are slightly higher than the 7Q10. Nonpoint source impacts are generally more sporadic, and may be related to: wet weather, storm events, or certain activities like irrigation, fertilizing, and harvest seasons, construction schedules, or the manure spreading/storing period. Seasonally stratified sampling designs are useful when a study area has a mix of point and nonpoint source impacts. With seasonal designs, samples are collected at two or more periods within the year to address different types of problems.

There are several sampling designs to choose from once the general sampling period is established. A routine sampling schedule (same site at same time of day, at set intervals) may be appropriate for basic water quality characterization or long-term trends. Changes between sample runs can be compared, but the diurnal variability in parameter concentrations at a specific site may be missed. A random sampling schedule can address station variability, but may not be effective in describing critical events, or following qualitative changes as a block of water moves downstream, or seaward. Specific event (rainstorm, treatment plant overloads, 7Q10, lowest mean tide, etc.) monitoring is important in some situations. It can also be difficult because sometimes the investigator cannot predict when the events will occur. Usually a "warning system" of local observers has to be created, and a high level of organization, readiness, and coordination must be maintained.

The investigator needs to decide how samples will be collected over the survey period. Grab, continuous, composite, and sequential sampling methods have been used by Ecology.

Grab samples taken once or twice at selected stations are the most common method used. They can usually be collected quickly, with minimal equipment and processing needs. However, they may be less representative of the station, and require careful planning and forethought before collection (see below).

Continuous monitoring using data-logging and probe devices is usually limited (by the technology available) to a few parameters, (e.g., discharge, temperature, pH, dissolved oxygen (D.O.), and conductivity). Monitoring in this manner can yield valuable

information on diurnal cycles. Equipment security, cost, maintenance, and calibration are the major difficulties with using data-loggers for monitoring.

Automatic composite and sequential samplers can be used to monitor parameters that once collected, are stable over the sampling/storage period. Both types of samplers can be set to collect on a time interval or flow-paced basis. Compositor samples provide good average concentration. Sequential samples can be analyzed individually, or groups can be composited. Sequential samples can provide excellent information on changes in concentration, especially over a storm event or industrial waste process cycle. Manual sequential sample collection over a 24-hour period has also been performed. More personnel are required for manual compositing than for most surveys, but a larger variety of samples can be collected and analyzed. Sequential samplers generate more samples per survey and therefore increase costs.

7. Obtaining a representative sample from a waterbody requires that the investigator understand the interaction of physical factors existing at the station with the source being monitored. A station located where complete mixing or homogeneous water quality exists will require fewer samples than one located at the intersection of several sources. In most cases, maps and an on-site visit can be used to determine how many samples should be taken to characterize a station, but preliminary sampling may be necessary in other cases. For example, conductivity or temperature measurements can be quickly performed as a depth profile and/or transect across a waterbody at a preliminary station location. The depth profile may indicate stratification, so that upper and lower layer sampling may be necessary. The transect may suggest an influence from an unknown upstream source, so that the station must be moved farther downstream, or samples must be taken across the waterbody and averaged together.

The longitudinal and lateral mixing of an effluent with the receiving water, or a tributary with a mainstem, requires some calculation or testing to evaluate station placement. Fischer *et al.* (1979) provides calculations to estimate mixing distances (see RIVPLUM3.WK1 spreadsheet in Appendix D). Alternatively, conductivity or other tracer measurements can be taken to establish whether well-mixed conditions are present.

8. Quality assurance and quality control (QA/QC) procedures must be designed into each survey. The number of QC samples taken is directly related to the level of confidence an investigator wants in her or his findings. The level of QC is also dependent upon the parameters analyzed, media sampled, and the project budget. The two important concepts in QC are accuracy and precision. Accuracy refers to how close a test result comes to the true or actual amount of material present, whereas precision refers to the reproducibility of a test under repeated trials. Accuracy may be estimated through tests on standard reference materials, matrix spikes, and method spikes. Precision may be assessed through analysis of field replicates, lab duplicates, and duplicate spikes. Other useful QA/QC approaches include inter-laboratory comparisons and analysis of blank samples (transport, transfer, and filtration blanks in the field; method blanks in the lab). The laboratory (and

ultimately, the project leader) must decide if QC results indicate the need for data flagging, correction, and/or elimination.

There are no hard and fast rules for how many QC samples are enough. One general "rule of thumb" is: 10% to 20%, or a minimum of one blank, one field replicate, and one lab duplicate per sampling day. Standards for internal spike sampling, interlaboratory comparisons, and standard reference samples are also available through most commercial laboratories. Recommendations for spiked samples are generally included in the method description.

9. Safety is an important consideration in survey design. It goes without saying that the loss of life or limb would seriously impair your ability to sample again. A safety plan should be prepared before conducting field work. There should be safety-related items available (e.g., safety lines/harnesses, first aid kits, floatation device, eye protection). If you are ever in doubt about the safety of a given activity, the best advice to follow is: don't do it.

### **3.3.2 Lab and Equipment Scheduling and Budget**

It is important to schedule equipment and laboratory needs as soon as possible. Lab capacity may be limited for some parameters. The following are a few "tips" which may make your lab and equipment scheduling smoother and more successful:

1. Determine type of sample transport to lab and rough schedule (sometimes air or bus transport is necessary, so you need to know where the terminal is and departure/arrival schedule). Check these against sample holding times to determine if there will be a conflict. Also, travel time from project site to terminal and to your lodging should be considered if they're separated by long distances.
2. Know what you want to sample to meet the project objectives: are the type (Table 2) and number of samples adequate?
3. What QC samples are needed? Which QC samples need to be included in the lab budget and which will the lab pay for?
4. Check with the analytical lab to see what analyses they can do and detection limits they can achieve, and compare that to what you need.
5. If they can't perform a particular analysis or develop an appropriate procedure, contact a lab that can perform the analyses.
6. Talk with the lab person in charge of scheduling: know exactly what you want run (special detection limits or analyses, mixed media, etc.), roughly when and how samples will arrive, and how many. If the lab can't do the analyses because of lab load capacity, can you reschedule your dates and still meet objectives?

7. Ask for advice if you need it, and check cost estimate against budget.
8. Check equipment to see if it is operable, and also to familiarize yourself with its proper operation. If it is not operable, either schedule its repair or find an alternative.
9. If possible, bring back-up equipment.
10. Check if field reagents are fresh and adequate.

### **3.3.3 Reconnaissance Trip**

The complexity of a project may determine whether a reconnaissance trip to the project site may be warranted. A recon trip, if practical, is useful for meeting local contacts, verifying map and field conditions, locating boat launch sites, and dealing with other details. Some other tasks may include:

1. Getting permission to cross private property to access a sampling site.
2. Observing if chosen sites are representative and safely accessible.
3. Collecting some preliminary field data (e.g., dissolved oxygen, conductivity, pH, and discharge) to run in models or in simple calculations.
4. Talking to Wastewater Treatment Plant (WTP) operators about discharge routines, upsets, cycles, production volumes, and problems.

### **3.3.4 Final Preparations**

There are some details to attend to before going into the field:

1. Lodging reservations if necessary (at least one week ahead).
2. Review of survey plans with assisting staff (as early as possible).
3. Double-check with field contacts on meeting places, schedules, etc. (couple of days ahead).
4. Equipment checklist (e.g., see Appendix B).
5. Pack sampling equipment, safety equipment, and foul-weather equipment into vehicle.

Table 2. Sampling guidelines for suspected pollutant sources: 1 = normally useful; 2 = occasionally useful; 3 = seldom useful (Huntamer and Hyre 1991).

	Primary WTP	Secondary WTP	Advanced WTP	Receiving Waters	Drinking Water	Domestic Wells	Stream Samples	Marine Samples	Brewery	Cooling Water	Boiler Water	Steam & Electric	Agricul. Runoff
<b>PHYSICAL AND GENERAL INORGANICS</b>													
Turbidity	-	-	-	2	1	1	2	2	1	-	-	-	1
pH	1	1	1	1	1	1	1	2	1	1	1	2	1
Conductivity	1	1	1	1	2	1	1	3	-	1	1	-	2
Total Alkalinity	-	1	1	2	2	2	2	2	-	-	1	-	3
Acidity	-	-	-	-	-	-	-	-	-	-	-	-	-
Hardness, Total	-	-	-	2	-	2	2	-	-	1	1	-	3
Chloride	-	-	-	3	1	1	2	-	-	1	1	-	3
Fluoride, Total	-	-	-	-	1	1	-	-	-	2	-	-	-
Sulfate	-	-	-	-	2	2	-	-	-	-	2	-	-
Cyanide, Total	-	-	-	3	-	3	3	-	-	2	2	2	3
Color	-	-	-	3	2	2	3	3	1	-	-	-	2
Salinity	-	-	-	-	-	-	-	1	-	-	-	-	-
<b>OXYGEN DEMAND AND CARBON</b>													
BOD <sub>5</sub>	1	1	1	1	1	-	2	-	1	-	-	-	-
BOD <sub>5</sub> -Carboneous	3	1	2	2	-	-	-	-	-	-	-	-	-
COD-Chemical Oxygen Demand	1	1	1	3	-	3	2	-	1	-	-	-	2
TOC-Total Organic Carbon	2	2	2	2	-	3	3	2	-	-	-	-	2
<b>SOLIDS</b>													
TSS-Total Suspended Solids	1	1	1	1	-	3	1	2	1	1	1	1	-
TS-Total Solids	1	1	1	-	-	-	-	-	-	-	-	-	-
TVSS Volatile Solids	3	1	1	-	-	-	-	3	-	-	-	-	-
SS Settleable Solids	1	1	1	2	-	3	3	3	1	-	-	-	3
Percent Total Solids	1	1	1	-	-	-	-	-	-	-	-	-	-
<b>NUTRIENTS</b>													
Ammonia	1	1	1	1	1	1	1	1	2	1	1	1	1
Nitrate-Nitrite	1	1	1	1	1	1	1	1	1	1	1	-	1
Total Phosphorus	1	1	1	2	-	3	1	1	1	2	2	2	1
Soluble Reactive Phosphorus	2	2	2	2	-	-	1	1	-	1	1	-	1
TKN Kjeldahl Nitrogen	3	3	3	3	-	-	-	3	-	-	-	-	-
<b>BIOLOGICAL</b>													
Fecal Coliform Bacteria	1	1	1	1	1	1	1	1	1	-	-	1	1
Total Coliform Bacteria	-	-	-	3	-	-	-	-	-	-	-	2	-
Fish Bioassay	-	-	-	-	-	-	-	-	-	-	-	-	-
Percent Lipids	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. Continued.

	Primary WTP	Secondary WTP	Advanced WTP	Receiving Waters	Drinking Water	Domestic Wells	Stream Samples	Marine Samples	Brewery	Cooling Water	Boiler Water	Steam & Electric	Agricult. Runoff
<b>GC/MS ORGANIC SCANS</b>													
Base-Neutrals/Acids	2	2	2	2	-	-	2	-	-	1	1	-	-
Base-Neutrals Only	-	-	-	-	-	-	-	-	-	-	-	-	-
Acids Only	-	-	-	-	2	-	-	-	-	-	-	2	-
Volatile Organisms	2	2	2	2	3	1	2	-	-	1	-	-	-
<b>GC ORGANIC SCANS</b>													
Pesticides/PCBs	2	2	2	2	2	-	2	-	-	-	-	-	1
PCBs Only	-	-	-	-	-	-	-	-	-	2	2	1	-
Purgeable Halocarbons	-	-	-	-	-	1	2	-	-	-	-	-	2
Herbicides	-	-	-	-	2	-	2	-	-	-	-	-	1
<b>MISCELLANEOUS ORGANICS</b>													
PAH Polycyclic Aromatics	-	-	-	-	-	-	-	-	-	-	-	-	-
Oil Identification	-	-	-	3	-	-	-	-	-	-	-	2	-
Phenolics	3	3	3	3	1	3	3	3	-	2	2	1	3
Oil & Grease	-	-	-	3	-	3	-	3	1	1	1	1	3
Flashpoint	-	-	-	-	-	-	-	-	-	-	-	-	-
Halogenated Hydrocarbons	-	-	-	-	-	-	-	-	-	-	-	-	-
TOX	-	-	-	1	2	-	-	-	1	-	-	-	1
Trihalomethanes	2	2	2	-	2	3	3	-	-	-	-	-	-
<b>METALS</b>													
Priority Pollutant Metals	-	-	-	-	-	-	-	-	-	-	-	-	-
EP TOX Metals	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Specific Metals</b>													
Copper	1	1	1	1	2	2	2	3	-	1	1	1	-
Nickel	-	-	-	1	-	-	-	3	-	2	1	1	-
Chromium	2	2	2	2	2	2	3	2	-	2	2	2	-
Lead	2	2	2	2	2	2	2	2	-	2	2	1	-
Zinc	1	1	1	2	2	2	2	3	-	2	2	1	-
Cadmium	1	1	1	1	2	2	2	2	-	-	-	-	-

Table 2. Continued.

	Paint & Ink	Aluminum Mill Effluent	Landfill Leachate	Toxic Waste Sites	Chemical Plants	Inorganic Chemicals	Oil Refineries	Ground Water	Timber Industry	Electro- plating	Car Washes	Meat Prod. Industry	Pulp Mill Effluent
<b>PHYSICAL AND GENERAL INORGANICS</b>													
Turbidity	-	2	2	2	-	-	2	-	-	-	1	1	2
pH	2	1	1	1	1	1	1	1	1	1	1	1	1
Conductivity	-	1	1	1	-	1	1	1	-	-	-	-	-
Total Alkalinity	-	3	2	-	-	-	3	2	-	-	1	-	2
Acidity	-	-	-	-	-	-	-	2	-	-	-	-	-
Hardness, Total	-	3	3	2	-	-	3	2	-	-	-	-	3
Chloride	-	3	1	-	-	1	2	1	-	-	-	-	3
Fluoride, Total	1	1	-	-	1	-	-	2	-	-	-	-	-
Sulfate	-	-	3	-	1	-	-	2	-	-	-	-	-
Cyanide, Total	-	2	3	2	1	1	2	2	-	-	-	-	3
Color	-	3	2	-	-	-	2	2	1	-	-	1	2
Salinity	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>OXYGEN DEMAND AND CARBON</b>													
BOD <sub>5</sub>	-	-	-	-	-	-	-	-	-	-	-	-	-
BOD <sub>5</sub> Carbonaceous	-	-	-	-	-	-	-	-	-	-	-	-	-
COD-Chemical Oxygen Demand	1	3	1	1	1	2	1	-	1	1	1	1	1
TOC-Total Organic Carbon	1	3	2	2	1	-	1	2	2	-	-	-	1
<b>SOLIDS</b>													
TSS-Total Suspended Solids	-	1	2	-	1	1	1	2	1	1	1	1	-
TS-Total Solids	-	1	2	-	-	1	2	2	-	-	-	-	-
TVSS-Volatile Solids	-	-	-	-	-	-	-	-	2	-	-	-	-
SS-Settleable Solids	-	3	3	-	-	-	3	-	1	-	-	1	1
Percent Total Solids	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>NUTRIENTS</b>													
Ammonia	-	2	1	-	1	2	1	1	2	-	2	1	2
Nitrate-Nitrite	-	-	2	-	-	2	2	2	-	-	-	-	2
Total Phosphorus	-	2	3	-	-	-	2	2	-	-	1	1	2
Soluble Reactive Phosphorus	-	-	-	-	-	-	-	-	-	-	-	-	-
TKN Kjeldahl Nitrogen	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>BIOLOGICAL</b>													
Fecal Coliform Bacteria	-	3	3	-	-	-	-	-	-	-	-	1	-
Total Coliform Bacteria	-	-	-	-	-	-	1	-	-	-	-	2	-
Fish Bioassay	-	-	-	2	-	-	1	-	-	-	-	2	-
Percent Lipids	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. Continued.

	Paint & Ink	Aluminum Mill Effluent	Landfill Leachate	Toxic Waste Sites	Chemical Plants	Inorganic Chemicals	Oil Refineries	Ground Water	Timber Industry	Electroplating	Car Washes	Meat Prod. Industry	Pulp Mill Effluent
<b>GC/MS ORGANIC SCANS</b>													
Base-Neutrals/Acids	1	-	2	1	1	-	1	2	3	-	-	-	2
Base-Neutrals Only	-	-	-	-	-	-	-	-	-	-	-	-	-
Acids Only	3	-	-	-	1	2	2	-	1	-	-	2	-
Volatile Organics	1	1	1	1	1	1	1	2	3	-	-	-	1
<b>GC ORGANIC SCANS</b>													
Pesticides/PCBs	-	-	-	1	1	-	2	2	2	-	-	-	2
PCBs Only	-	-	-	1	2	-	-	3	-	-	-	-	1
Purgeable Halocarbons	1	-	-	2	-	-	-	1	-	-	-	-	-
Herbicides	1	-	-	2	2	-	-	2	1	-	-	-	1
<b>MISCELLANEOUS ORGANICS</b>													
PAH Polycyclic Aromatics	1	-	-	2	-	-	-	2	2	-	-	-	-
Oil Identification	-	-	-	-	-	-	1	2	-	-	-	-	-
Phenolics	1	2	2	2	1	2	1	2	1	-	-	1	2
Oil & Grease	1	2	3	2	1	1	1	2	1	1	1	1	2
Flashpoint	-	-	-	-	-	-	-	-	-	-	-	-	-
Halogenated Hydrocarbons	-	-	3	2	-	-	-	3	-	-	-	-	-
TOX	-	-	-	-	-	-	-	1	-	-	-	1	1
Trihalomethanes	-	-	-	-	-	-	-	2	-	-	-	-	-
<b>METALS</b>													
Priority Pollutant Metals	-	-	1	1	1	-	-	-	-	-	-	-	-
EP TOX Metals	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Specific Metals</b>													
Copper	1	2	2	2	1	2	2	1	1	2	1	1	-
Nickel	-	2	2	2	1	2	2	-	1	-	1	-	-
Chromium	2	2	2	-	1	-	-	1	-	-	1	2	-
Lead	2	2	2	2	1	2	2	2	-	2	1	2	-
Zinc	2	2	2	1	1	2	2	2	1	2	1	2	-
Cadmium	2	2	2	2	1	2	2	2	2	-	-	2	-

3-14

Table 2. Continued.

	Leather Tanning	Cement/Concrete Industry	Iron/Steel Industry	Hazardous Waste	Organic Pesticides	Cooling Tower Blowdown	Boiler Blowdown	Sediment Samples	Fish & Shellfish	Electronics Industry	Chemical Spills	Acid Rain	Wood Treatment
<b>PHYSICAL AND GENERAL INORGANICS</b>													
Turbidity	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	1	1	1	1	1	-	-	-	-	-	-	1	1
Conductivity	-	-	-	-	-	-	-	-	-	-	-	-	1
Total Alkalinity	-	1	-	-	2	-	-	-	-	-	-	1	-
Acidity	-	-	-	-	-	-	-	-	-	-	-	1	-
Hardness, Total	-	-	1	-	2	-	-	-	-	-	-	-	-
Chloride	-	-	1	-	2	-	-	-	-	-	-	-	-
Fluoride, Total	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	-	-	1	-	1	1	-	-	-	-	-	1	-
Cyanide, Total	-	-	1	-	1	1	-	-	-	-	-	-	-
Color	1	-	-	-	-	-	-	-	-	-	-	-	-
Salinity	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>OXYGEN DEMAND AND CARBON</b>													
BOD <sub>5</sub>	-	-	-	-	-	-	-	-	-	-	-	-	-
BOD <sub>5</sub> -Carbonaceous	-	-	-	-	-	-	-	-	-	-	-	-	-
COD-Chemical Oxygen Demand	1	2	-	-	1	-	-	-	-	-	-	-	1
TOC-Total Organic Carbon	1	-	-	2	1	-	-	1	-	-	-	-	2
<b>SOLIDS</b>													
TSS-Total Suspended Solids	1	1	1	-	1	1	-	-	-	-	-	-	-
TS-Total Solids	1	-	-	-	-	1	-	-	-	-	-	-	-
TVSS-Volatile Solids	1	-	-	-	-	-	-	-	-	-	-	-	-
SS-Settleable Solids	-	-	-	-	2	-	-	-	-	-	-	-	-
Percent Total Solids	-	-	-	-	-	-	-	1	1	-	-	-	-
<b>NUTRIENTS</b>													
Ammonia	1	-	1	-	-	1	2	-	-	-	-	1	-
Nitrate-Nitrite	-	-	-	-	2	-	-	-	-	-	-	-	-
Total Phosphorus	-	1	-	-	2	-	1	-	-	-	-	-	-
Soluble Reactive Phosphorus	-	-	-	-	-	-	-	-	-	-	-	-	-
TKN Kjeldahl Nitrogen	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>BIOLOGICAL</b>													
Fecal Coliform Bacteria	-	-	-	-	-	-	-	-	2	-	-	-	-
Total Coliform Bacteria	-	-	-	-	-	-	-	-	-	-	-	-	-
Fish Bioassay	-	-	-	2	-	-	-	-	-	-	-	-	-
Percent Lipids	-	-	-	-	-	-	-	-	1	-	-	-	-

Table 2. Continued.

	Leather Tanning	Cement/Concrete Industry	Iron/Steel Industry	Hazardous Waste	Organic Pesticides	Cooling Tower Blowdown	Boiler Blowdown	Sediment Samples	Fish & Shellfish	Electronics Industry	Chemical Spills	Acid Rain	Wood Treatment
<b>GC/MS ORGANIC SCANS</b>													
Base-Neutrals/Acids	1	-	2	2	2	-	1	1	3	-	-	-	-
Base-Neutrals Only	-	-	-	-	-	-	-	-	-	-	-	-	-
Acids Only	-	-	1	2	3	-	1	-	-	-	-	-	1
Volatile Organics	-	-	-	1	2	2	-	2	3	-	-	-	1
<b>GC ORGANIC SCANS</b>													
Pesticides/PCBs	2	-	-	1	1	-	-	1	1	-	-	-	1
PCBs Only	-	-	-	2	-	-	-	1	1	-	-	-	-
Purgeable Halocarbons	-	-	-	2	2	2	-	-	3	-	-	-	-
Herbicides	-	-	-	2	1	-	-	3	3	-	-	-	-
<b>MISCELLANEOUS ORGANICS</b>													
PAH Polycyclic Aromatics	-	-	1	2	-	-	-	2	-	-	-	-	1
Oil Identification	-	-	-	-	-	-	-	3	-	-	2	-	2
Phenolics	2	-	1	2	1	2	1	2	2	-	-	-	1
Oil & Grease	1	-	1	-	1	1	1	-	-	-	-	-	1
Flashpoint	-	-	-	2	-	-	-	-	-	-	-	-	-
Halogenated Hydrocarbons	-	-	-	2	3	-	-	-	-	-	-	-	-
TOX	-	-	-	-	-	-	-	-	-	-	-	-	1
Trihalomethanes	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>METALS</b>													
Priority Pollutant Metals	-	-	-	-	-	-	2	2	-	-	-	-	-
EP TOX Metals	-	-	1	-	-	-	-	-	-	-	-	-	-
<b>Specific Metals</b>													
Copper	-	1	2	-	1	1	1	1	-	-	-	1	1
Nickel	-	1	2	1	1	-	2	3	-	-	-	3	1
Chromium	-	-	2	1	-	-	2	2	-	-	-	1	1
Lead	-	-	2	1	1	-	1	1	-	-	-	3	1
Zinc	1	1	2	1	1	-	1	1	-	-	-	2	1
Cadmium	-	1	2	1	1	-	1	1	-	-	-	-	-

### 3.4 Field Survey

Anything that could have been done to plan ahead should have been done. Once in the field, your options to obtain bottles and replacement parts, or time to establish survey stations, become limited. A few field considerations:

1. Keep a detailed and legible notebook. Entries should include: project name, sampler's names, weather conditions, sampling date and time, site descriptions, and water quality or other data.
2. Keep a sense of order. Sample upstream to downstream (or reverse) to best meet project objectives. The upstream to downstream order on a small stream can sometimes create contamination problems downstream after upstream sites are sampled. The reverse order does not allow observation of a specific block of water. Estuarine or tidal river areas also can have difficult station sampling orders depending on the tide changes.
3. Collect water quality samples so as not to disturb benthic invertebrate or sediment sampling areas. Also, do not collect water samples downstream of where you are walking, wading or have recently disturbed the sediment.
4. Watch and be prepared for unexpected sources of contamination, and be flexible enough to deal with them. Take notes on land uses adjacent to and upstream of sampling site.
5. Call the lab when samples are coming/not coming on schedule, or if there have been major changes in the number or kind of samples.
6. Pack samples in cooler in a way which minimizes breakage and intrusion of ice water into sample containers. It is sometimes helpful to put sample bottles into plastic bags within the cooler. Also, "blue ice" is recommended when shipping samples via air freight to prevent water leakage from the cooler into the cargo area.
7. Make sure sample labels are clearly marked with appropriate information on sample data and analysis required. A waterproof pencil or indelible ink pen should be used.
8. Protect field meters against excessive exposure to water, shock, heat, or cold. When travelling overnight, take meters and calibration reagents into motel room during cold nights. Secure meters in vehicles and boats against jolting and falling.
9. Chain and camouflage long-term monitoring devices if they are located in unsecured areas.

Specific protocols on sample collection and handling can be found in the following publications: Mills *et al.* (1986), PSEP (1986), Striplin (1988), EILS (1989), Plafkin *et al.* (1989), APHA *et al.* (1992), and EPA/PSEP (1990). Other references can be found in sections that follow, and in the Annotated Bibliography.

*This page is purposely blank for duplex printing*

## SECTION 4 WATER QUALITY ASSESSMENT

The methods summarized in this section are drawn largely from the screening procedures presented by Mills *et al.* (1985), which provide a detailed procedure for screening surface and ground water systems for most conventional and toxic pollutant problems. Screening surveys generally include identification of observed or potential water quality standards violations based on WAC 173-201 and applicable EPA criteria. Examples and recommendations are provided for conducting specific types of assessments.

### 4.1 Pollutant Loading Calculations

Receiving waters are subjected to pollutant loading from a variety of point and nonpoint sources. Point sources are identifiable discrete discharges from municipal, institutional, and industrial waste water collection and treatment systems. Nonpoint sources are diffuse or distributed over large areas, and enter a waterbody through dispersed and often poorly defined pathways. Ecology studies typically are focused on surface water inputs.

Point source loading can usually be estimated from available data (e.g., NPDES Discharge Monitoring Reports [DMRs] on file at Ecology regional offices, or the Industrial Section of Central Programs in Olympia). Usually at least flow data are available in DMRs. The sampling plan for the survey will probably include collection of effluent quality data using either grab or composite sampling techniques. Historical effluent quality data for some pollutants of interest may also be contained in the DMRs. If no monitoring data are available and sampling is not feasible, then effluent quality may be estimated by reported concentrations for similar effluents. Typical pollutant concentrations in a variety of effluents are presented in Mills *et al.* (1985). Hallinan (1988) has compiled a summary of metals concentrations in effluents from Washington State municipal WTPs. Wasteloads from point sources are calculated as the product of flow and concentration (corrected for units).

Nonpoint source loads to a waterbody are usually greatest during the wet season, and may be insignificant during dry weather. Sampling to characterize nonpoint loads typically involves identifying tributary drains and surface channels that discharge to the waterbody. These inputs are most often sampled as near as possible to the point of entry to the receiving water.

If the nonpoint sources are too diffuse (i.e., no distinct channel or surface input), then the nonpoint load may be characterized by including sampling stations immediately above and below the suspected input within the receiving water and attributing increased loading between stations to nonpoint sources. Direct sampling of ground water quality from representative wells may also be included if ground water loading is expected to be significant. For example, nutrient loading estimates from septic systems may be based on upgradient and downgradient ground water sampling to evaluate nutrient retention in drainfields.

The quantity of nonpoint pollutant loading is affected by the land-use and land-cover characteristics of a drainage basin. Estimates of basin-wide loadings often are based on application of unit areal loading rates from specific land-use/land-cover types over the total areas for each type within a basin. Unit areal loading rates may be found from reported values in literature or sampling of representative areas within a basin. A variety of more complex nonpoint loading simulation models are also available, which require field studies for calibration of numerous coefficients. Inventories of diverse land-use/land-cover characteristics within a basin may be aided by the use of Geographic Information Systems (GIS) such as ARC-INFO.

#### 4.1.1 Streamflow Measurements

Most receiving water responses to watershed loadings are both a function of the quality and quantity of water. The quality of water is determined by measuring physical, chemical, and biological parameters, while the quantity is determined by measuring discharge or streamflow. Streamflow (flow) is defined as the volume of water passing a single point in the stream over time, and is most often measured by determining the cross-sectional area and velocity of the flowing water. Flow is usually expressed as volume per unit time (e.g., cubic feet per second (cfs) or meters cubed per second ( $m^3/sec$ )).

The two major types of flow measurements in streams and other open channels are instantaneous and continuous. Instantaneous flow is a measure of flow at one point in time, while continuous flow is usually based on a stage-discharge relationship and determined by continuously monitoring stage. Open channel flow measurements can be classified as velocity methods, head-discharge methods, and miscellaneous techniques. For a detailed review the reader should reference EPA's Handbook for Sampling and Sample Preservation of Water and Wastewater (EPA, 1982). Methods for estimating streamflow are discussed in Appendix C.

#### 4.2 Rivers and Streams

The location of a sampling station in a river or stream is one of the most critical design factors in water quality assessment. If the samples collected are not representative of the water mass, the number of samples collected as well as the data interpretation and presentation becomes unimportant. The water quality of a river or stream reflects natural background conditions and the wastes it is carrying. Water quality usually varies along the entire length of a river or stream, because both conservative and nonconservative pollutants may be added to its entire length. Therefore, there are three levels of design criteria in selecting river or stream sampling locations: (1) river or stream reaches to be sampled within a basin; (2) stations locations relative to special aspects within a river reach (e.g., outfall); and (3) points within the cross section of a reach that are representative locations (Sanders *et al.*, 1983). The number of contributing tributaries and/or indicators of stream use can be used to determine what reaches should be sampled. In order to determine where samples should be taken within a reach it is necessary to consider the uniformity of the sample concentrations in a river or stream's cross sectional area, especially if an outfall is present.

