Highway Runoff Water Quality Research Implementation Manual

Volume 2

Basis of Water Quality Criteria
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16. Abstract

The Washington State Department of Transportation (WSDOT)/University of Washington Highway Runoff Water Quality research project, conducted from 1977 to 1982, produced a number of results of potential use to WSDOT. An effort was required to implement these results in the Department's procedures. One phase of implementation completed previously involved preparation of a guide for assessing the impacts of operating highways on aquatic ecosystems and training WSDOT personnel in its use. The present phase involved formulating decision criteria in a number of water quality problem areas of concern to WSDOT and determining the need for revisions to department documents for consistency with the research results and the new criteria. The results of this phase are presented in a two volume implementation manual and a separate document listing the suggested modifications to four existing WSDOT manuals. Volume 1 of the implementation manual states the criteria, which were developed for: 1) identification of waters potentially sensitive to impact by operating highways; 2) the use of vegetated drainage courses to treat highway runoff; 3) the use of retention/detention facilities for highway stormwater drainage; 4) disposal of ditch cleaning spoils; 5) the use of woodwaste fills for highway construction; 6) highway sanding; 7) dilution of highway runoff in a receiving water; 8) highway cleaning; and 9) stream channel modification for highway construction. Volume 2 presents the basis of each criterion listed in Volume 1, including references to the research results and other literature, the reasoning followed, development of equations, etc.

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Highway Runoff Water Quality Research
Implementation Manual

Volume 2

Basis of Water Quality Criteria

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Final Report
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FOREWARD

This manual presents criteria for implementing the results of the Washington State Department of Transportation (WSDOT)/University of Washington Highway Runoff Water Quality research project completed in 1982. It consists of two volumes: Volume 1 states criteria for the protection of water resources in nine potential problem areas associated with operating highways; and Volume 2 presents the basis for these criteria. Companion documents to this manual are: (1) Suggested Revisions to WSDOT Manuals for Implementing Washington State Highway Runoff Water Quality Research Results; (2) Highway Hydraulic Manual (Washington State Department of Highways, 1972) and (3) Guide for Water Quality Impact Assessment of Highway Operations and Maintenance (Horner and Mar, 1982). The Highway Hydraulic Manual guides the design of highway drainage systems. The third document should be consulted to conduct a detailed environmental assessment when water quality criteria in this manual indicate that such an assessment is recommended. Other manuals issued by the Washington State Department of Transportation also cover aspects of these issues and should be consulted, as appropriate, in the design, specification, construction planning, and maintenance planning phases.

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SECTION 1

BASIS OF CRITERIA FOR IDENTIFICATION OF WATERS POTENTIALLY SENSITIVE TO HIGHWAY RUNOFF

1.01. Basis of Criteria for Streams and Rivers

Basis of Domestic Water Supply Criterion:

The Washington State Department of Social and Health Services (1983) has set water quality standards for public water systems. Constituents represented in these standards that may be affected by highway runoff and for which a data base is available to judge the potential effect of that runoff are:

Fecal coliforms ≤ 50/100 ml (Class AA waters) or 100/100 ml (Class A waters)

Lead ≤ 0.05 mg/l

Zinc ≤ 5 mg/l

Copper ≤ 1 mg/l

Nitrate-Nitrogen ≤ 10 mg/l

Chloride ≤ 250 mg/l

Turbidity ≤ 5 NTU over background

No standard was set for sodium, but the regulations require monitoring of that element in public water supplies so that information can be provided to those on sodium-restricted diets. A maximum of 20 mg/l was selected on the recommendation of the U.S. Environmental Protection Agency (1973) for the protection of individuals on sodium-restricted diets.

The research demonstrated that protection of water supplies from impacts by the above agents would also offer protection from impacts by others, such as organics and other metals, for which standards have been set (Zawlocki et al., 1981; Wang et al., 1982; Mar et al., 1982).

The impact assessment guide (Horner and Mar, 1982) presents a series of graphs with which the probability of exceeding any given concentration of a pollutant in any storm event may be estimated at different levels of dilution or treatment of highway runoff. These graphs were plotted for high and low traffic cases in Eastern and Western Washington. They were used in this analysis to determine the necessary dilution of highway runoff to reduce the probability of violating a standard to no more than 0.1 percent (one storm in every 1000 storms), an arbitrarily selected value representing a low frequency. Lead was the most critical pollutant, requiring the greatest dilution for protection of domestic water supply at the set level. No treatment capability in the public water system was assumed, except for fecal coliforms and turbidity, although the dilution level established on the basis of lead should insure maintenance of the turbidity standard, at least. Thus, the criterion would protect water supplied by small and relatively unsophisticated systems.

After the needed levels of dilution of highway runoff were established for the Eastern and Western Washington high and low traffic cases, it was reasoned that dilution ratio is approximately equal to the ratio of areas occupied by the highway and the watershed as a whole, corrected for any difference in runoff coefficients. This assumption implicitly ignores differences in the time of concentration (Washington State Department of Highways, 1972) between runoff from highway and watershed areas. Although these differences mean that maximum runoff from the highway generally will reach the stream much faster than maximum runoff from elsewhere in the watershed, an analysis demonstrated that the differences may be ignored and the simple equation given used as long as the total watershed area is at least five-to-ten times the highway area. This ratio of areas is maintained in almost all actual cases. With such a ratio, at least the dilution predicted by the equation will be attained because water yield from the total catchment area will compensate for the faster hydrograph response from the highway catchment.

In the absence of intermediate data between the high and low traffic cases, a linear relationship was assumed to establish drainage area relationships for intermediate traffic levels. This assumption of linearity is the basis for the equations given for R_T. These equations are strictly valid in the ADT ranges 7,700 - 53,000 for Western Washington and 2,000 - 17,300 for Eastern Washington, which provided the data base, but may be used for estimates slightly outside those ranges if necessary. It is likely, however, that the maximums will not be exceeded in actual cases of highway drainage to a single point.

The lower critical ratios for Eastern Washington represented by the equations for R_T are a consequence of the higher pollutant loadings to roadways in relation to traffic volume observed there compared to Western Washington. These higher loadings are considered to be the result of greater pollutant transport to highways from adjacent lands due to coarser soils, less vegetation cover, and higher and more continuous winds.

The highway runoff coefficients recommended in Table 1-2 are from the research results and are lower than those traditionally used for pavement because of the spray removal of water by relatively high speed traffic.

Basis of Fish Habitat Criterion:

Water Quality Standards for Waters of the State of Washington give specific, quantitative standards only for fecal coliforms, dissolved oxygen, total dissolved gas, temperature, pH, and turbidity. Fecal coliforms are not a threat to fish life, and runoff from operating Washington highways does not significantly impact dissolved oxygen, total dissolved gas, temperature, or pH, (Mar et al., 1982). Total suspended solids, for which considerable highway runoff data are available, is a surrogate for turbidity. Most of the concern with respect to highway runoff effects on fish life involves heavy metal toxicants (Portele et al., 1982; Mar et al., 1982), for which the Water Quality Standards only make the qualitative statement that concentrations of such materials shall be less than those that may affect public health, the natural aquatic environment, or the desirability of the water for any designated use. The U.S. Environmental Protection Agency, however, has established such standards (Federal Register, 45 FR 79318-79379, November 28, 1980). For heavy metals, maximum permissible concentrations depend on the total hardness of the water, since divalent cations that constitute hardness are generally antagonistic to heavy metals. For the purpose of selecting general standards for this analysis, total hardness values of 50 and 100 mg/l as calcium carbonate were applied to Western and Eastern Washington, respectively. The maximum stream or river concentrations for the protection of aquatic life on this basis are:

Metal	Maximum Concentration (mg/l)	
	Western Washington	Eastern Washington
Lead	0.074	0.170
Zinc	0.180	0.320
Copper	0.012	0.022

No formal standards have been set for total suspended solids or chloride. For the former constituent, the U.S. Environmental Protection Agency (1978) recommended a concentration no higher than 80 mg/l. McKee and Wolf (1963) reported that 95 percent of U.S. waters sustaining good fish life had less than 170 mg/l chloride, and that concentration was taken as a standard for this analysis.