#### **4.2.1 Mixing Zones**

A mixing zone is the area adjacent to and downstream of an effluent outfall where mixing results in the dilution of effluent with the receiving water. Water quality criteria may be exceeded in a mixing zone as conditioned and provided for in WAC 173-201A-100. It is usually not realistic to assume complete mixing with the receiving water if an objective of the project is to determine dilution factors within or at the boundary of the mixing zone (e.g., acute toxicity in the mixing zone). In these situations, it is reasonable to expect that sampling surveys, dye studies, and/or computer model simulations will be performed to better describe the discharge-induced and ambient-induced mixing processes.

Discharge-induced mixing processes are attributable to initial plume momentum and buoyancy characteristics and usually do not result in complete mixing. In mixing zone modeling these processes are referred to as near-field effects and would need to be characterized to better define the zone of acute criteria exceedance. Ambient-induced processes (far-field) are attributable to random diffusion and dispersion in the receiving water and may or may not result in complete mixing within the mixing zone. Both near- and far-field mixing processes must be defined at the chronic mixing zone boundary.

EPA's latest generation plume model (PLUMES) estimates dilution factors throughout the mixing zone by continuing the iterative calculation process through near-field into far-field (EPA, 1993). Thus, the model estimates dilution factors at both acute and chronic boundaries for most effluent, outfall and receiving water characteristics encountered. Ecology also uses a simple spreadsheet that allows estimation of effluent dilution from a point source to a river (see Appendix D), assuming that dilution is influenced mainly by ambient turbulence and dispersion, and not as much by the initial momentum and buoyancy of the effluent plume. This would be particularly for use in shallow, fast-moving rivers and streams.

The following general considerations apply to evaluating mixing zones in river systems:

1. A diagram or written description of the as-built diffuser length and diameter, port orientation, port diameters, and arrangement with respect to the river bottom or seabed (e.g., slope) and to other ports should be obtained. Also, the integrity of the diffuser structure should be verified.
2. Other outfalls or discharges which may influence the dilution zone under study should be identified and characterized as part of the dilution zone study.
3. The mixing study should be conducted during periods of river discharge that are as near the 7-day-10-year (7Q10) low flow as possible.
4. Plant discharge should be at the typical existing condition for the season of study when conducting sampling. The study should address extrapolating the results to "critical

condition" as defined in WAC 173-201A. Critical condition estimates are best determined using a mixing zone model.

5. Field studies should include characterization of representative channel geometry (e.g., depth, width, velocity, and slope) in the river reach that contains the mixing zone. This data will be useful for input to theoretical transverse mixing models (Fischer *et al.*, 1979, Appendix D).
6. River discharge should be approximately constant during the dilution zone study. River discharge rates should be accurately measured (accuracy  $\pm$  5-10%) using standard techniques (USGS, 1962).
7. A suitable conservative tracer should be identified for calculating the volume fraction of effluent at sampling points downstream from the discharge. Tracers that occur in the effluent may be used provided that the tracer concentration in the effluent is sufficiently elevated to detect approximately 1 percent effluent. As an approximate guideline, the concentration of tracer in the effluent should be higher than the ambient concentration (upstream from the input) by at least 100 times the precision of the method being used to measure the tracer. For example, if conductivity is being used as a tracer, and the precision of the method used to measure conductivity is  $\pm$  2  $\mu$ mhos/cm, then the effluent should have a conductivity of at least 200  $\mu$ mhos/cm greater than the upstream condition.
8. A common way to characterize effluent dilution zones is to conduct dye studies using Rhodamine WT. Mills *et al.* (1986) describe in detail a way to conduct dye studies of dilution zones.
9. Since one of the products of a dilution study is to develop dilution isopleths, the survey should include a suitable number of cross-channel (perpendicular to direction of flow) transects. As a rule of thumb, the change in the maximum tracer concentration across the channel between transects should not exceed a factor of three or four (Mills *et al.*, 1986). A minimum of two downstream transects, one at 30 and one at 300 feet downstream from the discharge, should be made (current mixing zone policy allows a maximum length of 300 feet for exemption from water quality standards for discharges to rivers). Additional transects would be helpful to better describe dilution isopleths. If complete mixing does not occur within 300 feet, then additional transects would be desirable below 300 feet until complete mixing is observed.

The upstream concentration of the tracer should also be measured (approximately three cross-channel samples would probably suffice). Each downstream transect should contain at least 5-10 sampling points across the channel, with emphasis on the zone of significant effluent concentration. Each transect should have enough sampling points to extend either into the region of the receiving water beyond the discharge influence or to the river banks.

Each of the downstream transect sampling points should include discrete sampling at enough depths in the water column to define vertical distribution of effluent. As a rule of thumb, sampling at 0.5 to 1.0 meter depth intervals from surface to bottom should be sufficient.

10. The method for determining and maintaining location within the sampling grid should be identified.
11. The study report should contain plan view and cross-sectional tracer concentration and dilution isopleths.
12. The report should also contain a tabular summary of the channel geometry, river flow, plant flow, and tracer concentration data measured, as well as a discussion of the methods, QA/QC, and results. Dilution factors observed during the study should be extrapolated to the design condition of river and plant discharge.
13. Certain unique outfall and receiving water conditions can be better modeled using CORMIX1 (Doneker and Jirka, 1990) and CORMIX2 (Akar and Jirka, 1990), which predict the initial dilution and downstream dispersion of effluent discharged from single and multiple port diffusers, respectively. As with PLUMES, CORMIX1 and CORMIX2 are expert systems (i.e., they check for data consistency, execute appropriate models, interpret simulation results, and suggest design alternatives to improve dilution). The methods in Fischer *et al.* (1979) can be used to estimate ambient-induced dilution from turbulence and dispersion (see Ecology spreadsheet RIVPLUM3.WK1 in Appendix D).

#### **4.2.2 River Segmentation**

Far-field modeling of river water quality is generally accomplished by dividing the river system into segments or reaches. Analyses of river systems normally begin at a segment where the boundary conditions are known (i.e., upstream from point and nonpoint loads) and proceed sequentially downstream. The initial upstream condition usually represents the background loading from natural processes. Sampling stations in rivers are generally located at the boundaries of segments. The following general rules apply when segmenting rivers (although they may be superseded by more direct knowledge):

1. Point sources and tributaries enter the river at the upstream boundary of a segment.
2. Distributed nonpoint sources enter throughout the length of a segment.
3. Pollutant concentrations at the upstream end of segments are obtained by mixing the pollutant concentration in the river with the point source or tributary input (if there are any). If the focus of the survey is on near-field effects (e.g., acute toxicity in the mixing zone), then it is probably not realistic to assume complete mix near the point of discharge, as discussed above.

4. Generally, constant hydraulic variables (e.g., depth and velocity) are used throughout a segment. If there is a gradual change in hydraulic variables over distance, an average value can be used. If hydraulic variables are known to change significantly, then new segments should be created.
5. Decay rates, reaeration rates, and other rate coefficients remain constant within a segment. If rate constants are known to change significantly, then a new segment may be created.

Typically, a major objective of river sampling surveys is to characterize the physical and chemical conditions of each stream segment for the time of sampling and for a set of design conditions which may represent a reasonable worst-case scenario.

#### 4.2.3 Dissolved Oxygen and BOD

Many wastes discharged into waterways contain biologically oxidizable materials that exert an oxygen demand. Dissolved oxygen concentrations in water are predominantly influenced by reaeration, photosynthesis, plant and animal respiration, SOD, BOD, nitrification, salinity, and temperature. The most commonly used technique to estimate the effect of a BOD load on a river is the Streeter-Phelps equation (Mills *et al.*, 1985), which is presented in detail in EPA guidance documents. Oxygen is consumed by first-order decay of BOD. At the same time, the atmosphere replenishes oxygen at a rate proportional to the depletion from saturation.

Ecology uses a spreadsheet (DOSAG.WK1-Lotus) that calculates the critical D.O. sag (minimum D.O.) and distance downstream to the critical sag for a single point source discharge to a river. An example of this spreadsheet is presented in Appendix D. If D.O. profiles are to be predicted for more complicated systems (e.g., multiple discharges or stream reaches), then a more complex model which simulates more constituents should be used. QUAL2E and WASP4 are currently EPA-supported models that are able to simulate more complex aquatic systems.

Stream sampling surveys for D.O. are usually designed to provide calibration data for input to Streeter-Phelps models. Dissolved oxygen sags typically become apparent several miles downstream from a BOD load. Therefore, preliminary calculations of D.O. sag and location may be useful in designing locations for sampling stations. BOD decay rates and D.O. reaeration rates often are calculated from published relationships with discharge, velocity, depth, and stream slope (Mills *et al.*, 1985).

The Streeter-Phelps equation requires an estimate of the load of "Ultimate Oxygen Demand" (UOD) from all carbonaceous and nitrogenous sources to predict D.O. depletion. Direct measurement of ultimate carbonaceous BOD (CBOD<sub>U</sub>; Stamer *et al.*, 1983) is preferable for model calibration and validation. However, an approximation from 5-day carbonaceous BOD (CBOD<sub>5</sub>) can be made as follows, assuming a CBOD decay rate (base e) of 0.23/day (Mills *et al.*, 1985):

$$(\text{CBOD}_U \text{ in mg/L}) \approx 1.46 * (\text{CBOD}_5 \text{ in mg/L})$$

This assumption has significant implications to water quality modeling because the ratio of CBOD<sub>U</sub>/CBOD<sub>5</sub> is both wasteload and receiving water specific (Bowie *et al.*, 1985). Ultimate to 5-day ratios as high as 30 have been reported for some paper industry wastewaters.

Ammonia and organic N may also affect instream dissolved oxygen, thus they should be considered as sources of "nitrogenous" BOD (NBOD), which is usually estimated as:

$$(\text{NBOD in mg/L}) \approx 4.57 * (\text{Ammonia} + \text{Organic-N mg/L})$$

The UOD is then determined as the sum of CBOD<sub>U</sub> and NBOD. Other sources and sinks of D.O. that may be important to consider include benthic demand, photosynthesis, and respiration.

#### 4.2.4 Nutrients and Eutrophication

The nutrients that are most often limiting to plant growth, nitrogen and phosphorus, can be elevated in rivers from point and nonpoint loads. However, increased nutrient levels do not always result in algal blooms. For example, algal growth may be restricted by turbidity and short residence time in the river environment. Even if other factors limit algal growth in rivers, nutrient loading will be of interest if the river discharges to a lake or estuary, in which case the eutrophication problem may be transferred downstream.

#### 4.2.5 Bacterial Indicators

Coliform bacteria are commonly used as an indicator of potential pathogen contamination. Until recently, coliforms were regarded as less sensitive to environmental stress than enteric pathogens. Therefore, coliforms were considered a more conservative index of potential pathogen levels.

Recent evidence (Bowie *et al.*, 1985) concerning enteric viruses and opportunistic pathogens suggests that coliform bacteria may not be the ideal indicator, because some pathogens may die off at a slower or faster rate than coliforms; have major non-fecal sources; or grow in the environment.

The coliform group, as a whole, consists of both fecal and non-fecal components. The fecal coliform (FC) subgroup includes *Klebsiella* species which are present and can multiply to high levels in pulp mill and some food processing plant effluents. *Klebsiella* can influence the FC test and there are specific methods for quantifying its presence. The major component of the fecal group is *Escherichia coli* (*E. coli*), which is usually only associated with fecal material and will not ordinarily multiply in the environment. There are effective methods for quantifying *E. coli*, and in the future it may be used much more as an indicator of fecal contamination.

In addition to FC, fecal streptococci (FS) provide another commonly used indicator of fecal contamination. As with FC, FS have both fecal and non-fecal components. Enterococci and *Streptococcus faecalis* are more specific to fecal sources than non-enteric streptococci. FS and

particularly enterococci have much slower die-off rates than FC and total coliform. Thus, they are more persistent in the environment and may be a more sensitive indicator of the presence of pathogens.

The ratio of FC/FS has been used to discriminate between human and non-human sources of fecal contamination (Geldreich and Kenner, 1969). If the ratio exceeds approximately one (although four is sometimes cited as the cutoff value), the source is presumed to be human fecal material (Bowie *et al.*, 1985). FC/FS less than one is presumed to be of non-human origin. The major problem with the FC/FS ratio is that it can be dramatically altered once the material enters natural waters, particularly if the sampling location is not close to the source. Because the ratio may change with time and location, it should be used with great caution.

#### **4.2.6 Toxic Substances**

The fate of toxic substances in natural waters is potentially very complex. Toxicants are influenced by sorption with suspended solids (particularly organic carbon), volatilization and decay of dissolved material, and diffusion and resuspension interactions with sediment. The most important fate processes depend on source characteristics (Mills *et al.*, 1985). A detailed description of the major fate processes for different sources of toxic substances is beyond the scope of this handbook.

The most often cited modeling approach for toxics is applied in EPA's WASP4 model (Ambrose *et al.*, 1988) and SMPTOX2 model (Limno-Tech, 1986). Suspended solids are first modeled using a first-order sedimentation rate. A partitioning coefficient (which is specific to the toxic substance being considered and the suspended solids concentration) is then used to determine the fractions of the substance that are dissolved and sorbed to solids. Volatilization rates are generally determined from Henry's law. A lumped first-order decay reaction that includes volatilization, biodegradation, photolysis, and hydrolysis is then applied to the dissolved fraction. Interactions with the sediments (resuspension and diffusion) may also be simulated with WASP4.

Due to the complexity of toxics modeling, most sampling surveys will be aimed at simply identifying whether or not priority pollutants are present in appreciable amounts. In practice, most mass balance modeling (especially in dilution zones) will probably be based on the assumption that the toxic substance is conservative in the environment.

#### **4.3 Lakes and Reservoirs**

As in sampling streams and rivers, one must consider spatial and temporal patterns when sampling lakes and reservoirs. In lake and reservoir sampling, spatial patterns can be defined by the vertical, lateral, and longitudinal spatial dimensions (Gaugash, 1987). The lateral dimension is along an axis perpendicular to the major hydrologic flow, and the longitudinal dimension is along an axis parallel to the major hydrologic flow. Vertical differences are usually in response to gradients in light and temperature. Lateral differences are usually low and not a significant contributor to spatial variance. Reservoirs and dendritic lakes with inlets

and outlets can display significant longitudinal gradients due to flow and morphometry. Temporal patterns are usually determined by the changing patterns of flow over time and the seasonal changes in temperature and solar radiation. Temporal patterns of concern for sampling relate mostly to changes in vertical thermal stratification.

#### **4.3.1 Eutrophication**

Eutrophy means literally a state of good nutrition. Eutrophication of lakes is caused by excessive inputs of algal nutrients, namely nitrogen and phosphorus. Phosphorus is most often the critical limiting nutrient. Studies of lake and reservoir eutrophication typically involve at least year-long monitoring of lake nutrient and algal biomass levels at bi-weekly to monthly intervals, as well as continuous monitoring of hydraulic and nutrient loading from tributaries and point sources. A detailed description of the monitoring needs for a lake eutrophication diagnostic study is contained in Cooke *et al.* (1986). This type of study requires a long-term commitment of labor and laboratory resources.

Most often Ecology screening studies for eutrophication will include short-term sampling of loading sources (e.g., agricultural drains, tributaries, etc.) rather than monitoring of the receiving lake. In these types of studies, nutrient loads are measured in a large number of sources simultaneously, and the various loading sources are ranked to identify major sources which may deserve further investigation (e.g., to identify specific nonpoint sources upstream).

Another type of eutrophication study may involve limited sampling of a large number of lakes. This type of study usually does not provide enough data to do a diagnostic analysis of eutrophication, but it may provide a basis for ranking identified problem areas. These types of screening surveys may also provide enough data to develop regional empirical calibrations of phosphorus model parameters (e.g., the phosphorus sedimentation rate). Reckhow and Chapra (1983) provide a detailed description of how limited data from a large number of lakes may provide insight for predicting regional eutrophication effects.

#### **4.3.2 Dissolved Oxygen**

Organic substances introduced to a lake with inflowing water, falling onto its surface, or generated in the water column via algal productivity exert a BOD and thus reduce D.O. concentrations. Other D.O. sinks include benthic demand, chemical oxidation, and animal and plant respiration. Sources of D.O. are atmospheric reaeration, photosynthesis, and D.O. in inflowing water, including rainfall. During summer stratification, D.O. is usually highest in the upper mixed layer due to photosynthesis and reaeration. D.O. decreases with depth and may reach zero, particularly if organic loading from algal production is high. If the lake completely mixes during winter and spring, D.O. concentrations will be largely uniform over depth.

### 4.3.3 Toxicant Screening

As in rivers, the fate processes of toxicants in lakes are complex. In general, screening techniques in lakes are conservative because they assume that loss mechanisms (e.g., volatilization, sorption, etc.) are insignificant. As a result, simple dilution models are often used to predict concentrations as a preliminary screening. Most sampling efforts are aimed at quantifying the loading of priority pollutants in point and nonpoint source inflows. Concentrations in the receiving water may then be calculated by a dilution model and compared to the actual concentration observed, as well as to water quality criteria.

## 4.4 Estuaries

Sampling in estuaries is complicated by the mixing of freshwater and saltwater and the pronounced tidal action that introduces changes in direction of flow. The flow changes, tidal action, and differences in specific gravity of fresh, brackish, and saltwater must be considered when sampling in an estuary.

### 4.4.1 Mixing Zones

Field studies to characterize buoyant plumes in marine or estuarine receiving waters are generally focused on defining the critical ambient conditions of vertical density stratification and current speed/direction. Dye studies may also be used, especially in situations where flushing characteristics of the receiving water are suspected of limiting available dilution. The following general considerations apply to evaluating mixing zones in estuarine systems:

1. A diagram or written description of the as-built diffuser length and diameter, port orientation, port diameters, and arrangement with respect to the seabed and other ports should be obtained. If possible, perform a hydraulic evaluation of diffuser performance at the design flow (e.g., method of Rawn *et al.*, 1961) as part of the study scope. For multiple port diffusers, the design flow of each port should be estimated based on the as-built diffuser configuration, since unequal flow may influence the actual dilution achieved. It is not necessary to calculate dilution for each port, but only for the segment of the diffuser with the worst dilution characteristics -- that is, the port with the highest design flow.
2. Worst-case ambient density profiles should be selected for input to buoyant plume dilution models. At the least, dilution in the cases of minimum and maximum stratification at the permitted design flow should be evaluated. Density profiles may be estimated from existing data if available. Otherwise, a sampling program to define density structure should be performed.
3. Since ambient currents may affect dilution, a modest current speed may be assumed (lowest 10th percentile of ambient currents). If no data are available, then current monitoring must be performed or current velocity assumed to be zero.

4. Several mathematical models are available from EPA which are appropriate for different oceanographic and diffuser conditions (Muellenhoff *et al.*, 1985; Doneker and Jirka, 1990). The dilution zone study should include a definition of input to plume models, including: discharge depth, flow rates per port, density of effluent, density gradients in the receiving water, ambient current speed and direction, diffuser port sizes, port spacing, and port orientation.
5. An evaluation of mixing beyond the zone of initial dilution may be included if current speed data are available (e.g., method of Brooks, 1960; Doneker and Jirka, 1990).

#### 4.4.2 Flushing Time Calculation

Flushing rates should be determined for estuaries which are suspected of having considerable tidal exchange. Flushing rates account for both tidal exchange and freshwater inflow. Flushing evaluations should also include characterization of refluxing, where a portion of the outflowing wastes are recirculated (recycled), thus reducing available dilution.

Flushing time is a measure of the time required to transport a conservative pollutant from some specified source location within the estuary or embayment (usually, but not necessarily, the most remote point or "head") to the mouth. Processes like pollutant decay and sedimentation, which can alter pollutant distribution within an estuary, are not considered in the concept of flushing. The flushing time and estuary volume also determine the dilution "discharge" available from tidal exchange, which is in addition to dilution available from freshwater inputs.

Two common methods are used to estimate estuary flushing. Both are described in detail in Mills *et al.* (1985) and are briefly summarized below:

1. Modified tidal prism method:
  - Segment the estuary so that each segment length reflects the excursion distance a particle can travel over one tidal cycle.
  - Calculate the exchange ratio for each segment, which is the portion of water which is exchanged with adjacent segments during each tidal cycle. The exchange ratio is the intertidal volume divided by the sum of intertidal volume and low tide volume.
  - Calculate segment flushing time as inverse of exchange ratio.
  - Calculate total estuarine flushing time by summing over all segments.
2. Fraction of freshwater method (assumes vertical stratification absent):
  - Graph the estuarine salinity profiles.

- Divide the estuary into segments selected so that salinity is reasonably constant over the length of each segment.
- Calculate each segment's fraction of freshwater based on salinity of local seawater and each segment's actual salinity.
- Calculate the quantity of freshwater in each segment.
- Calculate the exchange time in each segment as the ratio of freshwater in each segment over river discharge.
- Calculate total estuary flushing time as sum of segment flushing times.

#### **4.4.3 Far-field Approach to Pollutant Distribution**

Two general approaches are usually used in evaluating pollutant distributions in estuaries: far-field and near-field. In the far-field approach, pollutant loads are assumed to completely mix over the entire cross-section of the estuary or over a smaller portion of the estuary. The flushing rate methods discussed above are far-field methods that describe the transport of conservative pollutants. Pollutant distributions can be calculated by linking transport models (modified tidal prism or fraction of freshwater) with pollutant fate processes, which are usually described as either conservative or first-order decay.

The most common technique is to assume that the pollutant is conservative (i.e., losses only by dilution), which tends to over-predict concentrations and therefore err on the side of protecting water quality. The segmenting scheme used in the flushing rate analysis is often used in pollutant distribution calculations. Pollutant concentrations are calculated by assuming that the pollutant distribution will be identical to the freshwater distribution in the estuary segments.

#### **4.4.4 Pollutant Distributions from Sewage Outfalls**

Near-field analyses consider the buoyancy and momentum of the wastewater as it is discharged into the receiving water. The actual amount of mixing that occurs is calculated as an integral part of the method. Pollutant concentrations usually are calculated by assuming that the pollutant is conservative (i.e., loss processes are assumed to be negligible during the short period over which initial dilution occurs). This allows comparison of calculated pollutant concentrations with water quality criteria, which are applicable at the boundary of the initial dilution zone. The computer models discussed earlier are generally used to estimate initial dilution (Muellenhoff *et al.*, 1985; Doneker and Jirka, 1990).

## SECTION 5 TMDL ANALYSES

In 1971, the state of Washington enacted legislation which required dischargers to use "all known, available and reasonable methods of treatment" (AKART) prior to discharge regardless of the quality of the water to which the wastes are discharged. The requirements of AKART, also called technology-based control, represents a philosophy that all dischargers should provide a high level of treatment.

The primary mechanism for implementing Washington's water quality standards is provided under Section 303 of the Clean Water Act. Section 303(d) requires the states and EPA to establish total maximum daily loads (TMDLs) for all water quality limited segments (i.e., those waters which cannot meet standards after application of technology-based controls). The TMDL for a given pollutant is then apportioned between point sources (wasteload allocations - WLAs) and nonpoint sources (load allocations - LAs). The allocations are implemented through NPDES permits, grant projects, and nonpoint source controls. A portion of the TMDL may be set aside as a reserve to accommodate future growth. A reserve may also be allocated to provide a margin of safety in waters of particular sensitivity or complexity. Ecology's guidance for the TMDL process was recently issued by the Watershed Assessments Section (WAS, 1991).

EPA has developed a series of comprehensive technical guidance documents which describe in detail the procedures for performing TMDL/WLA/LA analyses (see Annotated Bibliography). The following discussion summarizes some of the information and techniques in these Technical Support Documents (TSDs), but the reader is advised to consult the actual TSDs before applying the concepts directly.

### **5.1 Chemical Specific Approach**

EPA has outlined two approaches to developing water quality-based WLAs for point sources: 1) chemical specific; and 2) whole effluent. Whole effluent toxicity is regulated under Chapter 173-205 WAC and is generally not included in Ecology TMDL analyses. The chemical specific approach is typically applied to conventional pollutants (e.g., BOD) or toxic pollutants on an individual basis.

#### **5.1.1 Chemical Specific Approach**

The chemical specific approach uses water quality criteria to limit specific toxicants or conventional pollutants individually. In the case of toxic substances, both acute and chronic toxicity are considered. The principal considerations of the chemical-specific approach are:

1. Treatment systems are more easily designed to meet chemical requirements if the pollutant is known.
2. The fate of the pollutant can be estimated through simulation modeling.

3. Chemical analyses may be less expensive than whole effluent biomonitoring.
4. All toxicants in complex wastewaters may not be identified.
5. Chemical analysis can be expensive, especially for organic toxicants.

### **5.1.2 Whole Effluent Approach**

The whole effluent approach to toxics control involves the use of toxicity tests to measure toxicity of effluents. An analogy between toxicity and BOD is made by EPA (1985). Both are quantifiable measurements of an aggregated biological effect. Whole effluent toxicity is expressed in "toxic units" which are the inverse of the effluent dilution that causes a toxic effect (acute toxic units are the inverse of the  $LC_{50}$  dilution; chronic toxic units are the inverse of the NOEL dilution). In modeling applications, the toxic units are treated exactly as if they were concentrations to calculate the toxicity of diluted effluent in the receiving water.

The principle considerations of the whole effluent approach are:

1. The aggregate and/or synergistic toxicity of all constituents in a complex effluent is measured, and toxic effects can be limited by limiting only one parameter -- effluent toxicity.
2. The bioavailability of toxic constituents is assessed, and the effects of constituent interactions are measured.
3. Properties of specific chemicals are not addressed.
4. Toxicity treatability data are lacking.
5. Toxicity which is "released" upon interaction of effluent and receiving water is not addressed.
6. Fate processes are not well understood and modeling is limited to simple dilution (i.e., toxicity is usually considered to be conservative in the receiving water).

### **5.2 Development of TMDL, WLA, and Permit Limits**

TMDL and WLA analyses range in complexity from very simple (e.g., single discharger, negligible nonpoint loading, and conservative pollutant) to very complex (e.g., multiple dischargers, significant nonpoint loads, and complex fate processes). Both near-field and far-field effects may be the focus of the WLA. In general, conventional pollutants like nutrients and BOD require far-field analyses, while toxicants like chlorine require near-field analyses. An interesting feature of developing TMDLs and WLAs is that existing effluent loading need not be known to determine the water quality-based WLA. The process begins with consideration

of applicable water quality criteria or standards which must be met. The available dilution and fate processes are dictated by the characteristics of the receiving water. The simplest example of a WLA (i.e., a single discharger of a toxic or conservative pollutant with no nonpoint or background load) best illustrates the water quality basis of the TMDL/WLA approach:

$$WLA = WQS * DF$$

Where WLA is the allowable effluent pollutant concentration, WQS is the water quality standard, and DF is the dilution factor in the receiving water. The background concentration (Cb) of a pollutant from unidentified or uncontrollable sources upstream can be factored into a WLA for a single discharger as follows:

$$WLA = ( WQS * DF ) - Cb * ( DF - 1 )$$

Although the existing effluent concentration is not needed to derive the WLA, it is needed to decide whether or not a water quality-based permit is required. The procedure to determine the need for permit limits is described in section 3.3 of EPA's TSD for Water Quality-Based Toxics Control (EPA, 1991).

Once a WLA is determined, section 3.3.2 of the TSD should be consulted to derive permit limits which incorporate effluent variability. WAS has developed a spreadsheet which calculates permit limits for chemical specific TMDLs for application of acute and chronic aquatic life criteria, as shown in Appendix D (WQBP2.WK1 for chemical specific toxicity). This spreadsheet also calculates WLAs for the simple case of a single discharge of a toxic or conservative pollutant and known background or upstream concentration.

## 5.2.1 Rivers and Streams

### 1. Design Conditions

A major consideration of the TMDL/WLA analysis is the design condition, which is the assumed set of conditions (i.e., quantity and quality of river and effluent) which represent an unlikely enough circumstance to meet the frequency requirement of acceptable water quality violations (e.g., no more than one violation of chronic or acute toxicity every three years). Chapter 173-201A in the WAC defines critical conditions for rivers as the 7-day-10-year low flow (7Q10) event.

Evaluation of seasonal permit limits should ensure that the risk of water quality impairment is no higher than that allowed under a nonseasonal program (Rossman, 1989; GKY and Associates, 1984). The recurrence intervals for seasonal design flows can be selected to maintain environmental equivalency with the annual 7Q10 as follows (GKY and Associates, 1984):

<u>Permit Time Interval</u>	<u>Annual Risk Equivalent Return Period (yrs)</u>
Annual	10
Semiannual	20
Quarterly	38
Monthly	114

For example, if seasonal permits are calculated for semiannual periods (six months), then the design flow for equivalent risk (annual ten percent risk) would be 7-day low flows with 20-year recurrence intervals from each six-month season.

Design parameters for other conditions of the receiving water (e.g., velocity, depth, temperature) are those which would be found during the design flow. If historical data are available, the design conditions for parameters other than flow are usually taken as restrictive values in the data record from the critical season (e.g., maximum, 95th percentile, or 90th percentile for temperature, pH, etc.), with the objective of conservatively estimating conditions present when the design flow occurs. WAS recommends the use of the most restrictive (highest or lowest) tenth percentile during the critical season from Ecology ambient monitoring data, if available, for estimating design conditions for parameters other than discharge.

## 2. BOD, Dissolved Oxygen, and Eutrophication

The considerations for TMDL modeling of D.O. are the same as those presented earlier. The Streeter-Phelps model (either in a spreadsheet like DOSAG.WK1 or in a complex river model like QUAL2E) is used to estimate the D.O. sag that will occur for a projected BOD load. A procedure to estimate the WLA from a predicted D.O. sag is presented in the TSDs.

Eutrophication problems in rivers are sometimes difficult to frame in terms of a WLA because there are no widely accepted nutrient criteria if the river is the only waterbody of concern. However, if the river discharges to a lake or reservoir, there are some general guidelines for prevention of lake eutrophication which may be used to set the riverine TMDL. For example, Ecology developed the TMDL for phosphorus loading to the Spokane River based on the protection of Long Lake, a downstream impoundment of the Spokane River.

## 3. Toxics

For single dischargers, TMDLs for toxics are most often based on near-field water quality (i.e., meeting acute criteria within the dilution zone and chronic criteria at the boundary of the dilution zone). Therefore, dilution zone characterization (through tracer or dye studies and/or plume modeling) is usually an integral part of the toxics WLA. If the dilution factor

and upstream/background conditions are known, then the WLA and permit limits can be calculated easily (e.g., using Ecology spreadsheet WQBP2.WK1; see Appendix D). However, in many cases the analysis is complicated by the presence of more than one discharger. In these instances, a TMDL must be apportioned equitably among the point and nonpoint sources, including some reserve for uncertainty and future growth. The procedures for conducting complex WLAs are somewhat site-specific and beyond the scope of this handbook.

TMDL modeling of complex systems can be simplified by assuming that the toxic substance is conservative in the receiving water. Therefore, simple dilution models can be used to predict the concentration profile in a river assuming additivity of all sources. However, this technique may tend to be overly restrictive since it does not account for processes like pollutant decay or sedimentation which tend to cleanse the system. If the outcome of dilution modeling requires very expensive or unfeasible levels of treatment, then it would be appropriate to build complexity into the modeling framework. This would be done by attempting to include fate processes in the model to account for loss mechanisms in the receiving water (e.g., sedimentation, decay, etc.). Appropriate models for evaluating toxic discharges to rivers are provided in the TSDs and in Thomann and Mueller (1987). A phased approach to adding complexity is usually best. A good rule for WLA modeling is to start with the simplest approach possible (e.g., dilution models) and only add complexity (e.g., fate processes) if the dilution model is judged to be overly conservative.

### **5.2.2 Lakes and Impoundments**

#### **1. Design Conditions**

This receiving water category encompasses lakes and reservoirs with mean residence times in excess of 15 days (WAC 173-201). Seasonal variations in water level, wind speed and direction, and solar radiation should be determined to define the critical design period. In the case of long and narrow reservoirs, areas above the plunge point (the point where stream-like flow ends and density-induced mixing and stratification begin) can be analyzed as rivers, and areas below as reservoirs.

Since effluent density relative to ambient density conditions may vary seasonally, no one season can be selected as the most critical dilution situation for all cases involving near-field studies. Therefore, near-field analyses should include an evaluation of all seasons to select the most limiting. All seasonal analyses should assume an ambient velocity of zero unless persistent currents are documented.

#### **2. Eutrophication**

TMDLs for control of eutrophication are generally designed to limit nutrient inputs. In most lakes, phosphorus is the nutrient which most limits algal growth. Therefore, phosphorus mass balance models (usually on an annual time scale) are used to predict lake

nutrient levels for various loading scenarios. The TMDL for phosphorus loading would correspond to the critical loading that would maintain the desired trophic status. The most appropriate models are presented in the TSDs. Also, Reckhow and Chapra (1983) present state-of-the-art techniques for lake eutrophication modeling.

### 3. Dissolved Oxygen

In general, D.O. modeling for lakes must account for organic matter produced within the lake by photosynthesis, as well as external inputs from point and nonpoint sources.

### 4. Toxics

The principles of conducting TMDLs for toxics in lakes are similar to those discussed for streams and rivers. Most toxics WLAs are focused on near-field effects. Therefore, dilution modeling or dye studies for characterizing mixing zones are usually an integral part of the WLA analysis.

## 5.2.3 Estuaries and Coastal Bays

### 1. Design Conditions

Determining the nature and extent of the estuarine discharge plume is complicated by tides, river inflows, wind intensity and direction, thermal and saline stratification, and other environmental factors. Because of the complexity of circulation and mixing processes, the available dilution water cannot be determined from the rate of receiving water discharge (e.g., 7Q10).

Evaluation of point sources of toxicants usually requires an analysis of effluent dilution in a mixing zone. Dilution at the boundary of a mixing zone is usually determined using models. The preferred models are PLUMES and CORMIX (Baumgartner *et al.*, 1993; Doneker and Jirka, 1990; Akar and Jirka, 1990; Jones and Jirka, 1991). Ecology's Permit Writer's Manual should be consulted for policy on applying the mixing zone rules contained in Chapter 173-201A WAC.

Dilution is usually determined at two locations: the acute and chronic mixing zone boundaries. For consideration of the acute boundary, the design conditions usually include depth at mean lower low water and the 10th percentile of current speed. For chronic dilution, the depth relative to mean sea level and median current speeds can be used for critical conditions. Other design conditions (e.g., temperature, salinity, pH) usually are taken as the 10th or 90th percentile (whichever is more limiting). Density stratification also affects dilution and usually the most restrictive density profile is considered for design.

## 2. BOD, Dissolved Oxygen, and Eutrophication

Specific guidance from EPA on TMDLs for estuarine D.O. and eutrophication problems are not yet available. In general, the principles are similar to those for lakes and reservoirs. D.O. modeling should include the effect of algal production, in addition to point source BOD loading. As in lakes, eutrophication problems are linked with D.O. problems because increased algal production results in greater internal production of oxygen demanding material. Nitrogen usually limits algal productivity more frequently than phosphorus in estuaries. However, algal productivity in estuaries is often limited by factors other than nitrogen and phosphorus (e.g., light). Therefore, eutrophication studies in estuaries require identification of specific factors that control algal growth.

## 3. Toxics

The principles of conducting TMDL analyses for toxics in estuaries are similar to those discussed for lakes. Discussion of specific elements of estuarine TMDLs for toxics is beyond the scope of this handbook. Most toxics WLAs are focused on near-field effects. Therefore, dilution modeling or dye studies for characterizing mixing zones are usually an integral part of the WLA analysis.

### 5.3 Development of TMDL and LA

The TMDL process provides flexibility to address nonpoint sources (NPS) of pollution. TMDLs can be expressed not only in terms of mass per time (i.e., a load), but also as toxicity (i.e., a toxic unit) or other appropriate measure such as a water quality target concentration or other environmental indicator. In this section we have described the TMDL process with respect to point sources, where NPS would be the residual of the measured concentration minus both known point sources and measured background levels. Waterbodies with mostly NPS usually have inadequate information (e.g., soil type, vegetation cover, evaporation, etc.) for accurately quantifying NPS contributions, and obtaining the data needed for NPS modelling is very expensive and difficult. Therefore, evaluating waterbodies with large NPS contributions may require a different approach than the evaluation of point sources, and could be a long-term program. For this reason, a "phased TMDL" approach is often appropriate for a NPS-dominated TMDL (EPA, 1991).

A phased TMDL is recommended when uncertainty is a factor, such as when loading reduction estimates involve best professional judgement, or when there is a lack of data for modelling NPS pollutant pathways. Its aim is to allow pollution reduction to proceed while data gaps are filled, especially to evaluate the effectiveness of NPS controls. A NPS allocation is implemented through application of Best Management Practices (BMPs), and includes monitoring for the effectiveness of BMPs and attainment of the TMDL criteria or water quality standards. If nonpoint source controls are found to be less effective than initially estimated in the first allocation decision, point and nonpoint source allocations may have to be adjusted or other nonpoint management techniques explored.

## SECTION 6 BIOLOGICAL SURVEYS

### 6.1 Freshwater Communities

Analysis of the biological component of freshwater ecosystems may be of value in examining habitat condition, trends over time, and cumulative impacts of pollution sources. Freshwater communities are comprised of various groups of organisms (e.g., fish, benthic macroinvertebrates, plankton, etc.). Each group may provide specific types of environmental information based on habitat requirements and the suitability of existing habitat, and should be surveyed based on the purpose of a particular investigation. The source of impact can often be identified by identifying possible point and nonpoint source impacts in the drainage.

Water quality sampling and analysis has historically been used to assess suspected environmental health problems. The use of biological information in environmental assessment integrates water quality over time, which differs from water samples that provide information for a more discrete time interval. Biotic and water quality information are complementary and explain existing or impending degradation of an aquatic environment.

Sampling the biological component of an aquatic ecosystem usually involves more effort than projects concerned solely with water sampling. For this reason, the biotic component is not included in many project efforts. The investigator may lack the experience and knowledge of the subject necessary to implement biological sampling and analysis. The purpose of this section is to provide a starting point for biological investigations. Each biotic component of the aquatic environment is discussed in terms of sample design and related considerations, equipment involved in sampling, and information that may be obtained from a survey following biological analysis. The components are further differentiated by the type of waterbody sampled: lakes and impoundments versus rivers and streams.

The first step in project planning is to formulate an objective(s) based on the types of questions asked regarding water quality and a suitable biotic indicator. These questions usually originate in aquatic ecosystems where people may have an interest, either aesthetic, recreational, or biological. A sample design should then be formulated with regard to the objective(s) and the type of analysis that will be applied to the data set. Table 3 provides a guideline of appropriate statistical data analyses for each biotic component of the aquatic environment.

The multivariate analytical techniques shown in Table 3 offer information on natural groupings within data sets. These natural groupings usually are of biological significance. Once characteristics of the natural groups have been identified, a comparison can be made to controlling physical and chemical variables in the environment, again using multivariate approaches. For example, application of principal component analysis has been used to identify significant variations in water quality within and among waterbodies.

Table 3. Methods for assessing freshwater communities.

Analytical Technique	Macro- phytes	Peri- phyton	Plank- ton	Inverte- brates	Fish	Habitat
Similarity Index	X	X	-	X	X	-
Diversity Index	-	X	X	X	X	-
Cluster Analysis	X	X	X	X	X	-
Ordination <sup>1</sup>	-	X	-	X	X	X
-Reciprocal Averaging						
-Detrended Correspondence						
-Principal Components <sup>3</sup>						
Rapid Bioassessment <sup>2</sup>	-	-	-	X	X	-
Hilsenhoff Biotic Index <sup>4</sup>	-	-	-	X	-	-
Index of Biotic Integrity <sup>5</sup>	-	-	-	-	X	-
Discriminant Analysis <sup>6</sup>	-	-	-	-	X	-
TWINSPAN <sup>7</sup>	-	X	-	X	-	-

<sup>1</sup>Rohm *et al.* (1987)

<sup>2</sup>EPA (1989)

<sup>3</sup>Whittier *et al.* (1988)

<sup>4</sup>Hilsenhoff (1977)

<sup>5</sup>Karr *et al.* (1986)

<sup>6</sup>Larsen *et al.* (1986)

<sup>7</sup>Whittier *et al.* (1987)

Habitat evaluation is an important component of any biological survey and should be designed to reflect the type of habitat impairment. For example, agricultural practices such as cattle grazing can increase bank erosion; forest practices such as logging can increase sediment transport to stream beds. There are many other potential stream effects caused by these activities which depend upon site specific characteristics. Information on the study area habitat will help in interpreting the biological community structure data. There are numerous protocols for habitat evaluation provided in Plafkin *et al.* (1989), Ralph (1990), and Cupp (1989). Plafkin's method is viewed as the most appropriate for Ecology's surveys because it is a rapid assessment technique. The method used in habitat evaluation should be consistent over time to adequately reflect habitat changes.

The sample design considerations which follow address some general points that should be considered when initiating a project. These considerations are important design characteristics derived from several standard sources (Slack *et al.*, 1973; Weber, 1973; Hellawell, 1978; APHA *et al.*, 1989). Sample design varies widely among projects, thus the rationale for consulting more than one reference. The sources cited above comprehensively review techniques that are only summarized in this document. Those standard sources should be consulted for detailed guidelines in implementing a biological survey.

### 6.1.1 Periphyton

#### General Sampling Considerations:

The autotrophic community often exhibits the first signs of impending environmental stress. In order to determine the effect of an impact on the periphyton community, the sample design should include a good control station to define the ambient condition, as well as stations located within, and downstream of, the impact zone. Examination of the periphyton community requires effort by an individual experienced in taxonomy and sampling methods.

#### 1. Sample design for lakes and impoundments

- Sample sites should be located adjacent to areas of concern and also in an unaffected reference area.
- Sampling should be restricted to depths within the euphotic zone.

#### 2. Sampling design for rivers and streams

- Sample sites should be spatially located above the pollution source and at one or more points below the pollution input.
- Larger streams should be sampled on both margins.

#### 3. Sampling technique

- Scrape submerged natural substrate of known area for quantitative estimates (e.g., stones). Uniformity of habitat characteristics should be maintained among the sample sites: depth, water velocity, light penetration.
- An alternative is to set an artificial substrate in the aquatic environment for a period of 2-6 weeks (e.g., glass slides, 25 x 75 mm). Note: the slide face should be set at an angle perpendicular to the prevailing current in rivers and streams.

#### 4. Potential survey information:

- Population structure
- Abundance estimates
- Spatial distribution
- Chlorophyll *a* (biomass indication)

## **6.1.2 Phytoplankton and Zooplankton**

Plankton populations are often surveyed as an indicator of the trophic status of lentic waterbodies. The presence of certain taxa may indicate a nutrient enriched condition, in which case source control could be in order. Studies of phytoplankton production may be useful in understanding nutrient cycling within a waterbody. Sedimentation of diatoms conveys information regarding the historical record of diatom population growth within a waterbody, which in turn may give clues about the eutrophic history of an aquatic system.

### **1. Sample Design for Lakes and Impoundments**

- Sampling should occur at regular depth intervals (e.g., 1 meter intervals from surface-to-bottom for zooplankton).
- Composites of plankton samples from depth intervals may provide a general description of community structure.
- Zooplankton samples may be taken from the epilimnion, metalimnion, and hypolimnion, but phytoplankton sampling is usually restricted to the euphotic zone.
- Sampling should be carried out on a monthly basis, although survey objectives may indicate a more or less rigorous sampling regime.

### **2. Sampling Design for Rivers and Streams**

- Routine monitoring of rivers and streams is not advised due to the highly variable nature of plankton distribution in running water.

### **3. Phytoplankton Samplers**

- Kemmerer bottle
- Van Dorn bottle

### **4. Zooplankton Samplers**

- Clarke-Bumpus
- Wisconsin net

### **5. Potential Survey Information**

- Population structure
- Abundance estimates
- Spatial distribution

## 5. Potential Survey Information (continued)

- Biomass determination (cell volume AFDM)
- Chlorophyll *a* (phytoplankton biomass indication)
- Production/respiration (light/dark bottle)

### 6.1.3 Macrophytes

Macrophytes serve as a food source, habitable substrate, and protection for various aquatic organisms. Proliferation of macrophytes in an aquatic environment often indicates a eutrophic status of a waterbody. Location of macrophyte growth may be an indication of nutrient sources within an aquatic system. Once macrophytes have appeared in a lake or riverine environment, eutrophication has probably reached moderate to advanced stages where sediments and/or water column nutrients are prevalent. Sampling aquatic macrophytes is conducted by locating a control station or transect where the unaffected condition can be determined. Areas in the waterbody where suspected nutrient input has been identified should be sampled for comparison to the control condition.

#### 1. Sample Design for Lakes and Impoundments

- Divide waterbody into regions or blocks and randomly sample a predetermined number of blocks.
- Establish randomly positioned transects within the blocks.
- Remove macrophytes from an area encompassed by a quadrant (e.g., 1 m<sup>2</sup>) that is placed at equal intervals along the length of the transect.

#### 2. Sampling Design for Rivers and Streams

- Same as above, except that sampling should be conducted from a downstream location with successive collection in an upstream direction. This method minimizes the risk of contaminating downstream sites via upstream plant removal.

#### 3. Potential Survey Information

- Population structure
- Spatial distribution
- Standing crop (dry weight)

### 6.1.4 Macroinvertebrates

Benthic macroinvertebrate communities provide information regarding habitat condition and suitability for colonization. Much attention has recently been given to assessment of the

biological component of aquatic environments using benthic macroinvertebrates as an indicator group. Macroinvertebrate population and community metrics are useful in defining available food resources, the influence of the physical/chemical environment, and ecological interactions among taxa. Benthic macroinvertebrate communities are best examined under similar habitat conditions in both control and impacted sites. Differences in community structure and function between control and impacted sites are more easily attributable to pollution sources when habitat differences are minimized.

#### 1. Sample Design for Lakes and Impoundments

- Site placement should be based on simple- or stratified random sampling procedures.
- Whole lake transects should be sampled so as to represent all depths.
- Transects may radiate out on a short or long axis from pollution sources or reference sites.

#### 2. Sampling Design for Rivers and Streams

- Site placement should be based on simple- or stratified random sampling procedures.
- Samples should be taken upstream and downstream of pollution sources.
- Rapid bioassessment techniques (EPA, 1989; especially protocol #2) have been used by WAS investigators in past surveys.

#### 3. Sampling Equipment

- Lakes: Ekman, Petersen, and Ponar grabs.
- Rivers: Kick net, Surber sampler, modified Hess sampler, artificial substrates, and drift nets.

#### 4. Potential Survey Information

- Population structure
- Abundance estimates
- Spatial distribution
- Trophic structure
- Similarity/diversity

### **6.1.5 Fish**

Fish surveys frequently define the presence/absence of populations in sample regions. Habitat evaluation is an important consideration when sampling for fish due to preferences exhibited by each species. Fish surveys represent a larger-scale investigation based on natural or anthropogenic habitat alteration within a drainage. Fish communities often reflect the quality of the physical and chemical environment of a given location. Investigations of point source influences on receiving water are usually approached by identifying an upstream control site and comparing this fish assemblage to that found in a downstream receiving site.

#### **1. General Sampling Considerations**

- Sampling permit from the Washington State Department of Wildlife is required.
- Sampling should be carried out in areas of the drainage in which the target species is located (i.e., specific habitats).
- Consideration should be given to general land use adjacent to the drainage or waterbody which may be a source of pollution input.
- Avoid choosing sample sites for their convenient access. One of the following sampling designs should be used based on the type of habitat found in the waterbody: simple random sampling, stratified random sampling, clustered sampling, or systematic sampling (Nielsen and Johnson, 1983).

#### **2. Sampling Equipment**

- Lakes: electrofishing, hook and line, gill net, fyke net, seines, setlines, popnets.
- Rivers: electrofishing, hook and line (see also rapid bioassessment protocols IV and V; EPA, 1989).

#### **3. Potential Survey Information**

- Spatial distribution
- Abundance estimates
- Species composition

### **6.2 Fish and Shellfish Tissue**

Surveys may sometimes involve sampling of fish or shellfish tissue for conventional or toxic parameters. Pollutants can accumulate in aquatic organisms through exposure to ambient water (bioconcentration) or ingestion of contaminated food (bioaccumulation). Both exposure routes

could produce measurable levels of pollutants which may have gone unnoticed in periodic water sampling.

The following discussion is divided into two sections, conventionals and toxics. A brief overview of sampling and analysis is provided for each, but the reader is advised to consult other texts, like the Puget Sound Protocols (PSEP, 1986) for additional information.

### **6.2.1 Conventional Pollutants**

Surveys of conventional pollutants in tissue usually concern contamination of edible marine shellfish with fecal coliform bacteria. Tissue sampling for fecal coliform is often accompanied by water column sampling in order to identify potential sources of bacterial contamination. A few considerations:

1. A species of local recreational or commercial importance should be selected (e.g., pacific oysters, little neck clams, bay mussels, etc.).
2. A composite sample will be required to achieve the minimum tissue bulk required for analysis (200 g). The number of organisms per composite will vary with organism size, but a general guideline would be 10 oysters, 15 clams, or 20 mussels.
3. If local shellfish populations are of insufficient size or otherwise incompatible with sampling design considerations, shellfish can be collected from a remote site, placed in plastic mesh bags with suitable substrate, and transplanted into the area of interest for a 2-4 week exposure period prior to sampling. A potential problem with this approach, however, is sample security (e.g., from vandalism). Also be aware that you may need a special permit to "transplant" shellfish to your study area.
4. Sampled organisms should be rinsed with on-site sea water, sealed in plastic bags, iced, and transported within 24 hours to a laboratory for analysis by the multiple-tube fermentation technique (MPN).
5. Analytical results should be compared to the marketability standard of 230 fecal coliform per 100 g tissue (MPN) set by the U.S. Food and Drug Administration (FDA) and Washington State Department of Health.

### **6.2.2 Toxic Pollutants**

Tissue studies conducted by Ecology more often concern toxic rather than conventional pollutants. There are a number of guidance documents that provide specific information on conducting tissue studies (EPA, 1989; USGS, 1992; EPA, 1993). The following are a few points of guidance for the assessment of toxic substances in tissue.

1. Fish are most often the group of concern, but freshwater and marine shellfish may be more appropriate in certain circumstances. The target species should preferably be consumed by humans (health issue) and widely distributed in the area of interest (to allow among-site comparisons). However, the choice of a target organism may be dictated by your sampling success or the success of others (e.g., if you intend to compare your results to that of other investigators, you should collect the species they collected). Sampling of species from different trophic levels (e.g., grazer vs. predator) may be insightful if biomagnification of toxicants through the food chain is suspected.
2. The optimal sampling season will depend on habitat constraints and the life history characteristics of the target organism. For example, sampling of edible fish tissue during a spawning season may produce misleading results given that the energy stores (lipids) of sexually maturing fish are often catabolized to support gonad development.
3. The type of tissue sampled will depend on project-specific considerations. For example, if the target species is a game fish consumed by humans, the ideal tissue to sample would be skinless muscle fillets. However, if the target fish species is consumed by predators like eagles, a whole-fish sample would be more appropriate. If the contaminant of concern accumulates in a particular part of the organism, the affected tissue or organ may be sampled via dissection.
4. Composite sampling can be employed to reduce variability among individual organisms and assure adequate sample for analysis. However, data on population variance is lost with use of composites. If the objective is to determine potential human exposure, then composite samples may be appropriate; if the objective is to quantify the distribution of toxic substances in a specific fish species in order to assess the potential for ecosystem bioaccumulation/bioconcentration, then individual fish samples should be collected, and length, weight, and age of the fish noted.

Composite samples should consist of several organisms (or parts thereof) for each species collected at a site. If possible, organisms representative of the same age class or size class should be used for composite samples. The number of organisms per composite will vary with organism size, but a general guideline would be 5 fish, 10 oysters, 15 clams, or 20 mussels.

5. Collected fish (or invertebrates) should be individually wrapped in aluminum foil (dull side in), sealed in labeled plastic bags, and iced. (NOTE: If the sample is for metals analysis, skip the foil and place organisms directly into plastic bags.) Shellfish should be afforded a 24-hour depuration period in on-site water to allow for sediment to clear the alimentary canal.
6. Fresh fish should be processed as soon after collection as possible, or frozen until a later date. Processing should occur in a clean environment, preferably a laboratory. Tissues should be dissected with scalpels and ground with a blender or commercial meat grinder.

All dissecting and grinding equipment should be stainless steel or glass, and pre-cleaned using (in order) Liqui-Nox® or equivalent detergent, hot tap water, 10 percent nitric acid, deionized water, and nanograde acetone (note - acetone is only required if organic toxicants are involved). Equipment should be oven-dried after cleaning to evaporate traces of acetone.

7. Toxicant scans should be accompanied by subsample analyses for total solids and percent lipids so that data can be corrected to dry weight and normalized for fat content (organic toxicants typically associate with lipids).
8. Contaminant levels in tissue suitable for human consumption may be related to FDA action levels for human health, EPA risk assessment guidelines for human carcinogens, and/or EPA acceptable daily intake levels for non-carcinogens (FDA 1985; EPA 1989). Toxicant levels in whole fish may be compared to maximum predatory concentrations recommended by the National Academy of Sciences (NAS/NAE 1973) or U.S. Fish and Wildlife Service (e.g., Eisler 1985, 1987).

Additional guidance for conducting bioaccumulation studies may be found in Callahan *et al.* (1979a,b), Mabey *et al.* (1982), and Tetra Tech Inc. (1985).

## SECTION 7 SEDIMENT CONTAMINATION SURVEYS

Assessment of sediment quality may be a priority objective on some surveys. Sediment quality can be affected by both conventional and toxic pollutants, though the latter are usually of most concern. The following discussion addresses some considerations in designing and performing sediment studies. The reader should consult pertinent references, like the Puget Sound Protocols (PSEP, 1986), for additional details.

### 7.1 Conventional Pollutants

Conventional parameters which are sometimes of interest in aquatic sediments include organic matter, nutrients, and bacteria. Organic material, measured as total volatile solids, may be of concern in receiving waters which are subject to organic solids loading (e.g., from fish hatcheries). Sediment core sampling for nitrogen and phosphorus can provide a long-term history of nutrient loading rates to lakes (atmospheric fallout of cesium-137 or lead-210 serves as a reference for dating the core). Bacteria, specifically fecal coliform, can remain viable in sediment if substrate quality and food resources are adequate. During freshets, increased flows can disturb accumulated sediments and resuspend bacteria, thus sediments may be a significant source of bacterial loading in some systems. In practice, sediment monitoring for organic matter, nutrients, and bacteria is rarely conducted during Ecology surveys.

### 7.2 Toxic Pollutants

Toxicants dissolved in water often adsorb onto suspended particles which eventually settle and accumulate as sediment. Consequently, sampling of stream or lake sediments can provide a historical record of chemical conditions in the overlying water. Water sampling programs may fail to detect toxicant contamination if levels are below detection limits or toxicant inputs are sporadic. In these instances, sediment sampling may be considerably more revealing. Here are some guidelines for sediment toxicant monitoring:

1. Sampling should be performed in depositional areas, like pools, embayments, or back-eddies. If depositional areas are unavailable, the sampler should seek sites where fine sediments (clays, silts, and detritus) are abundant relative to sandy or coarse sediments.
2. Ponar and Van Veen grab samplers are useful in lakes and slow-moving rivers or streams. In faster waters, an Emery pipe dredge should be used. River sediments tend to be scoured during high flows, thus sampling should be timed toward the end of low flow season.
3. The top 2 cm of sediment should be taken for analysis; avoid material which has come in contact with the sides of the sampling instrument. Samples collected with a pipe dredge may be too well mixed to separate surficial sediments; if so, make note of the approximate

depth of sampling (e.g, 4-5 cm of sediment). A composite of two or more samples may provide a more representative sample and will assure adequate sample for analysis.

4. Individual or composite samples should be homogenized using beakers and spoons, placed in priority-pollutant cleaned glass jars with teflon-lined lids, iced, and shipped to the laboratory for analysis. Sediment samples for volatile organics analysis should be taken from the grab sample prior to homogenizing and placed in glass vials with teflon-lined septa caps.
5. Sampling and homogenization equipment should be stainless steel and pre-cleaned using (in order) Liqui-Nox<sup>®</sup> or equivalent detergent, hot tap water, 10 percent nitric acid, deionized water, and nanograde acetone (acetone is not required if only metals are being sampled). Sampling gear should be well rinsed with ambient water between sampling sites, and sampling should proceed in order of anticipated increasing contamination. If possible, a sufficient number of beakers and spoons should be pre-cleaned to allow use of uncontaminated homogenization equipment at each site.
6. Subsamples should be taken for total solids, grain size, and TOC determination in order to correct results to dry weight and normalize for particle size and organic carbon (TOC and fines, like silt or clay, can greatly affect the ability of sediments to adsorb both organic and inorganic toxicants). Correlation analysis can assist in determining if normalization is appropriate.
7. Sediment core sampling, especially in lakes, may provide a long-term history of sediment contamination. Atmospheric fallout of cesium-137 or lead-210 can serve as a reference for dating core segments.
8. Detection of toxicants in relatively high concentration may dictate the need for sediment toxicity bioassays.

Additional information concerning the environmental fate of priority pollutants may be found in Callahan *et al.* (1979a,b) and Mabey *et al.* (1982).

## SECTION 8 REPORTING CONSIDERATIONS

### 8.1 Data Management

Data management is an important process in any water quality assessment program. Data management includes the recording process for collecting, analyzing, reporting, transferring, and storing data. The data management process should be defined during the planning phase of a data collection project, and includes preparing forms (field and laboratory) and procedures for entering data (on forms or in computer files).

Uniformity in data reporting formats allows data to be more easily transferred, and allows data users access to a much larger base of information. It is a goal of Ecology that collected data be reported in compatible formats. Ecology currently does not have an agency standard for data management. However, the Puget Sound Water Quality Authority (PSWQA) outlined a format for data storage which Ecology uses as an example of an appropriate data management system for water quality data. This format is designed to include all aspects of water quality data collection and laboratory analysis results. The PSWQA database was created to address environmental monitoring programs in Puget Sound. However, it also can be used for other water quality database management applications.

The PSWQA data format recommendations are described in PSWQA (1991). A description of each file type, and an outline of file components are detailed in this document. An example of the PSWQA format is presented in Tables 4 and 5. Database files should contain basic information regarding sampling location, date, time, collection method, water quality information, and analytical methods.

A data file should consist of information collected from a single "survey" where water samples are continuously collected over the period of one or more days. The file format includes a field or column called SURVEY ID which is unique to each sampling session within the monitoring program.

An example of the data entry for two parameters, fecal coliform and total phosphorus, into a spreadsheet using the PSWQA format is displayed in Table 6. First, note that the SURVEY ID name may be used to describe the watershed being sampled. The SURVEY ID changes between sampling DATE. PERIOD describes the amount of time taken to sample a given station. UPPERDEPTH and LOWERDEPTH describe the vertical range in the water column within which water samples are collected. VARIABLE lists the standardized code name for the applicable water quality parameter. VALUE is the concentration or count of a particular parameter. QUALIFIER is a coded comment on the numeric data value. In this example data file, there are no qualifiers for the fecal coliform or total phosphorus data reported so the column is blank. SIGNIFICANT DIGITS refers to the number of significant figures in which the value of the parameter is reported. METHOD denotes coded information that is listed

Table 4. Field Observation File Specifications.