The assessment proceeded exactly as described under the Basis of Domestic Water Supply Criterion. In this analysis, lead was the most critical pollutant for both Eastern and Western Washington high traffic cases, and total suspended solids was most critical for low traffic cases in both geographic areas.

It should be noted that the Washington State Department of Fisheries has prepared Stream Catalogs that provide salmonid utilization data for most streams in Western Washington. These catalogs have been issued in two volumes: Volume 1 for the Puget Sound area (Williams et al., 1975) and Volume 2 for the coastal region (Phinney et al., 1975).

1.02. Basis of Criteria for Lakes

Basis of Lake Eutrophication Criterion:

The equations represent a combination of two simple mathematical models, one predicting phosphorus loading from an operating highway and one forecasting the response of a phosphorus-limited lake to that loading. The phosphorus loading model was developed from the Washington State Highway Runoff Water Quality research results and is as follows (Horner and Mar, 1982):

$$L_p = K_p \, K \left(\frac{VDS/yr}{1000}\right) C$$

where: L_p = annual total phosphorus loading (units of mass/yr)

K_p = coefficient representing proportion of total suspended solids that is phosphorus (2.1×10^{-3})

K = total suspended solids loading rate (6.5 lb/highway mile/1000 VDS for Western Washington and 26 lb/highway mile/1000 VDS for Eastern Washington)

VDS/yr = total vehicles traveling during storm periods in a year = $\frac{(ADT)(\text{wet hr/yr})}{24\ \text{hr/day}}$

C_H = highway runoff coefficient

The number of wet hr/yr can be established from precipitation duration data presented by Horner and Mar (1982). For development of the criterion, four cases typical of broad areas of Washington were analyzed: (1) Western Washington interior lowlands, (2) Western Washington high mountain and coastal locations, (3) Eastern Washington low altitude arid areas, and (4) Eastern Washington higher altitude semi-arid areas.

The lake response model was proposed by Dillon (1975). It states, in one algebraic form, that:

$$L_c = P_c\,\bar{z}\,(\rho + \rho^{0.5})$$

where: L_c = critical annual phosphorus loading creating a eutrophic state (units of mass/unit area/yr)

P_c = critical early spring phosphorus concentration creating a eutrophic state (10 μg/l)

$\bar{z}$ = mean depth (units of length)

ρ = flushing rate (yr^{-1})

Several assumptions pertain to this model, most importantly that the limiting nutrient for algal growth is phosphorus and that the lake is a mixed, homogeneous body. Although the second assumption often does not hold at all times of the year, the model has been found to apply with reasonable accuracy in a large variety of cases (Welch, 1980).

The two models were related by dividing L_p by lake surface area (A), equating with L_c, and solving algebraically for A. Introduction of highway characteristics (using 0.75 for C_H), and unit conversion factors yielded the following equation:

$$A = \frac{2.43 \times 10^{-3}\ K\ (ADT)\ W\ L}{\bar{z}\ (\rho + \rho^{0.5})}$$

where: A = lake surface area (acres)

K is given above

W = wet hr/yr (1000, 1800, 400, and 600 used for cases 1-4 above, respectively)

L = highway segment length (miles)

ADT = average daily traffic

$\bar{z}$ = lake mean depth (ft)

ρ = flushing rate (yr^{-1})

Substitution of the appropriate values for K and W produced the four equations given in the criterion.

Data on three lake characteristics (A, $\bar{z}$, and ρ) are required to apply the criteria. Lakes of Washington, Volumes I and II, (Washington State Department of Conservation, 1961a, b) has data on many lakes in the state. In the absence of readily available data, these quantities can be estimated and assistance is available to do so from the WSDOT Headquarters Hydraulic Section. Area can be approximated from a scale map by planimetry or an alternative technique. The mean depth is the ratio of the lake volume to the surface area. If the volume is missing, it can be determined by a bathymetric (sounding) survey. In a small lake such a survey is not difficult or time-consuming and can be done with a manual sounding line.

The flushing rate is the number of times per year the entire water volume of the lake is renewed. It is the reciprocal of the water residence time and can be found as the ratio of the annual water outflow rate to the lake volume. Assuming no large net groundwater inflow or outflow:

$$O = I + P - E$$

where:
O = annual water outflow rate
I = annual water inflow rate
P = annual precipitation volume
E = annual evaporation volume

All quantities have the units of volume/yr. I, P, and E may be estimated as follows:

$$I = p\ A_W\ C_W$$

$$P = p\ A$$

$$E = e\ A$$

where: p = annual precipitation depth (units of depth/yr)
A_w = area of the lake's watershed (units of area)
C_w = watershed runoff coefficient (ratio of runoff volume to precipitation volume) (refer to Table 1-1 and the note to that table for estimation of a composite runoff coefficient)
A = lake area (units of area)
e = annual depth of water evaporated (units of depth/yr) (Figure 1-1)

Basis of Domestic Water Supply Criterion:

The theory upon which this criterion was developed is that highway runoff could enter water intakes with potentially insufficient dilution if the intakes and drainage discharge point are closer than the distance pollutants could diffuse in the lake before complete flushing occurs. Further, even if the spacing is adequate, the beneficial use would be potentially threatened unless an adequate dilution ratio is maintained.

To define the first condition (spacing), the diffusion rate of pollutants was estimated from relationships and data presented by Canale and Weber (1972) and Pasciak and Gavis (1974). To apply this information, a current velocity had to be assumed. A value of 10 cm/sec was selected, representing a relatively high current velocity in standing water and, therefore, on the conservative side. This assumption and the methods from the literature produced an estimated diffusion velocity of 6.3×10^{-3} cm/sec, from which, with the proper unit conversions, the condition stated was derived.

It is recognized that data on lake water residence time may not be readily available, especially for relatively small and obscure lakes. This parameter can be estimated as described in the Basis of Lake Eutrophication Criterion. However, because small lakes generally have water residence times of less than one year, it can be stated quite safely that the condition will be met in the case of such lakes if the discharge point and intakes are spaced at least one mile apart.

Development of the second condition (dilution) was based on the same water quality standards as used for the streams and rivers domestic water supply criterion. Critical dilution ratios also were determined as described in the basis for this criterion, using the probability charts in Horner and Mar (1982) and a violation probability of 0.1 percent. Lead was the most critical pollutant. Again, a linear relationship was assumed to estimate necessary dilution for traffic volumes other than those providing the data base. This assumption was the basis for the equations for D_C.

To estimate the actual dilution of runoff in a lake, it was assumed that runoff would be completely mixed throughout the lake volume in a period of time equal to the lake water residence time. With this assumption, the dilution ratio can be determined by mass balance as:

$$\frac{C_L'}{C_R} = \frac{Q_R C_R + V_L \bar{C}_L}{C_R(Q_R + V_L)}$$

where:
- C_L' = pollutant concentration in lake after mixing
- C_R = pollutant concentration in highway runoff
- Q_R = highway runoff flow volume over period equal to lake water residence time
- V_L = lake volume
- $\bar{C}_L$ = equilibrium pollutant concentration in lake before runoff

It is assumed that $\bar{C}_L$ is substantially less than C_R and can be considered negligible by comparison. That assumption simplified the dilution ratio to:

$$\frac{C_L'}{C_R} = \frac{Q_R}{Q_R + V_L}$$

Q_R may be estimated by the Rational Method for areas less than 50 acres according to:

$$Q_R = C_H \; I \; A_H$$

Making this substitution yields the ratio given in the criterion.

No data exist to develop a specific criterion for lakes subject to sodium chloride deicing agent runoff, as has been done for streams and rivers. However, it is believed that maintenance of the necessary dilution ratio based on lead will prevent exceeding the 20 mg/l sodium limit in domestic water supplies as well.