Field Name	Description	Maximum Field Length	Required ?	Codes
SURVEY ID	Identification of monitoring survey	8	Y	
STATION ID	Identifier for station	8	Y	
DATE	Date of observation/sample collection (yymmdd format)	6	Y	
TIME	Time of observation/sample collection (military format)	4	Y	
PERIOD	Period over which sample was collected (hhmm)	4	Y	
UPPER DEPTH	Upper depth where observation was made (nearest .1 m)	6	Y	
LOWER DEPTH	Lower depth where observation was made (nearest .1 m)	6	Y	
TIDE STAGE	Code for tide stage at which observation was made	1	N	1 = Ebb 2 = Ebb Slack 3 = Flood 4 = Flood Slack
VARIABLE	Variable measured or observed	10	Y	FLOW = flow DO = dissolved oxygen WTEMPERATUR = temperature, water TURBIDITY = turbidity CONDUCT = conductivity pH = pH WATERDEPTH = water depth
VALUE	Value of variable reported	10	Y	
QUALIFIER	Description to guide in interpretation of data	1	N	
SIGNIFICANT DIGITS	Number of significant digits reported in data value	1	N	
METHOD	Code for methods used	8	Y	OA = Dissolved oxygen-Winkler/Carpenter OB = Dissolved oxygen-Probe/Electrode T1 = Turbidity-Turbidometer T2 = Turbidity-Transmissometer (1 cm path) T3 = Turbidity-Fluorometer T4 = Turbidity-Nephelometer T5 = Turbidity-Transmissometer (10 cm Path)

Table 4. (Continued)

Field Name	Description	Maximum Field Length	Required ?	Codes
QUALITY LEVEL	Quality assurance level assigned to data by reviewer	1	N	1=Data collected in accordance with Puget Sound Protocols or methods acceptable for PSAMP and there are no data quality problems 2=Same as above except problems arose and were corrected 3=Data was not collected in accordance with protocols or quality control problems could not be corrected 4=Data were lost
UNITS	Units in which data value is reported	2	Y	MS=ppm (mg/kg) ML=ppm (mg/L) DC=degrees celsius UC=umhos/cm MC=meters/sec PH=pH
MEASUREMENT BASIS	Weight basis for data value measurement (wet or dry)	1	N	D=dry weight W=wet weight

Table 5. Water Chemicals/Conventionals File Specifications.

Field Name	Description	Maximum Field Length	Required ?	Codes
SURVEY ID	Identification of monitoring survey			
STATION ID	Identifier for station	8	Y	
DATE	Date of observation/sample collection (yymmdd format)	8	Y	
TIME	Time of observation/sample collection (military format)	6	Y	
PERIOD	Period over which sample was collected (hhmm)	4	Y	
UPPER DEPTH	Upper depth where observation was made (nearest .1 m)	4	Y	
LOWER DEPTH	Lower depth where observation was made (nearest .1 m)	6	Y	
TIDE STAGE	Code for tide stage at which observation was made	6	Y	
		1	N	1 = Ebb 2 = Ebb Slack 3 = Flood 4 = Flood Slack
VARIABLE	Variable measured or observed	10	Y	AMMONIA = Ammonia, Total (ug/L) PHOSPHATE = Phosphorus, Total (ug/L) ORTHO PHOS = Ortho Phosphorus (ug/L) NO3-N = Nitrate (ug/L) NO2-N = Nitrite (ug/L) TOT SOLIDS = Total Suspended Solids (mg/L) ALUMINUM = Aluminum (ug/L) ANTIMONY = Antimony (ug/L) ARSENIC = Arsenic (ug/L) CADMIUM = Cadmium (ug/L) CHROMIUM = Chromium (ug/L) COPPER = Copper, Total (ug/L) IRON = Iron (ug/L) LEAD = Lead (ug/L) MANGANESE = Manganese (ug/L) MERCURY = Mercury, Total (ug/L) NICKEL = Nickel, Total (ug/L) SILVER = Silver (ug/L) ZINC = Zinc (ug/L) CATIONS = Cations (mg/L) ANIONS = Anions (ng/L) FECALCOLIF = Fecal Coliform (MPN/100 mL) HARDNESS = Total Hardness (mg/L) ALKLNTY = Alkalinity (mg/L)

Table 5. (Continued)

Field Name	Description	Maximum Field Length	Required ?	Codes
VALUE	Value of variable reported	10	Y	
QUALIFIER	Description to guide in interpretation of data	1	N	
SIGNIFICANT DIGITS	Number of significant digits reported in data value	1	N	
METHOD	Code for methods used	8	Y	P8603CS=Recommended methods for analysis of sediment conventionals SM85CW=Standard Methods (APHA 1985) P8608M-CVAA=Cold vapor atomic absorption spectrometry P8608M-GFAA=Graphite furnace atomic absorption spectrometry P8608M-ICP=Inductively coupled plasma emission spectroscopy P8608M-HGAA=Hydride generation atomic absorption P8610F-SW=Recommended methods for fecal coliform analysis in water or sediment
QUALITY LEVEL	Quality assurance level assigned to data by reviewer	1	N	1=Data collected in accordance with Puget Sound Protocols or methods acceptable for PSAMP and there are no data quality problems 2=Same as above except problems arose and were corrected 3=Data was not collected in accordance with protocols or quality control problems could not be corrected 4=Data was lost
UNITS	Units in which data value is reported	2	Y	MS=ppm (mg/kg) ML=ppm (mg/L) DC=degrees celsius UC=umhos/cm MC=meters/sec PH=pH
MEASUREMENT BASIS	Weight basis for data value measurement (wet or dry)	1	N	D=dry weight W=wet weight

Table 6. Formatted data file following the PSWQA recommendations for standardization of data reporting.

Survey ID	Station ID	Date	Time	Period	Upper- depth	Lower- depth	Variable	Value	Qualifier	Signif	Method	QA Level	Units	Variable	Value	Qualifier	Signif	Method	QA Level	Units	
AnyCrk1	P1.3	881221	0833	0015	0.1	0.3	FECALCOLIF	20		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.200		3	P8603CS	1	ML	
AnyCrk1	P2.5	881221	1053	0010	0.1	0.3	FECALCOLIF	520		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.130		3	P8603CS	1	ML	
AnyCrk1	P5.2	881221	1130	0010	0.1	0.3	FECALCOLIF	220		2	SM85CW	1	MPN/100ml								
AnyCrk1	P6.0	881221	0924	0015	0.1	0.3	FECALCOLIF	530		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.340		3	P8603CS	1	ML	
AnyCrk1	P7.3	881221	1310	0015	0.1	0.3	FECALCOLIF	250		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.370		3	P8603CS	1	ML	
AnyCrk1	F0.8	881221	1325	0010	0.1	0.3	FECALCOLIF	32		2	SM85CW	1	MPN/100ml								
AnyCrk1	F4.3	881221	1345	0015	0.1	0.3	FECALCOLIF	66		2	SM85CW	1	MPN/100ml								
AnyCrk1	UN2.0	881221	1500	0015	0.1	0.3	FECALCOLIF	49		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.120		3	P8603CS	1	ML	
AnyCrk1	P3.7	881221	1415	0015	0.1	0.3	FECALCOLIF	66		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.100		3	P8603CS	1	ML	
AnyCrk1	UN5.4	881221	1545	0010	0.1	0.3	FECALCOLIF	3		2	SM85CW	1	MPN/100ml								
AnyCrk1	P7.1	881221	1010	0015	0.1	0.3	FECALCOLIF	170		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.150		3	P8603CS	1	ML	
AnyCrk1	UN8.0	881221	1235	0010	0.1	0.3	FECALCOLIF	170		2	SM85CW	1	MPN/100ml								
AnyCrk1	F2.5	881221	1212	0010	0.1	0.3	FECALCOLIF	20		2	SM85CW	1	MPN/100ml								
AnyCrk2	UN2.0	890109	0855	0015	0.1	0.3	FECALCOLIF	75		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.170		3	P8603CS	1	ML	
AnyCrk2	P3.7	890109	1230	0010	0.1	0.3	FECALCOLIF	26		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.150		3	P8603CS	1	ML	
AnyCrk2	UN5.4	890109	1125	0010	0.1	0.3	FECALCOLIF	110		2	SM85CW	1	MPN/100ml								
AnyCrk2	P7.1	890109	1030	0015	0.1	0.3	FECALCOLIF	370		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.320		3	P8603CS	1	ML	
AnyCrk2	UN8.0	890109	1430	0015	0.1	0.3	FECALCOLIF	240		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.440		3	P8603CS	1	ML	
AnyCrk2	F2.5	890109	1420	0010	0.1	0.3	FECALCOLIF	200		2	SM85CW	1	MPN/100ml								
AnyCrk2	P1.3	890109	1450	0015	0.1	0.3	FECALCOLIF	80		2	SM85CW	1	MPN/100ml								
AnyCrk2	P2.5	890109	1510	0015	0.1	0.3	FECALCOLIF	210		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.120		3	P8603CS	1	ML	
AnyCrk2	P5.2	890109	1600	0015	0.1	0.3	FECALCOLIF	210		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.220		3	P8603CS	1	ML	
AnyCrk2	P6.0	890109	1552	0010	0.1	0.3	FECALCOLIF	63		2	SM85CW	1	MPN/100ml								
AnyCrk2	P7.3	890109	1147	0015	0.1	0.3	FECALCOLIF	330		2	SM85CW	1	MPN/100ml	PHOSPHATE	0.150		3	P8603CS	1	ML	
AnyCrk2	F0.8	890109	1335	0010	0.1	0.3	FECALCOLIF	120		2	SM85CW	1	MPN/100ml								
AnyCrk2	F4.3	890109	1315	0010	0.1	0.3	FECALCOLIF	6		2	SM85CW	1	MPN/100ml								

in Table 4; each of the codes describes a method outlined by a standard guide. QALEVEL (QUALITY LEVEL in Table 4) refers to the reliability of the data based on a quality assurance determination. Finally, UNITS correspond to the measurement basis of the reported data values.

Although the PSWQA database format provide for a good data management system, other formats can be used as long as they are sufficiently documented. An example of a data spreadsheet with field and laboratory measurements that do not follow the PSWQA formats is presented in Table 7. Note that there are two sample dates with 13 sites and 12 parameters for Anywhere Creek, WA. Not all parameters were measured at each site, which explains the blank cells in the spreadsheet. In order to transfer the data presented in Table 7, a data dictionary would have to be created which provides information on the contents and structure of the database (e.g., define: variable names, units of measurements, data qualifiers, etc.).

Each data file may contain one or more water quality parameters. The decision on how many parameters are included in each data file is left to the discretion of the investigator. For example, one may wish to separate nutrient and physical data into separate data files. On the other hand, it may be more convenient to retain all data from a particular survey in a single file. Individual data files should eventually be combined into a database. Creating a database facilitates different combinations of data queries.

Sample station locations should be archived along with the data. The location of sampling stations should be plotted on a U.S. Geological Survey 1:24000 (if coverage is available) or 1:62500 series topographic maps. Sampling stations should be clearly labeled with STATION ID designations.

## **8.2 Data Analysis and Presentation**

One of the most difficult parts of any water quality assessment project is determining how the data should be analyzed and presented based on the original study objectives. All too often, investigators impose their personal bias into the data analysis process. In order to maintain objectivity, investigators normally rely on statistical methods for the reduction and analysis of water quality data. If water assessment studies are properly designed, the need for qualitative interpretation of the data can be replaced by statistical testing. This is not to suggest that qualitative judgements are not needed, but the data should be analyzed and presented as objectively as possible.

The scope and breadth of statistics is formidable. Persons interested in developing an understanding of statistical design and analysis of environmental data should consult basic textbooks on the subject, such as Biostatistical Analysis by Zar (1984) or Biometry by Sokal and Rohlf (1983). However, there are a number of issues relative to water quality data that are particularly important to understand in applying statistical analyses and presenting data. The following is a brief discussion of some of those important considerations.

Table 7. Raw data table for Anywhere Creek, WA.

Anywhere Creek, WA

Date	Station	Temp (°C)	Cond (umhos)	pH	DO (mg/L)	Flow (CFS)	Turb (NTU)	TSS (mg/L)	NO3+NO2 (mg N/L)	NH3 (mg N/L)	TP (mg P/L)	FC (#/100 mL)	BOD5 (mg O2/
12/20/88	P1.3	5.25	171	6.99	8.72	46.67	3	6	2.600	0.530	0.200	20	3 U
12/20/88	UN2.0	5.69	105	6.6	9.01	3.89	2	4	0.970	0.050	0.130	520	
12/20/88	P2.5	5.51	186	6.99	5.28			2				220	
12/20/88	P3.7	5.62	172	6.94	6.02	36.75	2	6	2.200	0.370	0.340	530	3
12/20/88	P5.2	5.47	171	6.97	8.5	20.18	3	4	2.000	1.200	0.370	250	
12/20/88	UN5.4	5.70	201	7.06	6.07			2				32	
12/20/88	P6.0	6.73	217	7.29	8.44			3				66	
12/20/88	P7.1	4.77	81	7.23	12.72	11.15	2	4	2.000	0.020	0.120	49	3 U
12/20/88	P7.3	4.63	82	7.15	12.37	5.30	3	2	1.800	0.020	0.100	66	
12/20/88	UN8.0	6.76	154	7.01	10.8			4				3	
12/20/88	F0.8	4.32	109	7.18	12.34	14.69	3	8	2.500	0.030	0.150	170	3 U
12/20/88	F2.5	4.58	106	7	11.91			9				170	
12/20/88	F4.3	5.52	102	7.19	11.72			8				20	
01/09/89	P1.3	4.44	140	6.77	9.44	72.95	3	26	2.900	0.080	0.170	75	3 K
01/09/89	UN2.0	5.00	100	6.24	9.45	4.85	2	7	1.200	0.050	0.150	26	
01/09/89	P2.5	4.82	167	6.75	6.27			2				110	
01/09/89	P3.7	4.71	155	6.72	7.19	34.71	2	7	2.200	0.200	0.320	365	3 K
01/09/89	P5.2	4.86	157	6.81	9.06	29.15	3	6	2.200	1.000	0.440	240	
01/09/89	UN5.4	5.33	207	6.92	5.99			2				200	
01/09/89	P6.0	6.46	210	7.2	8.76			3				80	
01/09/89	P7.1	4.21	76	7.09	12.85	18.65	3	6	2.100	0.010	0.120	210	3 K
01/09/89	P7.3	4.11	75	6.68	12.44	9.74	3	5	2.100	0.110	0.220	210	
01/09/89	P8.1	4.11	63	7.29	12.75			5				63	
01/09/89	F0.8	3.54	97	6.84	12.41	29.45	3	28	2.500	0.060	0.150	330	3 K
01/09/89	F2.5	4.21	99	7	11.99			12				120	
01/09/89	F4.3	4.80	95	7.2	12.15			9				6	

88

As mentioned in Section 3, data analysis should be considered during the design of the project to avoid collecting spurious data. When analyzing water quality data, it is important to be aware if they are autocorrelated; non-normally distributed; contain trends (e.g., seasonal); overly emphasize a particular time period; or contain observations below detection limits (censored).

These data characteristics can be a problem if not recognized. For example, the assumption that water quality data are distributed normally may lead to misinterpretation of a non-normally distributed parameter (e.g., fecal coliform data). There are statistics and procedures to apply to a data-set to test, and in some cases, correct the data. In the book, Engineering Approaches for Lake Management by Rechow and Chapra (1983) these issues and the concept of "robust" statistics are reviewed (is the statistic appropriate, even when underlying assumptions are violated?).

After analysis, data are best presented with simple figures and tables. Avoid generating figures that rely on color for clarification, because these do not easily reproduce. Also avoid three-dimensional drawings unless they are very clear, because usually only the author knows what they mean. Finally, make sure each figure and table is self-explanatory (i.e., can stand on its own). Captions should clearly explain the content and footnotes should be used to highlight anything that might be unclear. A reader should not have to cross-reference text or other figures and tables to understand the content of a figure or table.

### 8.3 Reporting

After the data analysis is completed, it is time to write up the findings of the study. The underlying goal of the study report should be to address the original objectives stated in the project plan. The report should be focused toward deriving concise conclusions and recommendations based on the original objectives. If the project failed to achieve one or more of the original objectives, it should be stated in the conclusions and recommendations section of the report why they could not be met.

The following are some general considerations for report preparation:

1. The format of reports is not fixed. However, there are some things that are included in most reports. The example table of contents in Appendix E lists some of the more important sections which a report should cover.
2. The report should be clear and accurate. Jargon should be avoided; simplicity in style is preferred. Strive to be concise -- don't spend a paragraph to make a point when a sentence will suffice.
3. In final form, the narrative portion of reports should not exceed 20 pages typed single spaced (10 or less is best), with total report length less than 50 pages. Reports based on studies of long duration (greater than two years) may exceed 50 pages, but the writer should bear in mind that the probability of their work being read is often inversely proportional to the weight of the final product.
4. Data which form the basis of conclusions and recommendations should always be made available in the report, either in tables, figures, appendices, or through the reference page.
5. Draft reports should be typed double-spaced, and tables and figures need not be in polished form.

6. If the project is funded by Ecology, at least two copies of the draft report should be sent to the Ecology project officer for review.
7. The authors are expected to address all review comments. If the writers disagree with certain comments, they should discuss their concerns with the project officer.
8. A final report should be prepared after all review comments are resolved. Two copies of the final report and data should be submitted to the project officer. Data should be contained on IBM-PC compatible floppy disks and conform to the protocols discussed in the Data Management section of this report.

SECTION 9  
ANNOTATED BIBLIOGRAPHY

**General Guidance**

APHA *et al.*, 1989. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Standard Methods for the Examination of Water and Wastewater. 17th ed., Washington, DC.

This manual is a standard reference for methodology in water quality and biological analyses.

Bailey, G., 1993. Ecology Permit Writer's Manual. Washington State Department of Ecology draft report, Olympia, WA.

Provides an overview of the NPDES permitting process and detailed guidance for deriving technology- and water quality-based effluent limits for wastewater treatment plants.

EPA, 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. EPA Region 10, Seattle, WA. 166 pp.

Provides guidance for designing water quality monitoring projects to assess forest management practices.

-----, 1993. Monitoring Protocols to Evaluate Water Quality Effects of Grazing Management on Western Rangeland Streams. EPA Region 10, Seattle, WA. 134 pp.

This manual provides monitoring protocols that are easy to use and cost-effective. The manual focuses on attributes of the stream channel, stream bank, and streamside vegetation of small streams impacted by grazing.

-----, 1993. Dilution models for effluent discharges. EPA report 600/R-93/139. Washington, DC. 181 pp.

Provides an overview of general aspects of dilution modeling and a Users Manual for EPA's PLUMES modeling system (UM, RSB, and far-field dilution models).

Gilbert, R.O., 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold Company, New York. 320 pp.

Provides sampling designs and statistical tests suited to water pollution data. Numerous examples and case studies are given to illustrate the use of these procedures with real data.

Hammer, M.J., and K.A. MacKichan, 1981. Hydrology and Quality of Water Resources. John Wiley and Sons, New York. 486 pp.

Presents and integrates both the hydrology and quality of ground water, flowing waters, and impounded systems. Contains a useful discussion of oxygen modeling in streams and rivers.

USGS (United States Geological Survey), 19xx. Techniques of Water-Resources Investigations of the United States Geological Survey. Washington, DC.

A series of manuals which describe specialized work methods in water investigations, Subject areas include: measurement of stream discharge and time of travel; determination of organic and inorganic substances in water; and methods for collection and analysis of aquatic biological and microbiological samples.

Welch, E.B., 1980. Ecological Effects of Wastewater. Cambridge University Press, Cambridge, UK.

Presents general concepts about aquatic ecology, including limnology, biology, and nutrient cycling. Also discusses effects of waste discharge on plankton, periphyton, macrophytes, invertebrates, and fish.

Zar, J.H., 1984 Biostatistical Analysis. 2nd ed., Prentice-Hall, Inc., Englewood Cliffs, NJ. 718 pp.

A good introductory and reference text for statistical treatment of biological and water quality data.

### **TMDL Studies**

Ambrose, R.B., and J.L. Martin (eds.), 1989. Technical Guidance Manual for Performing Wasteload Allocations, Book III - Estuaries: Part I - Estuaries and Wasteload Allocation models. EPA draft report, Washington, DC.

Summarizes estuarine water quality problems, processes which affect those problems, and simulation models available for addressing the problems.

Ambrose, R.B., and J.L. Martin (eds.) 1989. Technical Guidance Manual for Performing Wasteload Allocations, Book III - Estuaries: Part II - Application of Estuarine Wasteload Allocation Models. EPA draft report, Washington, DC.

Provides guidance on estuarine monitoring and model calibration/testing. Includes a case study on simulation of wasteload allocation problems in a simplified estuarine system.

Ambrose, R.B., Jr., J.P. Connolly, E. Southerland, T.O. Barnwell, Jr., and J.L. Schnoor, 1989. Wasteload Allocation Simulation Models. Journal WPCF 60(9):1646-1655.

Reviews models which may be used to develop WLAs for toxic chemicals.

Bowie, G.L., W.B. Mills, D.B. Porcella, C.L. Campbell, J.R. Pagenkopf, G.L. Rupp, K.M. Johnson, P.W.H. Chan, and S.A. Gherini, 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling. 2nd ed., EPA report 600/3-85-040, Washington, DC.

A reference text of constants and formulas for water quality modeling applications.

Chadderton, R.A., A.C. Miller, and A.J. McDonnell, 1981. Analysis of Wasteload Allocation Procedures. Water Resources Bulletin 17(5):760-766.

Presents background on TMDL procedures, some general information on modeling, and a discussion of several allocation schemes for distributing the TMDL among multiple dischargers.

Delos, C.G., W.L. Richardson, J.V. DePinto, R.B. Ambrose, P.W. Rodgers, K. Rygwelski, J.P. St. John, W.J. Shaughnessy, T.A. Faha, and W.N. Christie, 1984. Technical Guidance Manual for Performing Wasteload Allocations, Book II - Streams and Rivers: Chapter 3 - Toxic Substances. EPA report 440/4-84-022, Washington, DC. 203+ pp.

Presents detailed guidance on modeling the fate of toxicants discharged to streams and development of WLAs for same. Contents include modeling framework, parameter estimation, and model application.

Downing, D., and S. Sessions, 1985. Innovative Water Quality-Based Permitting: A Policy Perspective. Journal WPCF 57:358-365.

Presents preliminary findings of a project to evaluate innovative water quality-based permits. Two generic innovations are: 1) those that make greater use of stream assimilative capacity (e.g., seasonal permits); and 2) those that involve allocation trading (e.g., between point sources).

Driscoll, E.D., J.L. Mancini, and P.A. Mangarella, 1984. Technical Guidance Manual for Performing Wasteload Allocations, Book II- Streams and Rivers: Chapter 1 - Biochemical Oxygen Demand/Dissolved Oxygen. EPA report 440/4-84-020, Washington, DC.

Discusses dissolved oxygen/BOD processes in streams and presents detailed information on oxygen modeling for WLAs.

Ecology, 1978. Criteria for Sewage Works Design. Ecology report 78-5, Olympia, WA. 276 pp.

A manual for the design of sewage collection and treatment systems; includes description of various treatment processes.

-----, 1989. Guidance for Conducting Water Quality Assessments. Ecology Report 89-28, Olympia, WA. 44 pp.

Provides guidance to watershed management committees as they gather and evaluate water quality information to define and control nonpoint source problems. Major sections include water quality monitoring and riparian corridor/land use assessments.

EPA, 1980. Technical Guidance Manual for Performing Wasteload Allocations, Simplified Analytical Method for Determining NPDES Effluent Limitations for POTWs Discharging into Low-Flow Streams. Washington, DC. 64 pp.

Presents a mass-balance method for ammonia and the Streeter-Phelps method for oxygen as two simple techniques for use on small streams receiving secondarily-treated municipal wastewater.

-----, 1983. Technical Guidance Manual for Performing Wasteload Allocations, Book II - Streams and Rivers: Chapter 2 - Nutrient/Eutrophication Impacts. EPA Report 440/4-84-021, Washington, DC.

This manual is essentially a supplement to Book II, Chapter 1, BOD/oxygen impacts in streams. It superimposes the effect of nutrient inputs and excessive phytoplankton growth on the basic dissolved oxygen analysis.

-----, 1983. Technical Support Manual: Waterbody Surveys and Assessments for Conducting Use Attainability Analyses, Volume I: Stream and River Systems. Washington, DC.

Describes how to: 1) assess the aquatic uses being achieved in running waters; 2) identify potential uses which could be attained; and 3) characterize the sources of use impairment.

-----, 1984. Technical Guidance Manual for Performing Wasteload Allocations, Book VII - Permit Averaging Periods. EPA Report 440/4-84-023, Washington, DC.

Provides an approach for determining which types of permit limits (daily maximum, weekly average, or monthly average) are appropriate based upon the expected frequency of acute criteria violations.

-----, 1984. Technical Support Manual: Waterbody Surveys and Assessments for Conducting Use Attainability Analyses, Volume II: Estuarine Systems. Washington, DC.

Describes how to: 1) assess the aquatic uses being achieved in estuaries; 2) identify potential uses which could be attained; and 3) characterize the sources of use impairment.

-----, 1985. Guidance for State Water Monitoring and Wasteload Allocation Programs. EPA Report 440/4-85-031, Washington, DC. 30+ pp.

Defines and discusses monitoring and wasteload allocation activities in accordance with EPA regulations. Information presented is administrative, rather than technical, in scope.

-----, 1991. Technical Support Document for Water Quality-Based Toxics Control. EPA Report 505/2-90-00, Washington, DC. 145+ pp.

Presents detailed guidance on developing WLAs for the point source discharge of toxicants. Subject matter includes: derivation of criteria for individual toxicants and whole-effluent toxicity; mixing zone analyses; steady-state and dynamic modeling of toxicant exposure; and development of effluent limits for toxics.

-----, 1986. Guidance on EPA's Review and Approval Procedure for State Submitted TMDLs/WLAs. Washington, DC. 7+ pp.

Addresses the administrative aspects of performing TMDLs/WLAs and submitting them to EPA for review and approval.

-----, 1986. Technical Guidance Manual for Performing Wasteload Allocations, Book VI - Design Conditions: Chapter 1 - Stream Design Flow for Steady-State Modeling. EPA report 440/4-87-004, Washington, DC.

Presents two methods to estimate design low stream flows for the steady-state modeling of any pollutant which has a two-number (i.e., acute and chronic) water quality criterion. One method recommends using the 1Q10 as an acute design flow and the 7Q10 as a chronic design flow.

-----, 1988. Final Guidance for Implementation of Requirements Under Section 304(l) of the Clean Water Act as Amended. Washington, DC. 39+ pp.

Provides an interpretation of 304(l), which requires states to identify point source discharges that cause toxic impacts and develop individual control strategies for each of these sources.

-----, 1988. Technical Guidance Manual for Performing Wasteload Allocations, Book VI - Design Conditions: Chapter 2 - Technical Guidance on Supplementary Stream Design Conditions for Steady State Modeling. Washington, DC. 81 pp.

Provides guidance on the calculation of design conditions for flow, temperature, pH, dissolved oxygen, alkalinity, hardness, and upstream pollutant concentration. A mainframe computer program, DESCON, is used to compute design conditions.

-----, 1989. Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish: A Guidance Manual. EPA report 503/8-89-002, Washington, DC. 89+ pp.

Presents a standardized procedure for health risk assessments related to chemically contaminated fisheries.

GKY and Associates, Inc., 1984 Technical Guidance Manual for Performing Wasteload Allocations, Book IX - Innovative Wasteload Allocations. EPA draft report, Washington, DC.

Presents guidance on developing wasteload allocations which take advantage of time-variable assimilative capacity, yet provide the same failure frequency as annual allocations.

HydroQual, Inc., 1986. Technical Guidance Manual for Performing Wasteload Allocations, Book IV - Lakes, Reservoirs and Impoundments: Chapter 3 - Toxic Substances Impact. EPA report 440/4-87-002, Washington, DC. 221+ pp.

Presents a framework for projecting the fate of toxicants introduced to lakes and impoundments. Reviews basic modeling principles and provides detailed discussion on modeling of toxics discharged to lakes.

Kendra, W., 1990. Proposed Method for Determination and Allocation of Total Maximum Daily Loads in Washington State. Ecology draft report, Olympia, WA. 11 pp.

A generic description of the technical and administrative procedures that Ecology will follow in implementing Section 303(d) of the Clean Water Act, which deals with TMDLs.

Mancini, J.L., G.G. Kaufman, P.A. Mangarella, and E.D. Driscoll, 1983. Technical Guidance Manual for Performing Wasteload Allocations, Book IV - Lakes and Impoundments: Chapter 2 - Eutrophication. EPA Report 440/4-84-019, Washington, DC.

Describes lake eutrophication processes and presents several models which are available for eutrophication WLAs. Discussion includes basic principles, model selection and use, and data requirements.

Mills, W.B., D.B. Porcella, M.J. Unga, S.A. Gherini, K.V. Summers, Lingfung Mok, G.L. Rupp, G.L. Bowie, and D.A. Haith, 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water - Part I. EPA Report 600/6-85-002a, Athens, GA. 609 pp.

Provides simplified methods for assessing the loading and fate of conventional and toxic pollutants in water. Much of the data required for these methods is provided in the document.

Mills, W.B., D.B. Porcella, M.J. Unga, S.A. Gherini, K.V. Summers, Lingfung Mok, G.L. Rupp, G.L. Bowie, and D.A. Haith, 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water - Part II. EPA Report 600/6-85-002b, Athens, GA. 444+ pp.

Provides simplified methods for assessing the loading and fate of conventional and toxic pollutants in water. Much of the data required for these methods is provided in the document. Part II presents assessment techniques for impoundments, estuaries, and ground water.

Mills, W.B., G.L. Bowie, T.M. Grieb, K.M. Johnson, and R.C. Whittemore, 1986. Stream Sampling for Wasteload Allocation Applications. EPA Report 625/6-86/013, Washington, DC.

Provides guidance on design of stream surveys to support modeling for wasteload allocations; addresses both chemical specific and whole effluent techniques.

Schnoor, J.L., C. Sato, D. McKechnie, and D. Sahoo, 1987. Processes, Coefficients, and Models for Simulating Toxic Organics and Heavy Metals in Surface Waters. EPA Report 600/3-87-015, Washington, DC.

A reference text for modeling the transport and fate of toxic organic chemicals and heavy metals in water.

Stein, S.M., J.S. Krolak, and G.K. Young, 1985. A Systems Approach for Wasteload Allocations. pp. 305-312 In J.C. O'Shaughnessy (ed.). Proceedings of 1985 conference on environmental engineering, ASCE, Boston, MA.

Discussion of seasonal water quality-based permits which optimize use of the receiving water's assimilative capacity, yet maintain the same failure rate as annual allocations.

Walton, R., T.S. George, and L.A. Roesner, 1984. Selecting Estuarine Models. EPA draft report, Washington, DC.

Provides a generic description of estuarine models and input/output parameters; also reviews considerations in selecting an estuarine model for use in TMDL/WLA analyses.

### **Biological Assessments**

Edmondson, W.T., 1959. Freshwater Biology. 2nd ed., John Wiley and Sons, New York. 1,248 pp.

This publication is a comprehensive key to identification of aquatic organisms, and contains detailed illustrations of a variety of species.

Gauch, H.G., Jr., 1982. Multivariate Analysis in Community Ecology. Cambridge University Press, New York. 298 pp.

One of the few statistics texts that describes advantages and disadvantages of each method and under what conditions they should be applied. Multivariate analysis is particularly useful for biological studies in that underlying patterns in large data sets are identified, which may reveal relationships between biota and their environment.

Hellawell, J.M., 1978. Biological Surveillance of Rivers: A Biological Monitoring Handbook. Water Research Centre, Stevenage, England. 332 pp.

Methodology for conducting surveys and monitoring programs are reviewed for each biotic component of the aquatic environment. This handbook serves as an excellent guide for establishing a sample design and collection methods.

Hynes, H.B.N., 1970. The Ecology of Running Waters. Liverpool University Press, Liverpool, England. 555 pp.

This text has served as the standard reference for information regarding the ecology of aquatic ecosystems. A review of information regarding physical/chemical parameters, algae/periphyton, benthic macroinvertebrates, and fish contains a comprehensive literature review and insightful integration of all the components.

Merritt, R.W., and K.W. Cummins, 1984. An Introduction to the Aquatic Insects of North America, 2nd ed. Kendall-Hunt Publishing Company, Dubuque, IA. 722 pp.

This is the most widely used key for identifying freshwater aquatic insects. A review of trophic classification, habits, and habitat preference accompanies each section.

Nielsen, L.A., and D.L. Johnson (eds.), 1983. Fisheries Techniques. American Fisheries Society, Bethesda, MD. 468 pp.

This text describes methods involved in planning and implementing fisheries surveys. It contains an amalgamation of information authored by many experts.

Patrick, R., and C.W. Reimer, 1966. The Diatoms of the United States Exclusive of Alaska and Hawaii. Monographs of the Academy of Natural Sciences of Philadelphia, No. 13., Philadelphia, Volume 1 - 688 pp; Volume 2 - 213 pp.

This two volume monograph remains the most complete work in diatom identification and ecology. It is regarded as the standard for any biological investigation of the diatoms.

Pennak, R.W., 1989. Freshwater Invertebrates of the United States. John Wiley and Sons, New York. 628 pp.

This key presents comprehensive information regarding freshwater organisms, including protozoans, arthropods, and mollusks. It was one of the first keys of its type that covered a large variety of organisms.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughesm, 1989. Rapid Bioassessment Protocols for use in Streams and Rivers: Benthic Macroinvertebrates and Fish. EPA Report 444/4-89-001, Washington, DC.

Provides several methods for rapidly assessing the status of invertebrate or fish communities in a stream. The methods vary in complexity, but all five techniques include habitat assessments as part of the bioassessment.

Prescott, G.W., 1978. How to Know the Freshwater Algae. Wm. C. Brown Company Publishers, Dubuque, IA. 293 pp.

Provides keys to the freshwater algae, as well as information concerning habitat and distribution of species.

Prescott, G.W., 1980. How to Know the Aquatic Plants. Wm. C. Brown Publishers, Dubuque, IA. 158 pp.

Provides keys to macrophytes, as well as information concerning habitat and distribution of species.

Resh, V.H., and D.M. Rosenberg (eds.), 1984. The Ecology of Aquatic Insects. Praeger Publishers, New York. 803 pp.

An amalgamation of all aspects regarding the ecology of macrobenthics are discussed by numerous experts in this text. An extensive literature review accompanies each chapter, which serves as an excellent start point for aquatic insect investigations.

Rossman, L.A., 1989. Risk Equivalent Seasonal Wasteload Allocation. Water Resources Research 25(10):2083-2090.

Presents a method for designing seasonal discharge limits that provide the same risk of water quality standards violations as nonseasonal limits.

Sanders, T.G., R.C. Ward, J.C. Loftis, T.D. Steele, D.D. Adrian, and V. Yevjevich, 1983. Design of Networks for Monitoring Water Quality. Water Resources Publications, Littleton, CO. 328 pp.

This book was developed from a Colorado State University short course of the same name. Articles cover various monitoring design issues: statistical representation, station location, sampling frequency, parameter selection, and step-by-step procedures for setting-up a network.

Scott, W.B., and E.J. Crossman, 1975. Freshwater Fishes of Canada. Fisheries Research Board of Canada, Bulletin 184, Ottawa, Ontario. 966 pp.

A comprehensive review of each fish species regarding distribution, habits, and identification are covered in this text. This work is regarded as one of the best of its kind in fisheries biology.

Slack, K.V., R.C. Averett, P.E. Greeson, and R.G. Lipscomb, 1973. Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples. Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5, Laboratory Analysis. Washington, DC. 165 pp.

Methods discussed in this document are strictly related to biological surveys of freshwater ecosystems. Information regarding sample design, collection, and analysis can be found in this work for each biotic component of the aquatic environment.

Smith, G.M., 1950 The Fresh-Water Algae of the United States, 2nd ed. McGraw-Hill Book Company, New York. 719 pp.

A comprehensive guide to the natural history of algal families, this book also contains keys and detailed illustrations that assist in identification.

Weber, C.I., (ed.) 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. U.S. Environmental Research Center, Cincinnati, Ohio.

An excellent manual for use in planning and implementing freshwater biological studies. A discussion of methods of analysis and a good review of available literature accompanies each section regarding a biotic component.

Wydoski, R.S., and R.R. Whitney, 1979. Inland Fishes of Washington. University of Washington Press, Seattle. 220 pp.

This document contains a great deal of information regarding fish species found in basins and drainages of Washington State. Identification, behavior, desired habitat, and distribution are discussed for each species.

SECTION 10  
LITERATURE CITED AND ADDITIONAL READING

- Adler, P.H., and K.C. Kim, 1986. The Blackflies of Pennsylvania (*Simuliidae: Diptera*): Bionomics, Taxonomy, and Distribution. Pennsylvania State University Agricultural Experiment Station Bulletin 856, University Park, PA. 88 pp.
- Akar, P.J., and G.H. Jirka, 1990. CORMIX2: An Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Multiport Diffuser Discharges. Final Report to U.S. EPA Environmental Research Laboratory. Athens, GA.
- Ambrose, R.B., and J.L. Martin (eds.), 1989. Technical Guidance Manual for Performing Wasteload Allocations. Book III - Estuaries: Part I - Estuaries and Wasteload Allocation Models. EPA draft report, Washington, DC.
- , 1989. Technical Guidance Manual for Performing Wasteload Allocations. Book III - Estuaries: Part II - Application of Estuarine Wasteload Allocation Models. EPA draft report. Washington, DC.
- Ambrose, R.B. *et al.*, 1988. WASP4: A Hydrodynamic and Water Quality Model, Model Theory, User's Manual, and Programmer's Guide. EPA 600/3-87/039.
- Ambrose, R.B., Jr., J.P. Connolly, E. Southerland, T.O. Barnwell, Jr., and J.L. Schnoor, 1988. Wasteload Allocation Simulation Models. Journal WPCF 60(9):1646-1655.
- Anderson, N.H., 1976. The Distribution and Biology of the Oregon Trichoptera. Oregon State University Agricultural Experiment Station Technical Bulletin 134, Corvallis, OR. 152 pp.
- APHA *et al.*, 1992. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Standard Methods for the Examination of Water and Wastewater. 18th ed. Washington, DC.
- Bailey, G., 1989. Ecology Permit Writer's Manual. Washington State Department of Ecology draft report. Olympia, WA.
- Baumann, R.W., A.R. Gaufin, and R.F. Surdick, 1977. The Stoneflies (*Plecoptera*) of the Rocky Mountains. Memoirs of the American Entomological Society No. 31, American Entomological Society, Academy of Natural Sciences, Philadelphia. 208 pp.
- Beck, W.M., and E.C. Beck, 1966. Chironomidae (*Diptera*) of Florida. Part I. *Pentaneurini (Tanypodinae)*. Bulletin of the Florida State Museum 10(8):305-379.

- Bowie, G.L., W.B. Mills, D.B. Porcella, C.L. Campbell, J.R. Pagenkopf, G.L. Rupp, K.M. Johnson, P.W.H. Chan, and S.A. Gherini, 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling. 2nd ed., EPA report 600/3-85-040, Washington, DC.
- Brooks, J.L., 1957. The Systematics of North American *Daphnia*. Memoirs of the Connecticut Academy of Arts and Sciences, Vol. XIII, Yale University Press, New Haven, CT. 180 pp.
- , 1960. Diffusion of Sewage Effluent in an Ocean Current. In: Waste Disposal in the Marine Environment, E.A. Pearson (ed.). Pergamon Press.
- Brown, H.P., 1972. Biota of Freshwater Ecosystems Identification Manual No. 6: Aquatic Dryopoid Beetles (*Coleoptera*) of the United States. EPA, Washington, DC. 82 pp.
- Burch, J.B., 1972. Biota of Freshwater Ecosystems Identification Manual No. 3: Freshwater *Shpaeriacean* Clams (*Mollusca: Pelecypoda*) of North America. EPA, Washington, DC. 31 pp.
- Cairns, J., Jr., 1982. Artificial Substrates. Ann Arbor Science Publishers, Ann Arbor, MI.
- Callahan, M.A., M.W. Slimak, N.W. Gabel, I.P. May, C.F. Fowler, J.R. Freed, P. Jennings, R.L. Durfee, F.C. Whitmore, B. Maestri, W.R. Mabey, B.R. Holt, and C. Gould, 1979a. Water-Related Environmental Fate of 129 Priority Pollutants, Volume 1: Introduction and Technical Background, Metals and Inorganics, Pesticides and PCBs. EPA report 440/4-79-029a. Washington, DC. 514 pp.
- , 1979b. Water-Related Environmental Fate of 129 Priority Pollutants, Volume 2: Halogenated aliphatic Hydrocarbons, Halogenated Ethers, Monocyclic Aromatics, Phthalate Esters, Polycyclic Aromatic Hydrocarbons, Nitrosamines, and Miscellaneous Compounds. EPA report 440/4-79-029b. Washington, DC.
- Carefoot, T., 1977. Pacific Seashores a Guide to Intertidal Ecology. University of Washington Press, Seattle. 176 pp.
- Carl, G.C., W.A. Clemens, and C.C. Lindsey., 1967. The Fresh-Water Fishes of British Columbia, Provincial Museum Handbook 5. British Columbia, Canada. 192 pp.
- Carlander, K.D., 1969. Handbook of Freshwater Fishery Biology, Vol. 1: Life History Data on Freshwater Fishes of the United States and Canada, Exclusive of the Perciformes. Iowa State University Press, Ames, IA. 752 pp.

- Carr, N.G., and B.A. Whitton (eds.), 1973. The Biology of Blue-Green Algae. University of California Press, Berkeley, CA. 676 pp.
- Chadderton, R.A., A.C. Miller, and A.J. McDonnell, 1981. Analysis of Wasteload Allocation Procedures. Water Resources Bulletin 17(5):760-766.
- Cooke, G.D. *et al.*, 1986. Lake and Reservoir Restoration. Butterworth Publishers.
- Cooper, E.L., 1983. The Fishes of Pennsylvania. Pennsylvania State University Press, State College. 243 pp.
- Cressey, R.F., 1972. Biota of Freshwater Ecosystems Identification Manual No. 2: the Genus *Argulus* (Crustacea: Branchiura) of the United States. EPA, Washington, DC. 14 pp.
- Cupp, C.E., 1989. Stream Corridor Classification for Forested Lands of Washington: T/F/W Ambient Monitoring Program. Hosey and Associates Engineering Company, Bellevue, WA. 46 pp.
- Delos, C.G., W.L. Richardson, J.V. DePinto, R.B. Ambrose, P.W. Rodgers, K. Rygwelski, J.P. St. John, W.J. Shaughnessy, T.A. Faha, and W.N. Christie, 1984. Technical Guidance Manual for Performing Wasteload Allocations, Book II - Streams and Rivers: Chapter 3 - Toxic Substances. EPA report 440/4-84-022, Washington, DC. 203+ pp.
- Doneker, R.L. and G.H. Jirka, 1990. Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Submerged Single Port Discharges (CORMIX1). EPA report 600/3-90/012, Athens, GA. 250 pp.
- Downing, D., and S. Sessions, 1985. Innovative Water Quality-Based Permitting: a Policy Perspective. Journal WPCF 57:358-365.
- Driscoll, E.D., J.L. Mancini, and P.A. Mangarella, 1985. Technical Guidance Manual for Performing Wasteload Allocations, Book II - Streams and Rivers: Chapter 1 - Biochemical Oxygen Demand/Dissolved Oxygen. EPA report 440/4-84-020, Washington, DC.
- Dunne, T. and L.B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman and Company, San Francisco.
- Duxbury, A.C., 1971. The Earth and its Oceans. Addison-Wesley Publishing Co., Reading Massachusetts. 381 pp.
- Ecology, 1985. Criteria for Sewage Works Design. Ecology report 78-5, Olympia, WA, 276 pp.

- , 1989. Guidance for Conducting Water Quality Assessments. Ecology report 89-28, Olympia, WA. 44 pp.
- , 1991. Guidelines and Specifications for Preparing Quality Assurance Project Plans. Ecology, Quality Assurance Section, Manchester, WA. 17 pp.
- Eddy, S., 1957. How to Know the Freshwater Fishes. Wm. C. Brown Company, Dubuque, IA. 253 pp.
- Edmondson, W.T., 1959. Freshwater Biology. 2nd ed., John Wiley and Sons, New York, 1,248 pp.
- Edmondson, W.T., and C.G. Winberg, 1971. A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters; IBP Handbook No. 17. Blackwell Scientific Publications, Oxford, England. 358 pp.
- Edmunds, G.F., S.L. Jensen, and L. Berner, 1976. The Mayflies of North and Central America. University of Minnesota Press, Minneapolis, MN. 330 pp.
- Eisler, R., 1985. Cadmium Hazards to Fish, Wildlife and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.2). 46 pp.
- , 1987. Mercury Hazards to Fish, Wildlife and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.10). 90 pp.
- EPA, 1980. U.S. Environmental Protection Agency. Technical Guidance Manual for Performing Wasteload Allocations, Simplified Analytical Method for Determining NPDES Effluent Limitations for POTWs Discharging into Low-Flow Streams. Washington, DC. 64 pp.
- , 1983. Technical Guidance Manual for Performing Wasteload Allocations, Book II - Streams and Rivers: Chapter 2 - Nutrient/Eutrophication Impacts. EPA report 440/4-84-021, Washington, DC.
- , 1983. Technical Support Manual: Waterbody Surveys and Assessments for Conducting Use Attainability Analyses, Volume I: Stream and River Systems. Washington, DC.
- , 1984. Technical Guidance Manual for Performing Wasteload Allocations, Book VII - Permit Averaging Periods. EPA report 440/4-84-023, Washington, DC.
- , 1984. Technical Support Manual: Waterbody Surveys and Assessments for Conducting Use Attainability Analyses, Volume II: Estuarine Systems. Washington, DC.

- , 1985. Guidance for State Water Monitoring and Wasteload Allocation Programs. EPA report 440/4-85-031, Washington, DC. 30+ pp.
- , 1986. Guidance on EPA's Review and Approval Procedure for State Submitted TMDLs/WLAs. Washington, DC. 7+ pp.
- , 1986. Technical Guidance Manual for Performing Wasteload Allocations, Book VI - Design Conditions: Chapter 1 - Stream Design Flow for Steady-State Modeling. EPA report 440/4-87-004, Washington, DC.
- , 1986. Quality Criteria for Water 1986. EPA report 440/5-86-001, Washington, DC.
- , 1988. Final Guidance for Implementation of Requirements Under Section 304(l) of the Clean Water Act as Amended. Washington, DC. 39+ pp.
- , 1989. Technical Guidance Manual for Performing Wasteload Allocations, Book VI - Design Conditions: Chapter 2 - Technical Guidance on Supplementary Stream Design Conditions for Steady State Modeling. Washington, DC. 81 pp.
- , 1989. Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish: a Guidance Manual. EPA report 503/8-89-002, Washington, DC. 89+ pp.
- , 1991. Technical Support Document for Water Quality-Based Toxics Control. EPA report 505/2-90-001, Washington, DC. 145+ pp.
- , 1993. Dilution models for effluent discharges. EPA report 600/R-93/139. Washington, DC. 181 pp.
- , 1993. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Vol. 1: Fish Sampling and Analysis. EPA report 823-R-93-002. Washington, DC.
- EPA/PSEP, 1990. EPA/Puget Sound Estuary Program. Recommended Protocols for Measuring Conventional Water Quality Variables and Metals in Fresh Waters of the Puget Sound Region Draft Report. Seattle.
- FDA, 1985. U.S. Food and Drug Administration. Action Levels for Poisonous or Deleterious Substances in Human Food and Animal Feed. Washington, DC. 13 pp.
- Fischer, H.B., *et al.*, 1979. Mixing in Inland and Coastal Waters. Academic Press.
- Foster, N., 1972. Biota of Freshwater Ecosystems Identification Manual No. 4: Freshwater Polychaetes (Annelida) of North America. EPA, Washington, DC. 15 pp.

- Frick, W.E., 1991. The Planned EPA Plumemodel and user Interface: UMi/RSB. U.S. EPA Hatfield Marine Science Center. Newport, OR.
- Gauch, H.G., Jr., 1982. Multivariate Analysis in Community Ecology. Cambridge University Press, New York. 298 pp.
- Gaugush, R.F., 1987. Sampling Design for Reservoir Water Quality Investigations. Environmental & Instruction Report E-87-1, Department of the Army, Waterways Experiment Station, Corps of Engineers PO Box 631, Vicksburg Mississippi, 39180-0631. 79 pp.
- Geldreich, E.E., and B.A. Kenner, 1969. Concepts in Fecal Streptococci in Stream Pollution. JWPCF 41:336-352.
- Gilbert, R.O., 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold Company, New York. 320 pp.
- GKY and Associates, Inc., 1984. Technical Guidance Manual for Performing Wasteload Allocations, Book IX - Innovative Wasteload Allocations. EPA draft report, Washington, DC.
- Goldman, C.R. and A.J. Horne., 1983. Limnology. McGraw-Hill Book Company, New York, NY. 464 pp.
- Hammer, M.J., and K.A. MacKichan, 1981. Hydrology and Quality of Water Resources. John Wiley and Sons, New York. 486 pp.
- Hellawell, J.M., 1978. Biological Surveillance of Rivers: A Biological Monitoring Handbook. Water Research Centre, Stevenage, England. 332 pp.
- Hilsenhoff, W.L., 1977. Use of Arthropods to Evaluate Water Quality of Streams. Wisconsin Department of Natural Resources Technical Bulletin No. 100, Madison, WI. 15 pp.
- Hobbs, H., Jr., 1972. Biota of Freshwater Ecosystems Identification Manual No. 9: Crayfishes (Astacidae) of North and Middle America. EPA, Washington, DC. 173 pp.
- Holsinger, J.R., 1972. Biota of Freshwater Ecosystems Identification Manual No. 5: the Freshwater Amphipod Crustaceans (Gammaridae) of North America. EPA, Washington, DC. 89 pp.

- Horner, R.R., B.W. Mar, L.E. Reinelt, J.S. Richey, and J.M. Lee., 1986. Design of Monitoring Programs for Determination of Ecological Change Resulting from Nonpoint Source Water Pollution in Washington State. Report to the Washington State Department of Ecology from the University of Washington Department of Civil Engineering, Olympia, WA.
- Huntamer, D. and J. Hyre, 1991. Laboratory User's Manual. Washington State Department of Ecology Report, Olympia, WA.
- HydroQual, Inc., 1986. Technical Guidance Manual for Performing Wasteload Allocations, Book IV - Lakes, Reservoirs and Impoundments: Chapter 3 - Toxic Substances Impact. EPA report 440/4-87-002. Washington, DC. 221+ pp.
- Hynes, H.B.N., 1970. The Ecology of Running Waters. Liverpool University Press, Liverpool, England. 555 pp.
- Jensen, S.L., 1966. The Mayflies of Idaho (Ephemeroptera). MS Thesis, University of Utah. 352 pp.
- Jones, G.R. and G. H. Jirka, 1991. CORMIX3: An Expert System for the Analysis and Prediction of Buoyant Surface Discharges. DeFrees Hydraulics Laboratory, School of Civil Environmental Engineering, Cornell University, Ithaca, NY (Draft).
- Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser, 1986. Assessing Biological Integrity in Running Waters: A Method and Its Rationale. Illinois Natural History Survey Special Publication No. 5. Champaign, Illinois. 28 pp.
- Kenk, R., 1972. Biota of Freshwater Ecosystems Identification Manual No. 1: Freshwater Planarians (Turbellarians) of North America. EPA, Washington, DC. 81 pp.
- Kim, K.C., and R.W. Merritt, 1987. Blackflies: Ecology, Population Management, and Annotated World List. Pennsylvania State University Press, University Park, PA. 528 pp.
- Klemm, D.J., 1972. Biota of Freshwater Ecosystems Identification Manual No. 8: Freshwater Leeches (Annelida: Hirudinea) of North America. EPA, Washington, DC. 53 pp.
- Knauss, J.A., 1978. Introduction to Physical Oceanography. Prentice-Hall, Inc. Englewood Cliffs, New Jersey 07632. 337 pp.
- Kozloff, E.N., 1973. Seashore Life of Puget Sound, the Strait of Georgia, and the San Juan Archipelago. University of Washington Press, Seattle. 282 pp.

- Krebs, C.J., 1985. Ecology: the experimental analysis of distribution and abundance, 3rd Ed. Harper and Row, Publishers, New York, NY. 800 pp.
- Larsen, D.P., J.M. Omernik, R.M. Hughes, C.M. Rohm, T.R. Whittier, A.J. Kinney, A.L. Gallant, and D.R. Dudley, 1986. Correspondence Between Spatial Patterns in Fish Assemblages in Ohio Streams and Aquatic Ecoregions. Environmental Management 10:815-828.
- Limno-Tech, 1986. Simplified Method Program - Toxics (SMPTOX), User's Manual. Prepared for USEPA Monitoring and Support Division, Washington, DC.
- Mabey, W.R., J.H. Smith, R.T. Podoll, H.L. Johnson, T. Mill, T.W. Chou, J. Gates, I. Waight Partridge, H. Jaber, and D. Vandenberg, 1982. Aquatic Fate Process Data for Organic Priority Pollutants. EPA report 440/4-81-014, Washington, DC. 434 pp.
- Mancini, J.L., G.G. Kaufman, P.A. Mangarella, and E.D. Driscoll, 1983. Technical Guidance Manual for Performing Wasteload Allocations, Book IV - Lakes and Impoundments: Chapter 2 - Eutrophication. EPA report 440/4-84-019, Washington, DC.
- McAlpine, J.F., B.V. Peterson, G.E. Shewell, H.J. Teskey, J.R. Vockeroth, and D.M. Wood, 1981. Manual of Nearctic Diptera, Vol. 1. Biosystematics Research Institute, Research Branch Agriculture Canada, Ottawa, Ontario. 674 pp.
- McPhail, J.D. and C.C. Lindsey, 1970. Freshwater Fishes of Northwestern Canada and Alaska. Fisheries Research Board of Canada Bulletin 173, Ottawa, Ontario. 381 pp.
- Merritt, R.W., and K.W. Cummins, 1984. An Introduction to the Aquatic Insects of North America, 2nd ed. Kendall-Hunt Publishing Company, Dubuque, IA. 722 pp.
- Mills, W.B., D.B. Porcella, M.J. Unga, S.A. Gherini, K.V. Summers, Lingfung Mok, G.L. Rupp, G.L. Bowie, and D.A. Haith, 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water -- Part I. EPA report 600/6-85-002a, Athens, GA. 609 pp.
- Mills, W.B., D.B. Porcella, M.J. Unga, S.A. Gherini, K.V. Summers, Lingfung Mok, G.L. Rupp, G.L. Bowie, and D.A. Haith, 1985. Water Quality Assessment: a Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water -- Part II. EPA Report 600/6-85-002b, Athens, GA. 444+ pp.
- Mills, W.B., G.L. Bowie, T.M. Grieb, K.M. Johnson, and R.C. Whittemore, 1986. Stream Sampling for Wasteload Allocation Applications. EPA Report 625/6-86/013, Washington, DC.

- Mitchell, L.G., J.A. Mutchmor and W.D. Dolphin, 1988. Zoology. The Benjamin/Cummings Publishing Company, Incorporated, Menlo Park, CA. 862 pp.
- Muellenhoff, W.P. *et al.*, 1985 Initial Mixing Characteristics of Municipal Ocean Discharges. EPA 600/3-85-073.
- NAS/NAE, 1973. National Academy of Sciences/National Academy of Engineering. Water Quality Criteria - 1972. EPA.R3.73.033. 594 pp.
- Needham, J.G., J.R. Traver, and Yin-Chi Hsu, 1935. The Biology of Mayflies with a Systematic Account of North American Species. Comstock Publishing Company, Ithaca, NY. 759 pp.
- Nielsen, L.A., and D.L. Johnson (eds.), 1983. Fisheries Techniques. American Fisheries Society, Bethesda, MD. 468 pp.
- Patrick, R., and C.W. Reimer, 1966. The Diatoms of the United States Exclusive of Alaska and Hawaii. Monographs of the Academy of Natural Sciences of Philadelphia, No. 13, Philadelphia, PA. Volume 1 - 688 pp; Volume 2 - 213 pp.
- Pennak, R.W., 1964. Collegiate Dictionary of Zoology. The Ronald Press Company, New York, NY. 567 pp.
- , 1989. Freshwater Invertebrates of the United States. John Wiley and Sons, New York. 628 pp.
- Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes, 1989. Rapid Bioassessment Protocols for use in Streams and Rivers: Benthic Macroinvertebrates and Fish. EPA report 444/4-89-001, Washington, DC.
- Prescott, G.W., 1962. Algae of the Western Great Lakes Area. Wm. C. Brown Company, Dubuque, IA. 977 pp.
- , 1978. How to Know the Freshwater Algae. Wm. C. Brown Company Publishers, Dubuque, IA. 293 pp.
- , 1980. How to Know the Aquatic Plants. Wm. C. Brown Publishers, Dubuque, IA. 158 pp.
- PSEP, 1986. Puget Sound Estuary Program. Puget Sound Protocols. Seattle.
- PSWQA, 1991. Puget Sound Water Quality Authority. Specifications for the Transfer of Data from the Puget Sound Ambient Monitoring Program. Seattle.

- Ralph, S.C., 1990. Timber/Fish/Wildlife Stream Ambient Monitoring Field Manual, version 2.0. Center for Streamside Studies, University of Washington, Seattle. 40 pp.
- Rawn *et al.*, 1961. Diffusers for Disposal of Sewage in Seawater. Trans. Am. Soc. Civ. Eng. 126, Part III. 344-88.
- Reckhow, K.H., and S.C. Chapra, 1983. Engineering Approaches for Lake Management, Volume 1 and 2. Butterworth Publishers.
- Reid, G.K., 1961. Ecology of Inland Waters and Estuaries. D. Van Nostrand Company, New York. 375 pp.
- Resh, V.H., and D.M. Rosenberg (eds.), 1984. The Ecology of Aquatic Insects. Praeger Publishers, New York. 803 pp.
- Ricker, W.E. (ed.), 1970. Methods for Assessment of Fish Production in Fresh Waters, IBP Handbook No. 3, Blackwell Scientific Publications, Oxford, England. 313 pp.
- Ricklefs, R.E., 1979. Ecology, 2nd Ed. Chiron Press, Incorporated, New York, NY. 966 pp.
- Rohm, C.M., J.W. Giese, and C.C. Bennett., 1987. Evaluation of an Aquatic Ecoregion Classification of Streams in Arkansas. Journal of Freshwater Ecology 4:127-140.
- Rossmann, L.A., 1989. Risk Equivalent Seasonal Wasteload Allocation. Water Resources Research 25(10):2083-2090.
- Round, F.E., 1973. The Biology of the Algae. 2nd ed., Edward Arnold Publishers Ltd., London, England. 278 pp.
- Ruttner-Kolisko, A., 1974. Plankton Rotifers: Biology and Taxonomy. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, Germany. 146 pp.
- Sanders, T.G., R.C. Ward, J.C. Loftis, T.D. Steele, D.D. Adrian, and V. Yevjevich, 1983. Design of Networks for Monitoring Water Quality. Water Resources Publications, Littleton, CO. 328 pp.
- Schnoor, J.L., C. Sato, D. McKechnie, and D. Sahoo, 1987. Processes, Coefficients, and Models for Simulating Toxic Organics and Heavy Metals in Surface Waters. EPA report 600/3-87-015, Washington, DC.
- Schultz, L.P., 1958. Keys to the Fishes of Washington, Oregon and Closely Adjoining Regions. University of Washington Press, Seattle. 228 pp.

- Scott, W.B., and E.J. Crossman, 1975. Freshwater Fishes of Canada. Fisheries Research Board of Canada, Bulletin 184, Ottawa, Ontario. 966 pp.
- Slack, K.V., R.C. Averett, P.E. Greeson, and R.G. Lipscomb, 1973. Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples. Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5 - Laboratory Analysis, Washington, DC. 165 pp.
- Smartt, M.M., F.A. Reid, and J.R. Jones, 1981. A Comparison of a Persulfate Digestion and the Kjeldahl Procedure for Determinations of Total Nitrogen in Freshwater Samples. Water Research 15:919-921.
- Smith, G.M., 1950. The Fresh-Water Algae of the United States, 2nd ed. McGraw-Hill Book Company, New York. 719 pp.
- Snoeyink, V.L. and D. Jenkins, 1980. Water Chemistry. John Wiley & Sons, New York. 463 pp.
- Sokal, R. and J. Rohlf, 1983. Biometry (2nd ed.). W.H. Freeman and Company, San Francisco.
- Stamer, J.K., J.P. Bennett, and S.W. McKenzie, 1983. Determination of Ultimate Carbonaceous BOD and the Specific Rate Constant (k<sub>1</sub>). U.S. Geological Survey Open File Report 82-645.
- Stein, S.M., J.S. Krolak, and G.K. Young, 1985. A Systems Approach for Wasteload Allocations. pp. 305-312 In J.C. O'Shaughnessy (ed.). Proceedings of 1985 Conference on Environmental Engineering, ASCE, Boston, MA.
- Striplin, P., 1988. Puget Sound Ambient Monitoring Program Marine Sediment Quality Implementation Plan. Washington State Department of Ecology, Olympia, WA.
- Strumm, W. and J.J. Morgan., 1981. Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters. John Wiley & Sons, New York. 780 pp.
- Surdick, R.F., and K.C. Kim, 1976. Stoneflies (Plecoptera) of Pennsylvania: a Synopsis. Pennsylvania State University Agricultural Experiment Station Bulletin 808. University Park, PA. 73 pp.
- Tetra Tech Inc., 1985 Bioaccumulation Monitoring Guidance: 1. Estimating the Potential for Bioaccumulation of Priority Pollutants and 301(h) Pesticides Discharged into Marine and Estuarine Waters. Prepared for U.S. Environmental Protection Agency, Washington, DC. 69 pp.

- Thomann, R.V., and J.A. Mueller, 1987. Principles of Surface Water Quality Modeling and Control. Harper and Row Publishers.
- Townes, H.K., Jr., 1945. The Nearctic Species of Tendipedini [Diptera, Tendipedidae (=Chironomidae)]. American Midland Naturalist 34:1-206.
- USDHEW, 1962. United States Department of Health, Education, and Welfare. Algae in Water Supplies: An Illustrated Manual on the Identification, Significance and Control of Algae in Water Supplies. Division of Water Supply and Pollution Control, Cincinnati, Ohio. 88 pp.
- USDI, 1966. United States Department of the Interior. A Guide to the Common Diatoms at Water Pollution Surveillance System Stations. Federal Water Pollution Control Administration, Cincinnati, OH. 98 pp.
- USGS, 1962. United States Geological Survey. Stream Gaging Procedure. Water Supply Paper 888.
- , 1965. Surface Water Techniques. Book 1 Chapter 14, "Measurement of Discharge by Dye-dilution Methods, Hydraulic Measurement and Computation," U.S. Geological Survey.
- , 19xx. Guidelines for Studies of Contaminants in Biological Tissues for the National Water-Quality Assessment Program. Open-File Report 92-494. 69 pp.
- Usinger, R.L., 1956. Aquatic Insects of California. University of California Press, Berkeley, CA. 508 pp.
- VanLandingham, S.L., 1982. Guide to the Identification, Environmental Requirements, and Pollution Tolerance of Blue-Green Algae (Cyanophyta). EPA 600/3-82-073, Cincinnati. 341 pp.
- Vollenweider, R.A. (ed.), 1969. A Manual on Methods for Measuring Primary Production in Aquatic Environments. IBP Handbook No. 12, Blackwell Scientific Publications, Oxford, England. 224 pp.
- Walton, R., T.S. George, and L.A. Roesner, 1984. Selecting Estuarine Models. EPA draft report, Washington, DC.
- WAS, 1991. Guidance for Determination and Allocation of Total Maximum Daily Loads (TMDL) in Washington State. Ecology report, Olympia, WA. 23 pp.
- Weber, C.I. (ed.) 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. U.S. Environmental Research Center, Cincinnati.

- Welch, E.B., 1980. Ecological Effects of Waste Water. Cambridge University Press, Cambridge, UK.
- Wetzel, R.G., 1983. Limnology. Saunders College Publishing, New York. 767 pp.
- Whittier, T.R., D.P. Larsen, R.M. Hughes, C.M. Rohm, A.L. Gallant, and J.M. Omernik, 1987. The Ohio Stream Regionalization Project: A Compendium of Results. U.S. EPA report 600/3-87/025, Corvallis, OR. 66 pp.
- Whittier, T.R., R.M. Hughes, and D.P. Larsen, 1988. Correspondence Between Ecoregions and Spatial Patterns in Stream Ecosystems in Oregon. Canadian Journal of Fisheries and Aquatic Sciences 45:1264-1278.
- Wiggins, G.B., 1977. Larvae of the North American Caddisfly Genera (*Trichoptera*). University of Toronto Press, Toronto, Ontario. 401 pp.
- Williams, W.D., 1972. Biota of Freshwater Ecosystems Identification Manual No. 7: Freshwater Isopods (*Asellidae*) of North America. EPA, Washington, DC. 45 pp.
- Wydoski, R.S., and R.R. Whitney, 1979. Inland Fishes of Washington. University of Washington Press, Seattle. 220 pp.
- Yearsley, J., 1987. Diffusion in Near-Shore and Riverine Environments. EPA 910/9-87-168.
- Zar, J.H., 1984. Biostatistical Analysis. 2nd ed., Prentice-Hall, Inc., Englewood Cliffs, NJ. 718 pp.

## Appendix A. Planning Check List

PLANNING CHECK LIST

Project \_\_\_\_\_

Date \_\_\_\_\_

Type of Survey

Point Source

\_\_\_ Municipal, \_\_\_ Industrial, \_\_\_ Combined, \_\_\_ Other  
\_\_\_ Number of point sources to be investigated

Non-Point Source

\_\_\_ One type, \_\_\_ Several types  
\_\_\_ Agriculture: \_\_\_ livestock, \_\_\_ row crop, \_\_\_ other:  
\_\_\_ Silviculture  
\_\_\_ Urban run-off: \_\_\_ storm drains, \_\_\_ CSOs  
\_\_\_ Development/Construction/Septic tanks, etc.  
\_\_\_ Mining/Resource Extraction  
\_\_\_ Other: \_\_\_\_\_

Other Surveys

\_\_\_ Baseline investigation  
\_\_\_ Phase I Lake diagnostic study  
\_\_\_ Bioassessment/habitat assessment

Waterbody Types

\_\_\_ River: \_\_\_ free-flowing, \_\_\_ regulated, \_\_\_ tidal  
\_\_\_ Stream: \_\_\_ perennial, \_\_\_ intermittent, \_\_\_ regulated  
\_\_\_ Lake: \_\_\_ natural, \_\_\_ reservoir  
\_\_\_ Estuary  
\_\_\_ Bay  
\_\_\_ Puget Sound: Describe \_\_\_\_\_  
\_\_\_ Ground Water: Describe \_\_\_\_\_  
\_\_\_ Combination: Describe \_\_\_\_\_  
\_\_\_ Other: Describe \_\_\_\_\_

Critical Period or Season

\_\_\_ Low Flow: \_\_\_ Summer/Fall, \_\_\_ Winter (freeze), \_\_\_ Other  
\_\_\_ High Flow: \_\_\_ Winter/Spring, \_\_\_ Other  
\_\_\_ Storm Event: Describe \_\_\_\_\_  
\_\_\_ Doesn't matter/anytime  
\_\_\_ Other: Describe \_\_\_\_\_

Parameter(s) of Concern or Problem Suspected

- Point Source Effluent
- NPDES regulated parameter:
  - BOD,  Temperature,  pH
  - TSS,  Fecal coliform
  - Residual Chlorine,  NH<sub>3</sub>,
  - Metal(s): \_\_\_\_\_
  - Oil and Grease,  Solids,
  - Bioassay
  - Other: Describe: \_\_\_\_\_

- Other parameter(s) of concern:
  - Metals: \_\_\_\_\_
  - Pesticides: \_\_\_\_\_
  - PCBs
  - Volatile Organics: \_\_\_\_\_
  - Base neutrals: \_\_\_\_\_
  - Acid extractables: \_\_\_\_\_
  - TOX
  - Nutrients
  - Other: \_\_\_\_\_

- Non-Point Parameters:
  - BOD,  Temperature,  pH,
  - TSS,  Fecal coliform/pathogens
  - NH<sub>3</sub>,  Metals: \_\_\_\_\_
  - Pesticides: \_\_\_\_\_
  - PCBs
  - Volatile Organics: \_\_\_\_\_
  - Base neutrals: \_\_\_\_\_
  - Acid extractables: \_\_\_\_\_
  - TOX
  - Nutrients
  - Other: \_\_\_\_\_

- General Problem:  Near-field,  Far-field
- Eutrophication
  - Toxicity
  - Water quality standard or criteria violation
  - Habitat destruction
  - Impairment of beneficial uses
  - Drinking water contamination
  - Problem unknown
  - Other: \_\_\_\_\_

Description: \_\_\_\_\_

\_\_\_\_\_

**Media to Sample**

Water:  Total,  Dissolved,  Particulate  
 Effluent:  Total,  Dissolved,  Particulate  
 Sediment:  Surficial,  Deep  
 Tissue:  Fish,  Shellfish,  Other: \_\_\_\_\_  
 Ground Water  
 Other: \_\_\_\_\_

**Report Considerations**

Full report  
 Memorandum only  
 "Quick and Dirty"

Date Due or Die: \_\_\_\_\_

## **Appendix B. Equipment Check List**

## EQUIPMENT CHECK LIST

PROJECT \_\_\_\_\_

Instruments

Batteries \_\_\_\_\_  
 Benthos Sieve/Forceps \_\_\_\_\_  
 Carpenter Square \_\_\_\_\_  
 Chlorine Kit \_\_\_\_\_  
 Compositors \_\_\_\_\_  
 Conductance Meter \_\_\_\_\_  
 Current Meter \_\_\_\_\_  
 Deionized Water \_\_\_\_\_  
 Drogues \_\_\_\_\_  
 Dye \_\_\_\_\_  
 Electrofisher \_\_\_\_\_  
 Float Buoy w/ Anchor \_\_\_\_\_  
 Hydrolab \_\_\_\_\_  
 Kemmerer/Van Dorn \_\_\_\_\_  
 Lead Fish \_\_\_\_\_  
 Measuring Tape \_\_\_\_\_  
 Messengers \_\_\_\_\_  
 Oxygen Reagents \_\_\_\_\_  
 pH Buffers \_\_\_\_\_  
 pH Meter \_\_\_\_\_  
 Ponar \_\_\_\_\_  
 Preservative \_\_\_\_\_  
 Salinometer \_\_\_\_\_  
 Secchi Disk \_\_\_\_\_  
 Sediment Pails/Spoons \_\_\_\_\_  
 Seines/Nets \_\_\_\_\_  
 Thermometer \_\_\_\_\_  
 Top Setting Rod \_\_\_\_\_

Bottles

1 Gallon Glass Jar \_\_\_\_\_  
 1 L Bottles \_\_\_\_\_  
 1 L Cubitainers \_\_\_\_\_  
 1/2 Gallon Glass Jar \_\_\_\_\_  
 1/2 L Bottles \_\_\_\_\_  
 2 L Bottles \_\_\_\_\_  
 8 Oz. Sediment Jar \_\_\_\_\_  
 Bacteria \_\_\_\_\_  
 Bacteria - Thio. \_\_\_\_\_  
 Biota Bottles \_\_\_\_\_  
 Dissolved Oxygen \_\_\_\_\_  
 Extra Bottles \_\_\_\_\_  
 Nutrient Bottles \_\_\_\_\_  
 Oil + Grease \_\_\_\_\_  
 Rinse Bottle \_\_\_\_\_  
 Sample Blanks \_\_\_\_\_  
 TOC Bottles \_\_\_\_\_  
 Twirl Paks \_\_\_\_\_  
 Volatile Organics \_\_\_\_\_

Miscellaneous

Binoculars \_\_\_\_\_  
 Buckets \_\_\_\_\_  
 Calculator \_\_\_\_\_  
 Camera/Film \_\_\_\_\_  
 Clip Board \_\_\_\_\_  
 Compass \_\_\_\_\_  
 Electrical Tape \_\_\_\_\_  
 Equipment Manuals \_\_\_\_\_  
 Field Notebook \_\_\_\_\_  
 Flashlight \_\_\_\_\_  
 Glass Tape \_\_\_\_\_  
 Ice \_\_\_\_\_  
 Ice Chests \_\_\_\_\_  
 Knife \_\_\_\_\_  
 Lab Manual/Forms \_\_\_\_\_  
 Maps/Charts \_\_\_\_\_  
 Pencils/Pens/Markers \_\_\_\_\_  
 Project File \_\_\_\_\_  
 Rags \_\_\_\_\_  
 Rope/Twine \_\_\_\_\_  
 Tags/Bands \_\_\_\_\_  
 Tide Tables \_\_\_\_\_  
 Tools \_\_\_\_\_  
 Van Fuel \_\_\_\_\_  
 Watch \_\_\_\_\_

Clothing

Boots \_\_\_\_\_  
 Chest Waders \_\_\_\_\_  
 Full Clothing Change \_\_\_\_\_  
 Gloves \_\_\_\_\_  
 Hat/Cap \_\_\_\_\_  
 Hip Waders \_\_\_\_\_  
 Raingear \_\_\_\_\_  
 Rubber Gloves \_\_\_\_\_  
 Sunglasses \_\_\_\_\_  
 Wader Socks \_\_\_\_\_

Boating

Anchor/Rope \_\_\_\_\_  
 Boat Fuel \_\_\_\_\_  
 Depth Sounder \_\_\_\_\_  
 Flares \_\_\_\_\_  
 Float Coats \_\_\_\_\_  
 Foghorn \_\_\_\_\_  
 Life Vests \_\_\_\_\_  
 Oil \_\_\_\_\_  
 Paddles \_\_\_\_\_  
 Winch/Meter \_\_\_\_\_

## Appendix C. Methods For Estimating Stream Flow

# METHODS FOR ESTIMATING STREAMFLOW

by Joy Michaud

## I. Estimating Discharge In Streams and Channels

The importance of obtaining good hydrological information cannot be over-emphasized. Accurate discharge measurements link precipitation to runoff and allow calculation of pollutant loadings. The hydrologic character of a stream and its change through time can be important indicators of the effects of development or stormwater controls.

### A. Development of a Gaging Station

A staff gaging station should be set up at the mouth of the watershed. The purpose of the gaging station is to develop a relationship between stream height (stage) and flow. Once this relationship is established, it will no longer be necessary to measure flow with a wading rod and current meter each sampling trip. Further, the information (used in conjunction with precipitation data) can be used to estimate changes in stream flows as watersheds develop. (Note: It is possible a gaging station already exists on a watershed. The USGS has established a network of gaging stations throughout the country. Contact the USGS Water Resources Division in Tacoma [telephone (206) 593-6510] for information on gaging station locations.)

#### 1. Site Selection Criteria

It is important to select a proper location to establish a staff gage station or a flow monitoring site. Proper site selection will improve the accuracy of flow measurements at all stream discharge levels. The following criteria should be considered when establishing a discharge measurement station. However, it is rarely possible to meet all the criteria recommended here. Be aware of the limitations of the site selected and possible effects on measurements.

##### a. Stream Reach Criteria

- (1) The stream should be straight for 300 feet upstream and downstream of the discharge site.
- (2) Flow is confined to one channel at all stages of discharge; i.e., there are no surface or subsurface bypasses, up to flood stage.
- (3) Stream bed is subject to minimal scour and relatively free of plant growth.

- (4) Stream banks are stable, high enough to contain maximum flows, and free of brush.
- (5) Gaging stations should be located a sufficient distance upstream of tributaries and tidal action to prevent these from affecting stage/discharge measurements.
- (6) All discharge stages should be measurable somewhere within the reach (it is not necessary to measure low and high flows at the exact same cross-section).
- (7) The site should be readily and safely accessible.

b. Cross-section Criteria

In selecting a cross-section within a stream reach, consider the following:

- (1) Stream banks should be relatively high and stable.
- (2) A straight section of the stream should be chosen, where stream banks are parallel to each other.
- (3) Depth and velocity must meet minimum requirements of the method and instrument being used.
- (4) The stream bed should be relatively uniform with few boulders or heavy aquatic plant growth.
- (5) Flow should be uniform and free of eddies, slack water, and excessive turbulence.
- (6) Sites downstream of rapid changes in stage and velocity should be avoided.

2. Setting Up a Staff Gage

- a. Attach staff gage vertically on a permanent structure (concrete piling, revetment, etc.).
- b. Set the zero point of the staff gage below the lowest level of stream flow to prevent negative values of gage height.

- c. Establish a datum point on the gage, and make two or three reference marks at the same level on nearby permanent features. (Use a point on the gage that is above the highest expected gage height to prevent flow-related erosion of the marks.) The datum may also be referenced to an official surveyors benchmark. By establishing reference elevations, the datum can be recovered if the staff gage is destroyed.
- d. Set the gage datum to an accuracy criterion of 0.01 feet and recheck it at least every two to three years.

### 3. Establishing a Rating Curve

- a. Take stream flow measurements over a wide range of gage heights. It will be easy to establish data points for average stream flows, but the relationship will not hold for high and low flows. Consequently, it is very important to get measurements during high and low stream flows so that a wide range of conditions is represented on the rating curve. Ideally, measurements for low, average and high flows should be separated by an order of magnitude.
- b. Note the gage height both before and after measuring flow. (If wave action occurs, read height as the average of the elevations of peaks and troughs.)
- c. Plot calculated stream flow (x-axis) versus gage height (y-axis). Provide a sufficient number of points to allow a smooth curve to be drawn through the points. As noted above, be sure the high and low ends of the curve are represented in the relationship.
- d. Make periodic checks of the discharge curve, especially after high waters or floods. Recalibrate the curve if checks indicate the stream flow/gage height relationship has changed, usually due to significant sediment deposition or erosion of the stream bed.

**NOTE:** Stream height can also be measured as the distance from the surface of the water to a permanent point above the stream. A bridge provides a convenient place for these measurements. Make a permanent mark on the bridge so stream height is always measured from the same location. Lower a marked, weighted tape until the weight just touches the water surface. Record the distance. Use this measurement as the gage height in establishing the rating curve. As with an instream gage, this method assumes there is no change in the bottom profile of the cross-section. Check the profile periodically.

## B. Stream Flow Measurement Techniques

### 1. Current meter measurements

- a. Select an appropriate cross-section.
- b. String measuring tape at right angles to the direction of flow and measure the width of the cross-section. (Leave the tape tightly strung across the stream.)
- c. Divide the width into approximately 20 points of measurement. (If previous flow measurements have shown uniform depth and velocity, fewer points may be used. Smaller streams may also require fewer points.) Measuring points should be closer where depths or velocities are more variable. Cross-sections with uniform depth and velocity can have equal spacing.
- d. At each of the measuring points:
  - (1) Record the distance from the initial starting bank
  - (2) Record the depth
  - (3) Record the velocity using a current meter. (See Following Notes)

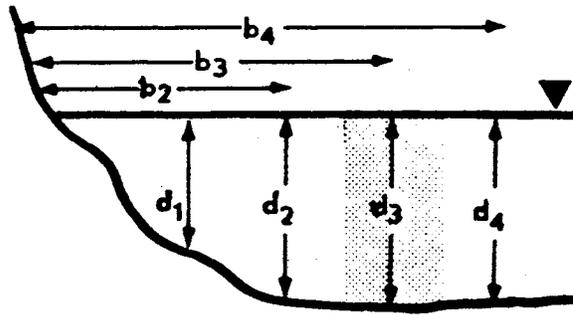
**MEASURING STREAM VELOCITY:** Stream velocity varies horizontally (from left bank to right bank) and vertically (top to bottom). Horizontal differences are accounted for by measuring velocity along a cross section of the stream, as described above. To correct for vertical differences, hydrologists have developed a standard technique to ensure consistency in determining average velocity. This technique assumes that the "average" vertical stream velocity occurs at some percentage of the stream depth. This percentage changes with stream depth. In streams where the maximum depth is 2.0 feet or less, the average stream velocity is assumed to occur at six-tenths of total depth (as measured from the surface). In streams deeper than 2.0 feet, the velocity is measured at two-tenths and eight-tenths of the total depth. Velocity is calculated as the average of these two measurements.

- (4) Calculate discharge as a summation of discharge in partial areas. Compute discharge in a partial area using the equation:

$$q_3 = v_3 d_3 (b_4 - b_2) / 2$$

where:  $b_2$  = distance from initial point to the preceding point (feet)  
 $b_4$  = distance from initial point to the following point (feet)  
 $d_3$  = mean depth of partial area 3 (feet)  
 $v_3$  = average velocity in partial area 3 (feet)  
 $q_3$  = discharge in partial area 3 (cfs)

Variables are illustrated below:



generalized equation:

$$q_x = v_x d_x (b_{x+1} - b_{x-1}) / 2$$

Note: In this example, the shaded area represents the partial area for which discharge is being calculated.

## 2. Float Method

When usual flow measurement methods cannot be used; e.g., during extremely high flows, or when equipment is not available, a floating object can be used to estimate velocity. The object can be an orange, a plastic sample bottle partially filled with water, or other semi-buoyant object.

- a. Locate a straight stretch of stream.
- b. Select two cross-sections within the stretch, measure (or estimate) their cross-sectional area and distance between them. (Sites should be far enough apart that float movement between sites exceeds 20 seconds.)
- c. Release the float at the upstream site and record the time it takes to reach the downstream site. Repeat twice and average the three measurements. To increase accuracy, release the float at different places across the width of the stream.

- d. Calculate the velocity as distance travelled divided by average travel time.
- e. Calculate the adjusted (true mid-depth) mean velocity of the water by multiplying the surface velocity by 0.85.
- f. Calculate discharge by multiplying velocity by the average cross-sectional area.

## II. Measuring Flow From Pipes

The flow measurement techniques described above also work for pipe discharges under certain conditions; e.g., if there is upstream access to release the float or tracer. However, often it is not possible to use these techniques with a pipe. The following methods can be used to estimate pipe discharge.

### A. Volumetric Measurement

In this method, discharge is calculated by observing the time required to fill a container of known volume. A limiting factor of this technique is that it can only be used with small discharges (*i.e.*, where all of the flow can be caught in one container). This technique can also be used to estimate discharge over a weir or at any place where flow is concentrated into a narrow stream.

1. Place bucket or other container below the discharge.
2. Time how long it takes to fill the container. Repeat three times (or more if there is a large difference between results). Whenever possible, the time interval should exceed 20 seconds.
3. Calculate discharge as the volume of the container divided by the average time to fill it.

### B. Discharge of a Jet of Water

This technique can be used on any discharge regardless of size. The limitations are that the pipe must be horizontal and the fluid must be confined on all sides (e.g., a pipe that is running full, with the fluid emerging in free fall). See illustration below.

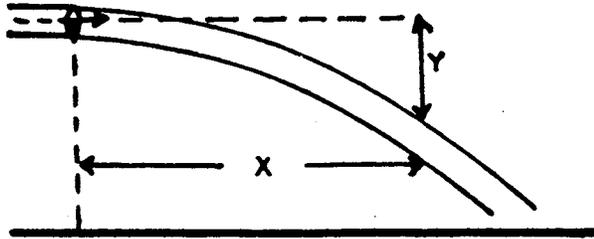
1. Measure or estimate the diameter of the pipe.
2. Measure the distance from the end of the pipe to the spot where the stream of water hits ground ("x").
3. Measure the vertical distance from "x" to the midpoint of the pipe orifice ("y").
4. Calculate the velocity ("v") as:

$$V = 4.01(x)/\sqrt{y}$$

5. Calculate the area ("A") of the pipe as:

$$A = \pi r^2$$

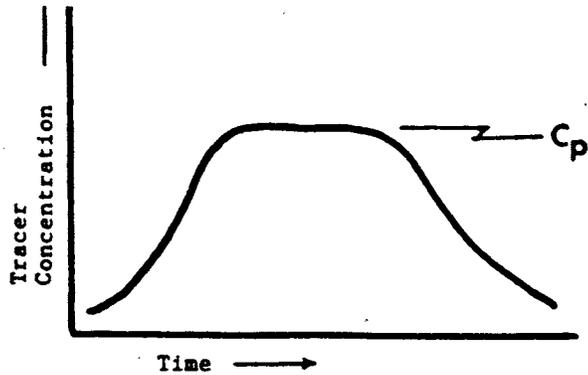
6. Calculate the discharge volume by multiplying area by velocity. Units of measurement must be the same.



### C. Dilution Method

Use common salt, fluorescein or rhodamine dye, or any easily measurable material not present in the stream and not likely to be lost by chemical or biological reactions. (Do not use any material that may damage the stream environment. The USGS recommends use of Rhodamine Wt dye because it is relatively unaffected by photosynthesis and adsorption and is minimally toxic compared to other common dyes.) Two methods are presented here. The first requires a constant-rate injection of the solution, the second allows for the solution to be "dumped" at one time. For both methods, it may be necessary to estimate the amount or concentration of tracer material needed, to minimize cost and possible environmental effects. The necessary computations are described in "Measurement of Discharge by Dye-dilution Methods" (USGS, 1965).

1. Constant-rate injection
  - a. A known concentration of tracer material is injected into the stream at a constant rate ( $q$ ) for a given period of time.
  - b. Samples are collected at a site far enough downstream to ensure complete mixing of the tracer with receiving water. Sufficient samples must be collected to form a concentration-time curve as shown below.
  - c. The peak concentration ( $C_p$ ) is estimated from the concentration-time curve.



d. Stream discharge (Q) is calculated as:

$$Q = q[C_s - C_p] / (C_p - C_b)$$

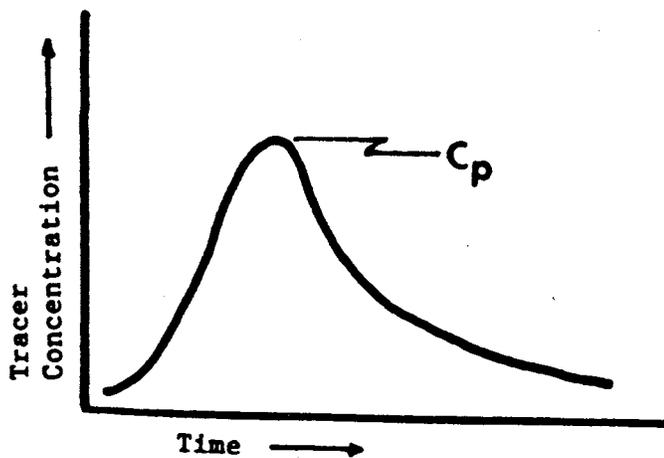
Where: Q, q, and  $C_p$  are defined above

$C_s$  = Initial concentration of tracer

$C_b$  = Background (stream concentration of tracer)

## 2. Sudden-dump Method

- a. A known concentration of a tracer solution is dumped into the stream.
- b. Samples are collected far enough downstream to ensure complete mixing of tracer in the stream. Collect enough samples at an appropriate frequency to develop a concentration-time curve as shown below.



c. The stream discharge (Q) is calculated as:

$$Q = (V_s * C_s) / \int_0^{\infty} (C - C_b) dt$$

Where: Q, C<sub>s</sub>, and C<sub>b</sub> are defined above

V<sub>s</sub> = Volume of tracer solution introduced

C = Tracer solution concentration at a given time

The term (C - C<sub>b</sub>)dt can be approximated by the term:

$$\sum_{i=1}^N (C_i - C_b) (T_{i+1} - T_{i-1}) / 2$$

Where: C and C<sub>b</sub> are defined above

i = sequence number of the sample

N = the total number of samples

T<sub>i</sub> = time when sample C<sub>i</sub> was taken

T<sub>i+1</sub> = time when sample following sample C<sub>i</sub> was taken (C<sub>i+1</sub>)

T<sub>i-1</sub> = time when sample preceding sample C<sub>i</sub> was taken (C<sub>i-1</sub>)

The final concentration of the tracer in the stream needs to be accurately measured in either of these methods.

**Appendix D. Spreadsheets for Water Quality-Based Permit Calculations**

## SECTION 1

### LIST OF AVAILABLE SPREADSHEETS

Spreadsheet Name	Description
DOSAG2.WK1	Calculates critical sag of dissolved oxygen downstream from a point source using the Streeter-Phelps equation.
IDOD2.WK1	Calculates concentration of dissolved oxygen at a mixing zone boundary accounting for dilution of dissolved oxygen and initial dissolved oxygen demand.
NH3FRESH.WK1	Calculates freshwater un-ionized and total ammonia criteria from temperature and pH.
NH3SALT.WK1	Calculates saltwater total ammonia criteria from temperature, pH, and salinity to meet the un-ionized ammonia criteria.
PHMIX2.WK1	Calculates the pH of a mixture of two sources from temperature, pH, and alkalinity.
RIVPLUM3.WK1	Simple dilution model for rivers.
WQBP2.WK1	Calculates water quality-based permit limits to meet acute and chronic aquatic life criteria for specific chemicals.

## **SECTION 2**

### **USER INSTRUCTIONS FOR SPREADSHEETS**

*This page is purposely blank for duplex printing*

## USER INSTRUCTIONS

**SPREADSHEET NAME:** DOSAG2.WK1 (Lotus 1-2-3)

**REVISION DATE:** 19-Oct-93

**DESCRIPTION:** This spreadsheet replaces a previous version called DOSAG.WK1. This spreadsheet calculates the critical dissolved oxygen sag and concentration downstream from a point source load of BOD in a river using the Streeter-Phelps equations. The method used is documented in EPA/600/6-85/002a (Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water). This spreadsheet is recommended for use as a screening tool to determine the potential for dissolved oxygen standards to be violated. DOSAG.WK1 may be overly simplistic for deriving limits for effluent BOD. If DOSAG.WK1 suggests the dissolved oxygen sag is close to or below the water quality standard, then a more sophisticated model such as QUAL2E or WASP5 should be used to derive appropriate effluent limits. Those water quality models are designed to more accurately simulate water movements, mass transport, and water column processes.

### USER INSTRUCTIONS FOR THE INPUT SECTION:

**Step 1:** Enter the permittees effluent characteristics, including permitted discharge and maximum (e.g, weekly) 5-day BOD (referred to as CBOD<sub>5</sub> for "carbonaceous" 5-day BOD). Carbonaceous 5-day BOD is less than the total 5-day BOD if nitrification occurs during the test. The minimum national standards for carbonaceous 5-day BOD in effluent after secondary treatment are a monthly average of 25 mg/L and weekly average of 40 mg/L (40 CFR Part 133). Guidance for determining if carbonaceous 5-day BOD should be substituted for total 5-day BOD is contained in Ecology's Permit Writers Manual (section V-3.6).

Nitrogenous BOD (NBOD) should also be estimated if it is significant (e.g. if nitrification is not significant during secondary treatment). NBOD can be estimated as:

$$\text{NBOD} = 4.57 * (\text{Ammonia N} + \text{Organic N})$$

where concentrations of NBOD, ammonia N and organic N are expressed in mg/L. Effluent temperature and dissolved oxygen for the analysis are also entered at this step.

The spreadsheet may be used to estimate the maximum permissible effluent CBOD<sub>5</sub> and NBOD that will meet the water quality standards for dissolved oxygen. A trial and error solution is necessary for this purpose. Trial values of effluent CBOD<sub>5</sub> and NBOD may be entered until the dissolved oxygen at the critical sag meets the water quality standard.

**Step 2:** Enter receiving water characteristics. These will generally be conditions at the 7Q10 discharge. Upstream CBOD<sub>5</sub>, NBOD, dissolved oxygen and temperature at the design

river flow (e.g., 7Q10) should be entered. The local channel elevation and channel slope (e.g., from USGS topographic maps) downstream from the discharge should also be entered. Downstream average channel depth and velocity at the design flow should be entered also.

If no receiving water data are available, it would be desirable to collect data. Channel cross-sections of depth and velocity can be measured during the critical season. If measurements are not taken near critical conditions, then Manning's equation may be used to estimate velocity and depths from the measurements. Several cross-sections proceeding downstream from the discharge may be needed to characterize the river to the point of critical sag if velocities and depths are not uniform. Dye studies to measure travel time may be useful if velocities are variable. If significant tributaries, groundwater inflows, or other pollutant loads occur before the predicted critical sag point, then a more sophisticated model should be used (e.g. QUAL2E).

Measurements of water quality (e.g. dissolved oxygen, ammonia, BOD) in the receiving water from upstream and at intervals downstream to the critical sag point are also desirable for model calibration. If the model is applied without sufficient data to demonstrate calibration, then the model should mainly be used to screen for potential violation of standards. If effluent BOD is required to be more restrictive than current technology-based limits, then calibration data are probably needed. Separate calibration and verification data sets taken on different dates may be needed in many cases where the accuracy of the model is in question.

**Step 3:** Enter the reaeration rate (base e) at 20°C in cell D27. Suggested values using empirical equations referenced in EPA/600/6-85/002a are given below cell D27 for guidance in selecting an appropriate value. If the calculated values are used, select the most appropriate equation based on applicable depth and velocity (e.g., if depth is < 1 to 2 feet, then use the value shown from the Tsivoglou-Wallace equation).

**Step 4:** Enter the BOD decay rate (base e) at 20 degrees C in cell D36. A calculated value based on the Wright and McDonnell equation referenced in EPA/600/6-85/002a is provided and may be entered in cell D36 at Step 4 if desired.

#### **USER INSTRUCTIONS FOR THE OUTPUT SECTION:**

The user does not need to change or enter any values or formulas in the Output Section. The travel time and distance to critical sag, deficit at critical sag, and dissolved oxygen concentration at critical sag are displayed in the Output Section.

## USER INSTRUCTIONS

**SPREADSHEET NAME:** IDOD2.WK1 (Lotus 1-2-3)

**REVISION DATE:** 19-Oct-93

**DESCRIPTION:** This spreadsheet replaces a previous version called IDOD.WK1. This spreadsheet calculates the dissolved oxygen concentration at a mixing zone boundary from dilution of dissolved oxygen in the effluent and ambient background and immediate dissolved oxygen demand of the effluent. The method used is presented in EPA/600/6-85-002b (Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water - Part II Revised 1985) and EPA/430/9-82-011 (Revised Section 301(h) Technical Support Document).

### USER INSTRUCTIONS FOR INPUT SECTION:

- Step 1:** Specify the dilution factor for effluent at the chronic mixing zone boundary. This value should represent dilution at critical conditions if the spreadsheet is being used for developing NPDES permit limits. The dilution factor used should represent the reciprocal of the volume fraction of effluent present at the mixing zone boundary (see Permit Writer's Manual section VI-2.1).
- Step 2:** Enter the background dissolved oxygen concentration in the receiving water. The 10th percentile during the critical season is recommended as a reasonable worst case. If no data are available it would be desirable to collect data describing background dissolved oxygen concentrations during the critical season (e.g. upstream from the discharge to a river).
- Step 3:** Enter the effluent dissolved oxygen concentration. The 10th percentile during the critical season is recommended as a reasonable worst case.
- Step 4:** Enter the immediate dissolved oxygen demand (IDOD) of the effluent if known. The IDOD represents the oxygen demand of reduced substances which are rapidly oxidized (e.g. sulfides to sulfates). If the effluent contains measurable dissolved oxygen, then the IDOD may be negligible. If IDOD is to be determined experimentally, the procedures in Standard Methods 1979 edition could be followed. However, the method was omitted from Standard Methods in the 1985 edition because of concerns about the accuracy of the test.

### USER INSTRUCTIONS FOR THE OUTPUT SECTION:

The user should not enter or change the value or formula in the output section. The dissolved oxygen at the mixing zone boundary is presented in the output section.

## USER INSTRUCTIONS

**SPREADSHEET NAME:** NH3FRESH.WK1 (Lotus 1-2-3)

**REVISION DATE:** 19-Oct-93

**DESCRIPTION:** This spreadsheet replaces a previous version called AMMONIA.WK1. This spreadsheet calculates the freshwater acute and chronic criteria for un-ionized and total ammonia for specified temperature and pH using the procedure described in the EPA Gold Book (EPA 440/5-86-001) and listed in WAC 173-201A. It also calculates the amount of un-ionized ammonia present in a sample if total ammonia, temperature, and pH are known.

### USER INSTRUCTIONS FOR INPUT SECTION:

- Step 1:** Specify the temperature (design condition at the mixing zone boundary) for which un-ionized ammonia criteria or concentrations are to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 90th percentile temperature during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe temperature at the mixing zone boundary.
- Step 2:** Specify the pH (design condition at the mixing zone boundary) for which un-ionized ammonia criteria or concentrations are to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 90th percentile pH during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe pH at the mixing zone boundary.
- Step 3:** Specify the sample total ammonia concentration if known. Entering a value here only affects Output Step 2 (calculation of un-ionized ammonia present in a sample). No input is required at this step if the spreadsheet is being used only to calculate criteria from temperature and pH (i.e. this step does not affect criteria calculations).
- Step 4:** Specify "Acute TCAP" according to the Gold Book (enter 20 if salmonids are present; 25 if salmonids are absent).
- Step 5:** Specify "Chronic TCAP" according to the Gold Book (enter 15 if salmonids are present; 20 if salmonids are absent).

### USER INSTRUCTIONS FOR THE OUTPUT SECTION:

The user should not enter or change any values or formulas in the Output Section. The spreadsheet calculates the amount of un-ionized ammonia present in a sample at Output Step 2 if the sample total ammonia was specified at Input Step 3. Output Step 3 provides the acute and chronic criteria for **un-ionized ammonia** expressed in  $\mu\text{g/L}$  as  $\text{NH}_3\text{-N}$ . Output Step 4 provides the acute and chronic criteria for **total ammonia** expressed in  $\mu\text{g/L}$  as  $\text{NH}_3\text{-N}$ .

## USER INSTRUCTIONS

**SPREADSHEET NAME:** NH3SALT.WK1 (Lotus 1-2-3)

**REVISION DATE:** 19-Oct-93

**DESCRIPTION:** This spreadsheet replaces a previous version called HAMPSON.WK1. This spreadsheet calculates water quality criteria for ammonia in saltwater using the method specified in EPA 440/5-88-004 (Ambient Water Quality Criteria for Ammonia (Saltwater)-1989).

### USER INSTRUCTIONS FOR INPUT SECTION:

**Step 1:** Specify the temperature (design condition at the mixing zone boundary) for which un-ionized ammonia criteria are to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 90th percentile temperature during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe temperature at the mixing zone boundary.

**Step 2:** Specify the pH (design condition at the mixing zone boundary) for which un-ionized ammonia criteria to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 90th percentile pH during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe pH at the mixing zone boundary.

**Step 3:** Specify the salinity (design condition at the mixing zone boundary) for which un-ionized ammonia criteria are to be estimated. If the spreadsheet is being used to calculate criteria for a NPDES permit limit, the 10th percentile salinity during the critical season is recommended for a reasonable worst-case condition. If no data are available it may be desirable to collect data during the critical season to describe salinity at the mixing zone boundary.

### USER INSTRUCTIONS FOR THE OUTPUT SECTION:

The user should not enter or change any values or formulas in the output section. The acute and chronic criteria are expressed three ways: 1) as unionized ammonia in mg/L as  $\text{NH}_3$  at Output Step 5; 2) as total ammonia in mg/L as  $\text{NH}_3$  at Output Step 6; and 3) as total ammonia in mg/L as  $\text{NH}_3\text{-N}$  at Output Step 7. For derivation of total ammonia waste load allocations and comparisons with effluent total ammonia data, it is recommended that the criteria be expressed as total ammonia in mg/L as  $\text{NH}_3\text{-N}$  for simplicity. [Note: the criteria in EPA 440/5-88-004 Tables 2 and 3 are for total ammonia as mg/L as  $\text{NH}_3$ , which should be multiplied by 0.822 to convert to mg/L as  $\text{NH}_3\text{-N}$ .]

## USER INSTRUCTIONS

**SPREADSHEET NAME:** PHMIX2.WK1 (Lotus 1-2-3)

**REVISION DATE:** 19-Oct-93

**DESCRIPTION:** This spreadsheet replaces a previous version called PH-MIX.WK1. This spreadsheet calculates the pH of a mixture of two flows using the procedure in EPA's DESCONE program (EPA, 1988. Technical Guidance on Supplementary Stream Design Conditions for Steady State Modeling. EPA Office of Water, Washington DC). The major form of alkalinity is assumed to be carbonate alkalinity. Also, alkalinity and total inorganic carbon are assumed to be conservative.

### USER INSTRUCTIONS FOR THE INPUT SECTION:

**Step 1:** Specify the dilution factor for effluent at the mixing zone boundary. This value should represent dilution at critical conditions if the spreadsheet is being used for developing NPDES permit limits. The dilution factor used should represent the reciprocal of the volume fraction of effluent present at the mixing zone boundary (see Permit Writer's Manual section VI-2.1).

**Step 2:** Specify the upstream characteristics, including temperature, pH, and alkalinity. For development of NPDES permit limits for ammonia, the 90th percentiles during the critical season are recommended. If no data are available, it is desirable to collect data describing upstream temperature, pH, and alkalinity during the critical season.

**Step 3:** Specify the effluent characteristics, including temperature, pH, and alkalinity. For NPDES permit limits, a reasonable worst case estimate of each may be estimated from DMR data (e.g. for ammonia limits use 90th percentile values from the DMR data during the critical season). If effluent data are not available then data should be collected during the critical season. In many cases, pH in ambient receiving water (at Step 2 above) may be assumed to represent the pH in the mixing zone.

### USER INSTRUCTION FOR THE OUTPUT SECTION:

The user does not need to enter or change any values or formulas in the Output Section. The spreadsheet calculates and displays the pH at the mixing zone boundary at Output Step 4. Some important factors that can influence pH are not included in this calculation. For example, photosynthesis in the receiving water may increase pH downstream from the mixing zone. In many cases where dilution is relatively large (e.g. greater than a dilution factor of 20) the pH in the mixing zone will be dominated by ambient conditions. This spreadsheet should be used mainly where effluent dilution is relatively low and effluent pH and alkalinity are much different than in the receiving water.

## USER INSTRUCTIONS

**SPREADSHEET NAME:** RIVPLUM3.WK1 (Lotus 1-2-3)

**REVISION DATE:** 19-Oct-93

**DESCRIPTION:** This spreadsheet replaces a previous version called RIVPLUME.WK1. This spreadsheet calculates dilution at a specified point of interest downstream from a point discharge to a river. The procedure used is described in Fisher *et al.*, 1979 (*Mixing in Inland and Coastal Waters*, Academic Press) and referenced in EPA/505/2-90-001 (TSD for WQ-based Toxics Control). The calculation for dilution factors incorporates the boundary effect of shorelines (Fisher *et al.*, equation 5.9) using the method of superposition.

This spreadsheet is based on the assumption that the discharge: 1) is a single point source, which is most appropriate for single port or short diffusers, or side-bank discharges; and 2) is completely and rapidly mixed vertically, which usually only occurs in shallow rivers. If the diffuser length occupies a substantial portion of the stream width, or the discharge is not vertically mixed over the entire water column within the acute mixing zone, an alternative model should be used such PLUMES or CORMIX. RIVPLUM3.WK1 is useful for estimating dilution in shallow rivers for side-bank discharges or single-port outfalls.

### USER INSTRUCTIONS FOR THE INPUT SECTION:

**Step 1:** Enter the effluent design flow (see Permit Writer's Manual section VI-3.3.2).

**Step 2:** Specify the receiving water characteristics, including average channel depth, velocity and width downstream from the discharge at the design flow (e.g, at 7Q10. NOTE: The product of depth\*width\*velocity should equal the receiving water discharge rate downstream from the discharge).

Also enter either the channel slope downstream from the discharge (e.g., as measured from a USGS topographic map) or Manning's "n" coefficient for roughness. Finally, enter either 0 (if slope is entered above) or 1 (if Manning's "n" is entered above).

The slope or Manning's "n" are used to estimate shear velocity and transverse mixing coefficients. Either method may be used, depending on which data are more readily available. It is not necessary to specify both slope and Manning's "n". If comparisons are made between the two methods then care should be taken to be sure that slope and Manning's "n" values are consistent with velocity, depth, and width data since all are related by Manning's equation.

In general, it is not desirable to overestimate Manning's "n" because a lower value will generally be more protective since it will predict a lower transverse mixing coefficient. If the Manning option is used, the following values may be appropriate estimates for Manning's "n" (EPA/600/3-87-007 after Henderson, F.M., *Open Channel Flow*, Macmillan Co., New York, NY, 1966):

Channel Type	Manning "n"
Artificial channel, earth, smooth, no weeds	0.020
Artificial channel, earth, some stones and weeds	0.025
Natural channel, clean and straight	0.025 - 0.030
Natural channel, winding with pools and shoals	0.033 - 0.040
Natural channel, very weedy, winding and overgrown	0.075 - 0.150

If no receiving water data are available, then data collection would be desirable. Measurements of channel cross-sections of width, depth, and velocity should be collected within the mixing zone at conditions near critical low flow (e.g. near 7Q10). If conditions are significantly different than 7Q10 during measurements, then data may need to be adjusted (e.g. using Manning's equation).

**Step 3:** Enter the distance between the diffuser midpoint and the nearest shoreline of the river (e.g., for a side-bank discharge enter 0).

**Step 4:** Enter the location of the downstream point at which dilution factors will be estimated, including the distance downstream from the diffuser and the distance from the nearest shoreline. The "point of interest" is the location at which dilution factors will be estimated in the Output Section. The highest concentration of effluent downstream from the outfall will be the same distance from shore as the point of discharge. Therefore, the distance from shore for the point of interest should be the same as for the diffuser midpoint in Step 3 for a worst case. However, the dilution at any point downstream may be estimated using any combination of distances downstream and from shore for the "point of interest."

**Step 5:** Enter the transverse mixing coefficient constant. A value of 0.6 is recommended for most natural channels. Fischer reports that the transverse mixing coefficient can range from 0.1 to 0.2 for straight artificial channels. Curves and sidewall irregularities increase the coefficient such that in natural streams it is rarely less than 0.4. If the stream is slowly meandering and the sidewall irregularities are moderate, then the coefficient is usually in the range of 0.4 to 0.8. Therefore, a value of 0.6 is usually recommended in natural channels. Uncertainty in this constant is usually at least  $\pm 50$  percent.

#### **USER INSTRUCTIONS FOR THE OUTPUT SECTION:**

The user does not need to enter or change any values or formulas in the Output Section. The plume characteristics incorporating the shoreline effect are displayed at Step 5 of the Output Section, including the approximate distance downstream to complete mix, theoretical maximum

available dilution at complete mix of effluent with the receiving water, and the calculated dilution factor at the specified point of interest downstream from the discharge.

The distance downstream to complete mixing is often overestimated because most natural channels contain sharp bends or changes that increase mixing beyond the processes included in the model. The model is most useful for predicting mixing where the channel is represented over a relatively short distance (e.g. to the mixing zone boundary).

## USER INSTRUCTIONS

**SPREADSHEET NAME:** WQBP2.WK1 (Lotus 1-2-3)

**REVISION DATE:** 19-Oct-93

**DESCRIPTION:** This spreadsheet replaces a previous version called WQBP-CON.WK1. This spreadsheet calculates water quality-based permit limits, including calculations of waste load allocations (WLAs) and permit limits incorporating effluent variability for specific chemical concentrations. The method used is documented in Box 5-2 of EPA/505/2-90-001 (Technical Support Document for Water Quality-based Toxics Control).

### USER INSTRUCTIONS FOR INPUT SECTION:

**Step 1:** Specify water quality standards/criteria that apply to the receiving water. These include the acute and chronic concentration values (e.g., mg/L or  $\mu\text{g/L}$ ) appropriate for the specific chemical of interest. The acute and chronic water quality criteria that apply to the conditions (e.g., hardness, pH, temperature) at the point of compliance (e.g., end-of-pipe or within the mixing zone for acute and 300 feet downstream from the discharge for chronic river) should be specified.

**Step 2:** Specify the upstream or background concentration of the parameter of interest in the receiving water for the acute and chronic evaluations (e.g. at river flow of 7Q10). The 90th percentile concentrations during the critical season are recommended for a reasonable worst-case. If no data are available it would be desirable to collect data during the critical season to characterize upstream concentrations unless background can be considered negligible (e.g. background can usually be considered negligible for residual chlorine).

**Step 3:** Enter the dilution factors that apply at the point of compliance with acute and chronic criteria (see Permit Writer's Manual section VI-2.1). Dilution factors should be defined as the reciprocal of the volumetric fraction of effluent present at the mixing zone boundary.

If actual dilution factors have been reliably estimated from tracer studies or plume modeling, then those values should be entered in the spreadsheet. In rivers, the dilution factors for permit limit calculations should not exceed the dilution obtained from mixing the effluent design flow with 25% or 2.5% of the critical upstream river flow for chronic and acute criteria, respectively. If water quality criteria are required to be met at the end-of-pipe, then a dilution factor of 1 should be entered.

**Step 4:** Enter the coefficient of variation for the effluent concentration of the parameter of interest (e.g., use 0.6 if less than 10 effluent samples are available).

**Step 5:** Specify the number of days for the chronic average (EPA recommends using 4 days).

**Step 6:** Specify the number of samples per month that the permittee will be required to report to monitor compliance with the permit.

**USER INSTRUCTIONS FOR THE OUTPUT SECTION:**

The user does not need to enter or change any values or formulas in the Output Section. The spreadsheet calculates permit limits incorporating effluent variability using the method described in the EPA TSD. Estimated daily maximum and monthly average permit limits are calculated and displayed in the Output Section at Step 4 in the same concentration units used for water quality criteria.

## **SECTION 3**

### **PRINTOUTS OF SPREADSHEET EXAMPLES**

---

 INPUT

## 1. EFFLUENT CHARACTERISTICS

Discharge (cfs):	1.86
CBOD5 (mg/L):	40
NBOD (mg/L):	2.6
Dissolved Oxygen (mg/L):	2
Temperature (deg C):	20.7

## 2. RECEIVING WATER CHARACTERISTICS

Upstream Discharge (cfs):	16
Upstream CBOD5 (mg/L):	1.5
Upstream NBOD (mg/L):	0.2
Upstream Dissolved Oxygen (mg/L):	8.32
Upstream Temperature (deg C):	20.7
Elevation (ft NGVD):	1540
Downstream Average Channel Slope (ft/ft):	0.00088
Downstream Average Channel Depth (ft):	0.46
Downstream Average Channel Velocity (fps):	0.98

3. REAERATION RATE (Base e) AT 20 deg C ( $\text{day}^{-1}$ ):

3.57

Reference	Applic. Vel (fps)	Applic. Dep (ft)	Suggested Values
Churchill	1.5 - 6	2 - 50	41.70
O'Connor and Dobbins	.1 - 1.5	2 - 50	41.12
Owens	.1 - 6	1 - 2	89.63
Tsivoglou-Wallace	.1 - 6	.1 - 2	3.57

4. BOD DECAY RATE (Base e) AT 20 deg C ( $\text{day}^{-1}$ ):

2.51

Reference	Suggested Value
Wright and McDonnell, 1979	2.51

---

## OUTPUT

## 1. INITIAL MIXED RIVER CONDITION

CBOD5 (mg/L):	5.5
NBOD (mg/L):	0.4
Dissolved Oxygen (mg/L):	7.7
Temperature (deg C):	20.7

## 2. TEMPERATURE ADJUSTED RATE CONSTANTS (Base e)

Reaeration ( $\text{day}^{-1}$ ):	3.63
BOD Decay ( $\text{day}^{-1}$ ):	2.59

## 3. CALCULATED INITIAL ULTIMATE CBODU AND TOTAL BODU

Initial Mixed CBODU (mg/L):	8.1
Initial Mixed Total BODU (CBODU + NBOD, mg/L):	8.6

## 4. INITIAL DISSOLVED OXYGEN DEFICIT

Saturation Dissolved Oxygen (mg/L):	8.477
Initial Deficit (mg/L):	0.82

## 5. TRAVEL TIME TO CRITICAL DO CONCENTRATION (days):

0.29

## 6. DISTANCE TO CRITICAL DO CONCENTRATION (miles):

4.60

## 7. CRITICAL DO DEFICIT (mg/L):

2.90

## 8. CRITICAL DO CONCENTRATION (mg/L):

5.57

Dissolved oxygen concentration following initial dilution.  
References: EPA/600/6-85/002b and EPA/430/9-82-011

Lotus File IDOD2.WK1 Revised 19-Oct-93

---

INPUT

1. Dilution Factor at Mixing Zone Boundary:	10
2. Ambient Dissolved Oxygen Concentration (mg/L):	6.5
3. Effluent Dissolved Oxygen Concentration (mg/L):	4
4. Effluent Immediate Dissolved Oxygen Demand (mg/L):	0

---

OUTPUT

Dissolved Oxygen at Mixing Zone Boundary (mg/L):	6.25
--	------

---

Calculation of un-ionized ammonia concentration and criteria.  
Based on EPA Gold Book (EPA 440/5-86-001).

Lotus File NH3FRESH.WK1 Revised 19-Oct-93

---

**INPUT**

1. Temperature (deg C; $0 < T < 30$ ):	20.0
2. pH ( $6.5 < \text{pH} < 9.0$ ):	9.00
3. Total Ammonia (ug N/L):	200.0
4. Acute TCAP (Salmonids present- 20; absent- 25):	20
5. Chronic TCAP (Salmonids present- 15; absent- 20):	15

---

**OUTPUT**

1. Intermediate Calculations:	
Acute FT:	1.00
Chronic FT:	1.41
FPH:	1.00
RATIO:	16
pKa:	9.40
Fraction Of Total Ammonia Present As Un-ionized:	28.4298%
2. Sample Un-ionized Ammonia Concentration (ug/L as NH3-N):	56.9
3. Un-ionized Ammonia Criteria:	
Acute (1-hour) Un-ionized Ammonia Criterion (ug/L as NH3-N):	213.7
Chronic (4-day) Un-ionized Ammonia Criterion (ug/L as NH3-N):	29.1
4. Total Ammonia Criteria:	
Acute Total Ammonia Criterion (ug/L as NH3-N):	752
Chronic Total Ammonia Criterion (ug/L as NH3-N):	102

---

Calculation of seawater fraction of un-ionized ammonia  
from Hampson (1977). Un-ionized ammonia criteria for  
salt water are from EPA 440/5-88-004.

Lotus File NH3SALT.WK1 Revised 19-Oct-93

---

INPUT

1. Temperature (deg C):	15.0
2. pH:	8.0
3. Salinity (g/Kg):	20.0

---

OUTPUT

1. Pressure (atm; EPA criteria assumes 1 atm):	1.0
2. Molal Ionic Strength (not valid if >0.85):	0.407
3. pKa8 at 25 deg C (Whitfield model "B"):	9.292
4. Percent of Total Ammonia Present as Unionized:	2.362%
5. Unionized ammonia criteria (mg un-ionized NH3 per liter) from EPA 440/5-88-004	
Acute:	0.233
Chronic:	0.035
6. Total Ammonia Criteria (mg/L as NH3)	
Acute:	9.86
Chronic:	1.48
7. Total Ammonia Criteria (mg/L as NH3-N)	
Acute:	8.11
Chronic:	1.22

---

Calculation of pH of a mixture of two flows.  
Based on the procedure in EPA's DESCONE program (EPA, 1988. Technical  
Guidance on Supplementary Stream Design Conditions for Steady State  
Modeling. USEPA Office of Water, Washington D.C.)

Lotus File PHMIX2.WK1 Revised 19-Oct-93

---

INPUT

1. DILUTION FACTOR AT MIXING ZONE BOUNDARY	2.000
1. UPSTREAM/BACKGROUND CHARACTERISTICS	
Temperature (deg C):	12.00
pH:	7.50
Alkalinity (mg CaCO3/L):	50.00
2. EFFLUENT CHARACTERISTICS	
Temperature (deg C):	20.00
pH:	7.20
Alkalinity (mg CaCO3/L):	150.00

---

OUTPUT

1. IONIZATION CONSTANTS	
Upstream/Background pKa:	6.45
Effluent pKa:	6.38
2. IONIZATION FRACTIONS	
Upstream/Background Ionization Fraction:	0.92
Effluent Ionization Fraction:	0.87
3. TOTAL INORGANIC CARBON	
Upstream/Background Total Inorganic Carbon (mg CaCO3/L):	54.41
Effluent Total Inorganic Carbon (mg CaCO3/L):	172.81
4. CONDITIONS AT MIXING ZONE BOUNDARY	
Temperature (deg C):	16.00
Alkalinity (mg CaCO3/L):	100.00
Total Inorganic Carbon (mg CaCO3/L):	113.61
pKa:	6.41
pH at Mixing Zone Boundary:	7.28

---

Spread of a plume from a point source in a river with and without boundary effects from the shoreline (Fischer et al., 1979).

Lotus File RIVPLUM3.WK1 Revised 19-Oct-93

---

INPUT

1. Effluent Discharge Rate (cfs):	20.00
2. Receiving Water Characteristics Downstream From Waste Input	
Stream Depth (ft):	5.00
Stream Velocity (fps):	2.00
Channel Width (ft):	200.00
Stream Slope (ft/ft) or Manning roughness "n":	0.0002
0 if slope or 1 if Manning "n" in previous cell:	0
3. Discharge Distance From Nearest Shoreline (ft):	0.00
4. Location of Point of Interest to Estimate Dilution	
Distance Downstream to Point of Interest (ft):	300.00
Distance From Nearest Shoreline (ft):	0.00
5. Transverse Mixing Coefficient Constant (usually 0.6):	0.6

---

OUTPUT

1. Source Conservative Mass Input Rate	
Concentration of Conservative Substance (%):	100.00
Source Conservative Mass Input Rate (cfs*%):	2,000.00
2. Shear Velocity	
Shear Velocity based on slope (ft/sec):	0.179
Shear Velocity based on Manning "n":	
using Prasuhn equations 8-26 and 8-54 assuming hydraulic radius equals depth for wide channel	
Darcy-Weisbach friction factor "f":	NA
Shear Velocity from Darcy-Weisbach "f" (ft/sec):	NA
Selected Shear Velocity for next step (ft/sec):	0.179
3. Transverse Mixing Coefficient (ft <sup>2</sup> /sec):	0.538
4. Plume Characteristics Assuming No Shoreline Effect	
Unbounded Plume Width at Point of Interest (ft):	50.833
Concentration at Point of Interest (Fischer Eqn 5.7):	6.28E+00
Calculated Dilution Factor at Point of Interest:	15.927
5. Plume Characteristics Accounting for Shoreline Effect	
C <sub>0</sub> :	1.00E+00
x':	2.02E-03
y' <sub>0</sub> :	0.00E+00
y' at point of interest:	0.00E+00
Solution using superposition equation (Fischer eqn 5.9)	
Term for n= -2	0.0000
Term for n= -1	0.0000
Term for n= 0	2.0000
Term for n= 1	0.0000
Term for n= 2	0.0000
C/C <sub>0</sub> (dimensionless):	1.26E+01
Concentration at Point of Interest (Fischer Eqn 5.9):	1.26E+01
Approximate Downstream Distance to Complete Mix (ft):	59,443
Theoretical Dilution Factor at Complete Mix:	100.000
Calculated Dilution Factor at Point of Interest:	7.964

---

Water Quality-Based Permit Limits for acute and chronic criteria.  
(based on EPA/505/2-90-001 Box 5-2).

Lotus File WQBP2.WK1 Revised 19-Oct-93

---

INPUT

1. Water Quality Standards (Concentration)	
Acute (one-hour) Criteria:	19.000
Chronic (n-day) Criteria:	11.000
2. Upstream Receiving Water Concentration	
Upstream Concentration for Acute Condition (7Q10):	0.000
Upstream Concentration for Chronic Condition (7Q10):	0.000
3. Dilution Factors (1/{Effluent Volume Fraction})	
Acute Receiving Water Dilution Factor at 7Q10:	26.000
Chronic Receiving Water Dilution Factor at 7Q10:	100.000
4. Coefficient of Variation for Effluent Concentration (use 0.6 if data are not available):	0.600
5. Number of days (n1) for chronic average (usually four or seven; four is recommended):	4
6. Number of samples (n2) required per month for monitoring:	30

---

OUTPUT

1. Z Statistics	
LTA Derivation (99%tile):	2.326
Daily Maximum Permit Limit (99%tile):	2.326
Monthly Average Permit Limit (95%tile):	1.645
2. Calculated Waste Load Allocations (WLA's)	
Acute (one-hour) WLA:	494.000
Chronic (n1-day) WLA:	1100.000
3. Derivation of LTAs using April 1990 TSD (Box 5-2 Step 2 & 3)	
Sigma <sup>2</sup> :	0.3075
Sigma <sup>2</sup> -n1:	0.0862
LTA for Acute (1-hour) WLA:	158.615
LTA for Chronic (n1-day) WLA:	580.177
Most Limiting LTA (minimum of acute and chronic):	158.615
4. Derivation of Permit Limits From Limiting LTA (Box 5-2 Step 4)	
Sigma <sup>2</sup> -n2:	0.0119
Daily Maximum Permit Limit:	494.000
Monthly Average Permit Limit:	188.704

---

## **SECTION 4**

### **PRINTOUTS OF SPREADSHEET FORMULAS**

A1: PR [W32] 'Streeter-Phelps analysis of critical dissolved oxygen sag.  
A3: PR [W32] 'Lotus File DOSAG2.WK1 Revised 19-Oct-93  
A5: PR [W32] \\_  
B5: PR [W10] \\_  
C5: PR [W18] \\_  
D5: PR [W12] \\_  
A7: PR [W32] 'INPUT  
A9: PR [W32] '1. EFFLUENT CHARACTERISTICS  
A10: PR [W32] ' Discharge (cfs):  
D10: (G) U [W12] 1.86  
A11: PR [W32] ' CBOD5 (mg/L):  
D11: (G) U [W12] 40  
A12: PR [W32] ' NBOD (mg/L):  
D12: (G) U [W12] 2.6  
A13: PR [W32] ' Dissolved Oxygen (mg/L):  
D13: (G) U [W12] 2  
A14: PR [W32] ' Temperature (deg C):  
D14: (G) U [W12] 20.7  
A16: PR [W32] '2. RECEIVING WATER CHARACTERISTICS  
A17: PR [W32] ' Upstream Discharge (cfs):  
D17: (G) U [W12] 16  
A18: PR [W32] ' Upstream CBOD5 (mg/L):  
D18: (F1) U [W12] 1.5  
A19: PR [W32] ' Upstream NBOD (mg/L):  
D19: (G) U [W12] 0.2  
A20: PR [W32] ' Upstream Dissolved Oxygen (mg/L):  
D20: (G) U [W12] 8.32  
A21: PR [W32] ' Upstream Temperature (deg C):  
D21: (G) U [W12] 20.7  
A22: PR [W32] ' Elevation (ft NGVD):  
D22: (G) U [W12] 1540  
A23: PR [W32] ' Downstream Average Channel Slope (ft/ft):  
D23: (G) U [W12] 0.00088  
A24: PR [W32] ' Downstream Average Channel Depth (ft):  
D24: (G) U [W12] 0.46  
A25: PR [W32] ' Downstream Average Channel Velocity (fps):  
D25: (G) U [W12] 0.98  
A27: PR [W32] '3. REAERATION RATE (Base e) AT 20 deg C (day<sup>-1</sup>):  
D27: (F2) U [W12] 3.57  
A29: PR [W32] ' Reference  
B29: PR [W10] 'Applic.  
C29: PR [W18] 'Applic.  
D29: PR [W12] "Suggested  
B30: PR [W10] 'Vel (fps)  
C30: PR [W18] 'Dep (ft)  
D30: PR [W12] "Values  
A31: PR [W32] ' Churchill  
B31: PR [W10] '1.5 - 6  
C31: PR [W18] '2 - 50  
D31: (F2) PR [W12]  $11.6 * D25^{-0.969} * D24^{-1.673}$   
A32: PR [W32] ' O'Connor and Dobbins  
B32: PR [W10] '1.1 - 1.5  
C32: PR [W18] '2 - 50  
D32: (F2) PR [W12]  $(\text{aSQRT}(0.0000000225 * D25) / D24^{1.5}) * 86400$   
A33: PR [W32] ' Owens  
B33: PR [W10] '1.1 - 6  
C33: PR [W18] '1 - 2  
D33: (F2) PR [W12]  $21.6 * D25^{-0.67} / D24^{1.85}$   
A34: PR [W32] ' Tsivoglou-Wallace  
B34: PR [W10] '1.1 - 6

C34: PR [W18] '1.1 - 2  
 D34: (F2) PR [W12] (@IF(D23=0,@NA,@IF(D17+D10<10,7776\*D25\*D23,@IF((D17+D10)<3000,4665.6\*D25\*D23,2592\*D25\*D23)))/(1.024^5)  
 A36: PR [W32] '4. BOD DECAY RATE (Base e) AT 20 deg C (day^-1):  
 D36: (F2) U [W12] 2.51  
 A38: PR [W32] ' Reference  
 D38: PR [W12] "Suggested  
 D39: PR [W12] "Value  
 A40: PR [W32] ' Wright and McDonnell, 1979  
 D40: (F2) PR [W12] @IF(D17+D10<10,3.33,@IF(D17+D10<800,10.3/((D17+D10)^0.49),0.39))  
 A42: PR [W32] \  
 B42: PR [W10] \  
 C42: PR [W18] \  
 D42: PR [W12] \  
 A44: PR [W32] 'OUTPUT  
 A46: PR [W32] '1. INITIAL MIXED RIVER CONDITION  
 A47: PR [W32] ' CBOD5 (mg/L):  
 D47: (F1) PR [W12] (D\$17\*D18+D\$10\*D11)/(D\$17+D\$10)  
 A48: PR [W32] ' NBOD (mg/L):  
 D48: (F1) PR [W12] (D\$17\*D19+D\$10\*D12)/(D\$17+D\$10)  
 A49: PR [W32] ' Dissolved Oxygen (mg/L):  
 D49: (F1) PR [W12] (D\$17\*D20+D\$10\*D13)/(D\$17+D\$10)  
 A50: PR [W32] ' Temperature (deg C):  
 D50: (F1) PR [W12] (D\$17\*D21+D\$10\*D14)/(D\$17+D\$10)  
 A52: PR [W32] '2. TEMPERATURE ADJUSTED RATE CONSTANTS (Base e)  
 A53: PR [W32] ' Reaeration (day^-1):  
 D53: (F2) PR [W12] +D27\*1.024^(D50-20)  
 A54: PR [W32] ' BOD Decay (day^-1):  
 D54: (F2) PR [W12] +D36\*1.047^(D50-20)  
 A56: PR [W32] '3. CALCULATED INITIAL ULTIMATE CBODU AND TOTAL BODU  
 A57: PR [W32] ' Initial Mixed CBODU (mg/L):  
 D57: (F1) PR [W12] +D47/0.68  
 A58: PR [W32] ' Initial Mixed Total BODU (CBODU + NBOD, mg/L):  
 D58: (F1) PR [W12] +D57+D48  
 A60: PR [W32] '4. INITIAL DISSOLVED OXYGEN DEFICIT  
 A61: PR [W32] ' Saturation Dissolved Oxygen (mg/L):  
 D61: (F3) PR [W12] @EXP(-139.34411+(157570.1/(D50+273.15))-(66423080/(D50+273.15)^2)+(12438000000/(D50+273.15)^3)  
 -(862194900000/(D50+273.15)^4))\*(1-0.027\*D22/760)  
 A62: PR [W32] ' Initial Deficit (mg/L):  
 D62: (F2) PR [W12] +D61-D49  
 A64: PR [W32] '5. TRAVEL TIME TO CRITICAL DO CONCENTRATION (days):  
 D64: (F2) PR [W12] @IF((D53/D54)\*(1-(D62\*(D53-D54)/(D54\*D58)))<0,0,(1/(D53-D54))\*@LN((D53/D54)\*(1-(D62\*(D53-D54)/(D54\*D58))))))  
 A66: PR [W32] '6. DISTANCE TO CRITICAL DO CONCENTRATION (miles):  
 D66: (F2) PR [W12] +D64\*D25\*60\*60\*24/5280  
 A68: PR [W32] '7. CRITICAL DO DEFICIT (mg/L):  
 D68: (F2) PR [W12] @IF(D64=0,+D62,@EXP(@LN(D54\*D58/D53)-D54\*D64))  
 A70: PR [W32] '8. CRITICAL DO CONCENTRATION (mg/L):  
 D70: (F2) PR [W12] +D61-D68  
 A72: PR [W32] \  
 B72: PR [W10] \  
 C72: PR [W18] \  
 D72: PR [W12] \

A1: PR [W60] 'Dissolved oxygen concentration following initial dilution.  
A2: PR [W60] 'References: EPA/600/6-85/002b and EPA/430/9-82-011  
A4: PR [W60] 'Lotus File ID002.WK1 Revised 19-Oct-93  
A6: PR [W60] \\_  
B6: PR [W12] \\_  
A8: PR [W60] 'INPUT  
A10: PR [W60] '1. Dilution Factor at Mixing Zone Boundary:  
B10: U [W12] 10  
A12: PR [W60] '2. Ambient Dissolved Oxygen Concentration (mg/L):  
B12: U [W12] 6.5  
A14: PR [W60] '3. Effluent Dissolved Oxygen Concentration (mg/L):  
B14: U [W12] 4  
A16: PR [W60] '4. Effluent Immediate Dissolved Oxygen Demand (mg/L):  
B16: U [W12] 0  
A20: PR [W60] \\_  
B20: PR [W12] \\_  
A22: PR [W60] 'OUTPUT  
A25: PR [W60] 'Dissolved Oxygen at Mixing Zone Boundary (mg/L):  
B25: (F2) PR [W12] +B12+((B14-B16-B12)/B10)  
A28: PR [W60] \\_  
B28: PR [W12] \\_

A1: PR [W60] 'Calculation of un-ionized ammonia concentration and criteria.  
A2: PR [W60] 'Based on EPA Gold Book (EPA 440/5-86-001).  
A4: PR [W60] 'Lotus File NH3FRESH.WK1 Revised 19-Oct-93  
A5: PR [W60] \\_  
B5: PR [W12] \\_  
A7: PR [W60] 'INPUT  
A9: PR [W60] ' 1. Temperature (deg C; 0<T<30):  
B9: (F1) U [W12] 20  
A11: PR [W60] ' 2. pH (6.5<pH<9.0):  
B11: (F2) U [W12] 9  
A13: PR [W60] ' 3. Total Ammonia (ug N/L):  
B13: (F1) U [W12] 200  
A15: PR [W60] ' 4. Acute TCAP (Salmonids present- 20; absent- 25):  
B15: U [W12] 20  
A17: PR [W60] ' 5. Chronic TCAP (Salmonids present- 15; absent- 20):  
B17: U [W12] 15  
A19: PR [W60] \\_  
B19: PR [W12] \\_  
A21: PR [W60] 'OUTPUT  
A24: PR [W60] ' 1. Intermediate Calculations:  
A26: PR [W60] ' Acute FT:  
B26: (F2) PR [W12] @IF(B9>=B15#AND#B9<=30,10^(0.03\*(20-B15)),@IF(B9>=0#AND#B9<B15,10^(0.03\*(20-B9)),@ERR))  
A27: PR [W60] ' Chronic FT:  
B27: (F2) PR [W12] @IF(B9>=B17#AND#B9<=30,10^(0.03\*(20-B17)),@IF(B9>=0#AND#B9<B17,10^(0.03\*(20-B9)),@ERR))  
A28: PR [W60] ' FPH:  
B28: (F2) PR [W12] @IF(B11>8#AND#B11<=9,1,@IF(B11>=6.5#AND#B11<=8,(1+10^(7.4-B11))/1.25,@ERR))  
A29: PR [W60] ' RATIO:  
B29: (F0) PR [W12] @IF(B11>=7.7#AND#B11<=9,16,@IF(B11>=6.5#AND#B11<7.7,24\*(10^(7.7-B11))/(1+10^(7.4-B11)),@ERR))  
A30: PR [W60] ' pKa:  
B30: (F2) PR [W12] 0.09018+2729.92/(273.2+B9)  
A31: PR [W60] ' Fraction Of Total Ammonia Present As Un-ionized:  
B31: (P4) PR [W12] 1/((10^(B30-B11))+1)  
A34: PR [W60] ' 2. Sample Un-ionized Ammonia Concentration (ug/L as NH3-N):  
B34: (F1) PR [W12] +B31\*B13  
A37: PR [W60] ' 3. Un-ionized Ammonia Criteria:  
A39: PR [W60] ' Acute (1-hour) Un-ionized Ammonia Criterion (ug/L as NH3-N):  
B39: (F1) PR [W12] 1000\*(0.52/B26/B28/2)\*0.822  
A40: PR [W60] ' Chronic (4-day) Un-ionized Ammonia Criterion (ug/L as NH3-N):  
B40: (F1) PR [W12] 1000\*(0.8/B27/B28/B29)\*0.822  
A43: PR [W60] ' 4. Total Ammonia Criteria:  
A45: PR [W60] ' Acute Total Ammonia Criterion (ug/L as NH3-N):  
B45: (,0) PR [W12] +B39/B31  
A46: PR [W60] ' Chronic Total Ammonia Criterion (ug/L as NH3-N):  
B46: (,0) PR [W12] +B40/B31  
A48: PR [W60] \\_  
B48: PR [W12] \\_

A1: PR [W60] 'Calculation of seawater fraction of un-ionized ammonia  
 A2: PR [W60] ' from Hampson (1977). Un-ionized ammonia criteria for  
 A3: PR [W60] ' salt water are from EPA 440/5-88-004.  
 A5: PR [W60] 'Lotus File NH3SALT.WK1 Revised 19-Oct-93  
 A7: PR [W60] \\_  
 B7: PR [W12] \\_  
 A9: PR [W60] 'INPUT  
 A11: PR [W60] '1. Temperature (deg C):  
 B11: (F1) U [W12] 15  
 A12: PR [W60] '  
 A13: PR [W60] '2. pH:  
 B13: (F1) U [W12] 8  
 A15: PR [W60] '3. Salinity (g/Kg):  
 B15: (F1) U [W12] 20  
 A17: PR [W60] \\_  
 B17: PR [W12] \\_  
 A19: PR [W60] 'OUTPUT  
 A21: PR [W60] '1. Pressure (atm; EPA criteria assumes 1 atm):  
 B21: (F1) U [W12] 1  
 A23: PR [W60] '2. Molal Ionic Strength (not valid if >0.85):  
 B23: (F3) PR [W12] (19.9273\*B15/(1000-1.005109\*B15))  
 A25: PR [W60] '3. pKa8 at 25 deg C (Whitfield model "B"):  
 B25: (F3) PR [W12] @IF(B23>0.85,@ERR,9.245+0.116\*B23)  
 A27: PR [W60] '4. Percent of Total Ammonia Present as Unionized:  
 B27: (P3) PR [W12] 1/((1+10^(B25+0.0324\*(298-B11-273))+0.0415\*B21)/(B11+273)-B13))  
 A29: PR [W60] '5. Unionized ammonia criteria (mg un-ionized NH3 per liter)  
 A30: PR [W60] ' from EPA 440/5-88-004  
 A31: PR [W60] ' Acute:  
 B31: PR [W12] 0.233  
 A32: PR [W60] ' Chronic:  
 B32: PR [W12] 0.035  
 A34: PR [W60] '6. Total Ammonia Criteria (mg/L as NH3)  
 A35: PR [W60] ' Acute:  
 B35: (F2) PR [W12] +B31/B\$27  
 A36: PR [W60] ' Chronic:  
 B36: (F2) PR [W12] +B32/B\$27  
 A38: PR [W60] '7. Total Ammonia Criteria (mg/L as NH3-N)  
 A39: PR [W60] ' Acute:  
 B39: (F2) PR [W12] +B35\*0.822  
 A40: PR [W60] ' Chronic:  
 B40: (F2) PR [W12] +B36\*0.822  
 A42: PR [W60] \\_  
 B42: PR [W12] \\_

A1: PR [W60] 'Calculation of pH of a mixture of two flows.  
A2: PR [W60] 'Based on the procedure in EPA's DESCONE program (EPA, 1988. Technical  
A3: PR [W60] 'Guidance on Supplementary Stream Design Conditions for Steady State  
A4: PR [W60] 'Modeling. USEPA Office of Water, Washington D.C.)  
A6: PR [W60] 'Lotus File PHMIX2.WK1 Revised 19-Oct-93  
A8: PR [W60] \  
B8: PR [W12] \  
A10: PR [W60] 'INPUT  
A12: PR [W60] '1. DILUTION FACTOR AT MIXING ZONE BOUNDARY  
B12: (F3) U [W12] 2  
A14: PR [W60] '1. UPSTREAM/BACKGROUND CHARACTERISTICS  
A15: PR [W60] ' Temperature (deg C):  
B15: (F2) U [W12] 12  
A16: PR [W60] ' pH:  
B16: (F2) U [W12] 7.5  
A17: PR [W60] ' Alkalinity (mg CaCO3/L):  
B17: (F2) U [W12] 50  
A19: PR [W60] '2. EFFLUENT CHARACTERISTICS  
A20: PR [W60] ' Temperature (deg C):  
B20: (F2) U [W12] 20  
A21: PR [W60] ' pH:  
B21: (F2) U [W12] 7.2  
A22: PR [W60] ' Alkalinity (mg CaCO3/L):  
B22: (F2) U [W12] 150  
A24: PR [W60] \  
B24: PR [W12] \  
A26: PR [W60] 'OUTPUT  
A28: PR [W60] '1. IONIZATION CONSTANTS  
A29: PR [W60] ' Upstream/Background pKa:  
B29: (F2) PR [W12]  $6.57 - 0.0118 * B15 + 0.00012 * (B15^2)$   
A30: PR [W60] ' Effluent pKa:  
B30: (F2) PR [W12]  $6.57 - 0.0118 * B20 + 0.00012 * (B20^2)$   
A32: PR [W60] '2. IONIZATION FRACTIONS  
A33: PR [W60] ' Upstream/Background Ionization Fraction:  
B33: (F2) PR [W12]  $1 / (1 + 10^{(B29 - B16)})$   
A34: PR [W60] ' Effluent Ionization Fraction:  
B34: (F2) PR [W12]  $1 / (1 + 10^{(B30 - B21)})$   
A36: PR [W60] '3. TOTAL INORGANIC CARBON  
A37: PR [W60] ' Upstream/Background Total Inorganic Carbon (mg CaCO3/L):  
B37: (F2) PR [W12]  $+B17/B33$   
A38: PR [W60] ' Effluent Total Inorganic Carbon (mg CaCO3/L):  
B38: (F2) PR [W12]  $+B22/B34$   
A40: PR [W60] '4. CONDITIONS AT MIXING ZONE BOUNDARY  
A41: PR [W60] ' Temperature (deg C):  
B41: (F2) PR [W12]  $+B15 + (B20 - B15) / B\$12$   
A42: PR [W60] ' Alkalinity (mg CaCO3/L):  
B42: (F2) PR [W12]  $+B17 + (B22 - B17) / B\$12$   
A43: PR [W60] ' Total Inorganic Carbon (mg CaCO3/L):  
B43: (F2) PR [W12]  $+B37 + (B38 - B37) / B\$12$   
A44: PR [W60] ' pKa:  
B44: (F2) PR [W12]  $6.57 - 0.0118 * B41 + 0.00012 * (B41^2)$   
A46: PR [W60] ' pH at Mixing Zone Boundary:  
B46: (F2) PR [W12]  $+B44 - @LOG((B43/B42) - 1)$   
A48: PR [W60] \  
B48: PR [W12] \

A1: PR [W60] 'Spread of a plume from a point source in a river with and without  
A2: PR [W60] 'boundary effects from the shoreline (Fischer et al., 1979).  
A4: PR [W60] 'Lotus File RIVPLUM3.WK1 Revised 19-Oct-93  
A6: PR [W60] \  
B6: PR [W12] \  
A8: PR [W60] 'INPUT  
A10: PR [W60] '1. Effluent Discharge Rate (cfs):  
B10: (F2) U [W12] 20  
A12: PR [W60] '2. Receiving Water Characteristics Downstream From Waste Input  
A13: PR [W60] ' Stream Depth (ft):  
B13: (F2) U [W12] 5  
A14: PR [W60] ' Stream Velocity (fps):  
B14: (F2) U [W12] 2  
A15: PR [W60] ' Channel Width (ft):  
B15: (F2) U [W12] 200  
A16: PR [W60] ' Stream Slope (ft/ft) or Manning roughness "n":  
B16: U [W12] 0.0002  
A17: PR [W60] ' 0 if slope or 1 if Manning "n" in previous cell:  
B17: U [W12] 0  
A19: PR [W60] '3. Discharge Distance From Nearest Shoreline (ft):  
B19: (F2) U [W12] 0  
A21: PR [W60] '4. Location of Point of Interest to Estimate Dilution  
A22: PR [W60] ' Distance Downstream to Point of Interest (ft):  
B22: (F2) U [W12] 300  
A23: PR [W60] ' Distance From Nearest Shoreline (ft):  
B23: (F2) U [W12] 0  
A25: PR [W60] '5. Transverse Mixing Coefficient Constant (usually 0.6):  
B25: U [W12] 0.6  
A27: PR [W60] \  
B27: PR [W12] \  
A29: PR [W60] 'OUTPUT  
A30: PR [W60] '  
A31: PR [W60] '1. Source Conservative Mass Input Rate  
A32: PR [W60] ' Concentration of Conservative Substance (%):  
B32: (F2) PR [W12] 100  
A33: PR [W60] ' Source Conservative Mass Input Rate (cfs\*%):  
B33: (,2) PR [W12] +B10\*B32  
A35: PR [W60] '2. Shear Velocity  
A36: PR [W60] ' Shear Velocity based on slope (ft/sec):  
B36: (F3) PR [W12] @IF(B17=0,@SQRT(32.2\*B13\*B16),@NA)  
A37: PR [W60] ' Shear Velocity based on Manning "n":  
A38: PR [W60] ' using Prasn equations 8-26 and 8-54 assuming  
A39: PR [W60] ' hydraulic radius equals depth for wide channel  
A40: PR [W60] ' Darcy-Weisbach friction factor "f":  
B40: (F3) PR [W12] @IF(B17=1,(B16\*@SQRT(8\*32.2)/(1.49\*B13^(1/6)))^2,@NA)  
A41: PR [W60] ' Shear Velocity from Darcy-Weisbach "f" (ft/sec):  
B41: (F3) PR [W12] +B14\*@SQRT(B40/8)  
A42: PR [W60] ' Selected Shear Velocity for next step (ft/sec):  
B42: (F3) PR [W12] @IF(B17=0,B36,@IF(B17=1,B41,@ERR))  
A44: PR [W60] '3. Transverse Mixing Coefficient (ft2/sec):  
B44: (F3) PR [W12] +B25\*B13\*B42  
A46: PR [W60] '4. Plume Characteristics Assuming No Shoreline Effect  
A47: PR [W60] ' Unbounded Plume Width at Point of Interest (ft):  
B47: (F3) PR [W12] 4\*@SQRT(2\*B44\*B22/B14)  
A48: PR [W60] ' Concentration at Point of Interest (Fischer Eqn 5.7):  
B48: (S2) PR [W12] ((B33/B14/B13)/(@SQRT(4\*@PI\*B44\*B22/B14)))\*@EXP(-((B19-B23)^2\*B14)/(4\*B44\*B22))  
A49: PR [W60] ' Calculated Dilution Factor at Point of Interest:  
B49: (F3) PR [W12] +B32/B48  
A51: PR [W60] '5. Plume Characteristics Accounting for Shoreline Effect  
A52: PR [W60] ' Co:

B52: (S2) PR [W12] +B33/(B14\*B13\*B15)  
 A53: PR [W60] ' x':  
 B53: (S2) PR [W12] (B22\*B44)/(B14\*B15^2)  
 A54: PR [W60] ' y'o:  
 B54: (S2) PR [W12] +B19/B15  
 A55: PR [W60] ' y' at point of interest:  
 B55: (S2) PR [W12] +B23/B15  
 A56: PR [W60] ' Solution using superposition equation (Fischer eqn 5.9)  
 A57: PR [W60] ' Term for n= -2  
 B57: (F4) PR [W12] @EXP(-((B55-2\*(-2)-B54)^2/(4\*B53)))+@EXP(-((B55-2\*(-2)+B54)^2/(4\*B53)))  
 A58: PR [W60] ' Term for n= -1  
 B58: (F4) PR [W12] @EXP(-((B55-2\*(-1)-B54)^2/(4\*B53)))+@EXP(-((B55-2\*(-1)+B54)^2/(4\*B53)))  
 A59: PR [W60] ' Term for n= 0  
 B59: (F4) PR [W12] @EXP(-((B55-2\*(0)-B54)^2/(4\*B53)))+@EXP(-((B55-2\*(0)+B54)^2/(4\*B53)))  
 A60: PR [W60] ' Term for n= 1  
 B60: (F4) PR [W12] @EXP(-((B55-2\*(1)-B54)^2/(4\*B53)))+@EXP(-((B55-2\*(1)+B54)^2/(4\*B53)))  
 A61: PR [W60] ' Term for n= 2  
 B61: (F4) PR [W12] @EXP(-((B55-2\*(2)-B54)^2/(4\*B53)))+@EXP(-((B55-2\*(2)+B54)^2/(4\*B53)))  
 A62: PR [W60] ' C/Co (dimensionless):  
 B62: (S2) PR [W12] (1/@SQRT(4\*@PI\*B53))\*@SUM(B61..B57)  
 A63: PR [W60] ' Concentration at Point of Interest (Fischer Eqn 5.9):  
 B63: (S2) PR [W12] @IF(+B62\*B52<=B32,B62\*B52,B32)  
 A65: PR [W60] ' Approximate Downstream Distance to Complete Mix (ft):  
 B65: (,0) PR [W12] 0.1\*B14\*((2-2\*B54)\*B15)^2/B44  
 A67: PR [W60] ' Theoretical Dilution Factor at Complete Mix:  
 B67: (,3) PR [W12] +B32/B52  
 A69: PR [W60] ' Calculated Dilution Factor at Point of Interest:  
 B69: (,3) PR [W12] +B32/B63  
 A71: PR [W60] \  
 B71: PR [W12] \

```

A1: [W60] 'Water Quality-Based Permit Limits for acute and chronic criteria.
A2: [W60] '(based on EPA/505/2-90-001 Box 5-2).
A4: [W60] 'Lotus File WQBP2.WK1 Revised 19-Oct-93
A6: [W60] \
B6: [W12] \
A8: [W60] 'INPUT
A10: [W60] '1. Water Quality Standards (Concentration)
A11: [W60] '    Acute (one-hour) Criteria:
B11: (F3) U [W12] 19
A12: [W60] '    Chronic (n-day) Criteria:
B12: (F3) U [W12] 11
A14: [W60] '2. Upstream Receiving Water Concentration
A15: [W60] '    Upstream Concentration for Acute Condition (7Q10):
B15: (F3) U [W12] 0
A16: [W60] '    Upstream Concentration for Chronic Condition (7Q10):
B16: (F3) U [W12] 0
A18: [W60] '3. Dilution Factors (1/{Effluent Volume Fraction})
A19: [W60] '    Acute Receiving Water Dilution Factor at 7Q10:
B19: (F3) U [W12] 26
A20: [W60] '    Chronic Receiving Water Dilution Factor at 7Q10:
B20: (F3) U [W12] 100
A22: [W60] '4. Coefficient of Variation for Effluent Concentration
A23: [W60] '    (use 0.6 if data are not available):
B23: (F3) U [W12] 0.6
A25: [W60] '5. Number of days (n1) for chronic average
A26: [W60] '    (usually four or seven; four is recommended):
B26: U [W12] 4
A28: [W60] '6. Number of samples (n2) required per month for monitoring:
B28: U [W12] 30
A30: [W60] \
B30: [W12] \
A32: [W60] 'OUTPUT
A34: [W60] '1. Z Statistics
A35: [W60] '    LTA Derivation (99%tile):
B35: [W12] 2.326
A36: [W60] '    Daily Maximum Permit Limit (99%tile):
B36: [W12] 2.326
A37: [W60] '    Monthly Average Permit Limit (95%tile):
B37: [W12] 1.645
A39: [W60] '2. Calculated Waste Load Allocations (WLA's)
A40: [W60] '    Acute (one-hour) WLA:
B40: (F3) [W12] (B11*B19) - (B15*(B19-1))
A41: [W60] '    Chronic (n1-day) WLA:
B41: (F3) [W12] (B12*B20) - (B16*(B20-1))
A43: [W60] '3. Derivation of LTAs using April 1990 TSD (Box 5-2 Step 2 & 3)
A44: [W60] '    Sigma^2:
B44: (F4) [W12] @LN(B23^2+1)
A45: [W60] '    Sigma^2-n1:
B45: (F4) [W12] @LN((B23^2/B26)+1)
A46: [W60] '    LTA for Acute (1-hour) WLA:
B46: (F3) [W12] +B40*@EXP(0.5*B44-B35*@SQRT(B44))
A47: [W60] '    LTA for Chronic (n1-day) WLA:
B47: (F3) [W12] +B41*@EXP(0.5*B45-B35*@SQRT(B45))
A48: [W60] '    Most Limiting LTA (minimum of acute and chronic):
B48: (F3) [W12] @MIN(B47..B46)
A50: [W60] '4. Derivation of Permit Limits From Limiting LTA (Box 5-2 Step 4)
A51: [W60] '    Sigma^2-n2:
B51: (F4) [W12] @LN((B23^2/B28)+1)
A53: [W60] '    Daily Maximum Permit Limit:
B53: (F3) [W12] +B48*@EXP(B36*@SQRT(B44)-0.5*B44)
A54: [W60] '    Monthly Average Permit Limit:
B54: (F3) [W12] +B48*@EXP(B37*@SQRT(B51)-0.5*B51)
A57: [W60] \
B57: [W12] \

```

**Appendix E. Example Table of Contents for WAS Reports**

*This page is purposely blank for duplex printing*

## TABLE OF CONTENTS

LIST OF TABLES .....	ii
LIST OF FIGURES .....	iii
LIST OF APPENDICES .....	iv
ACKNOWLEDGMENTS .....	v
ABSTRACT .....	vi
INTRODUCTION .....	1
METHODS	
Sampling Design .....	3
Data Analysis .....	4
QUALITY ASSURANCE .....	7
RESULTS	
Wastewater Characteristics .....	8
Receiving Water Quality .....	9
Biological Effects .....	12
DISCUSSION .....	15
CONCLUSIONS .....	19
RECOMMENDATIONS .....	21
REFERENCES .....	25