Basis of Fish Habitat Criterion:

Development of this criterion was based on the same water quality standards as used for the streams and rivers fish habitat criterion. The fundamental theory, assumptions, critical dilution ratios, and the method of estimating actual dilution were derived in the same manner as described for this criterion. In this analysis, lead was the most critical pollutant for high traffic cases, and total suspended solids was most critical for low traffic cases.

As with the streams and rivers case, no data exist to develop a specific criterion for sodium chloride deicing agent. Again, it is believed that maintenance of the necessary dilution ratio based on the above analysis will prevent exceeding a chloride concentration harmful to fish as well.

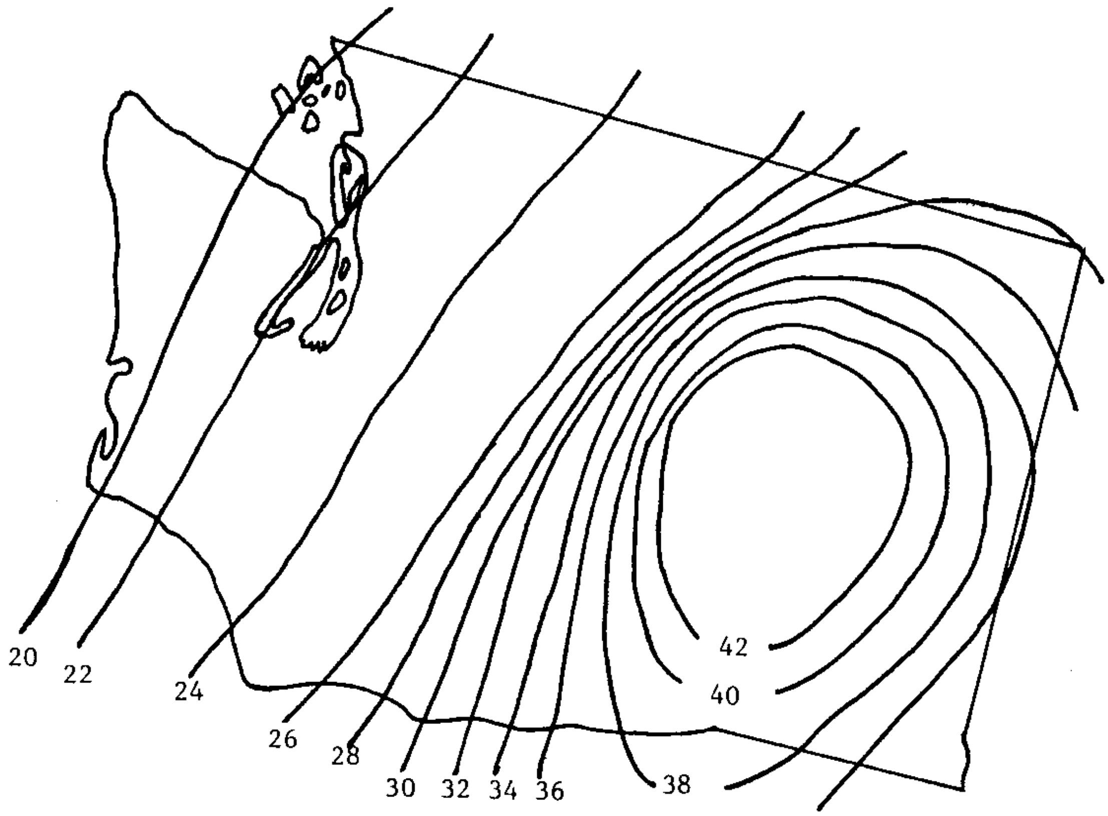

Figure 1-1 Mean Annual Lake Evaporation (Inches) in Washington (U. S. Department of Commerce, 1968)

Chapter 173-201 WAC
WATER QUALITY STANDARDS FOR WATERS OF THE STATE OF WASHINGTON

DISPOSITION OF SECTIONS FORMERLY CODIFIED IN THIS CHAPTER

173-201-020	Water use and quality criteria. [Statutory Authority: RCW 90.48.035. 78-02-043 (Order DE 77-32), § 173-201-020, filed 1/17/78; Order 73-4, § 173-201-020, filed 7/6/73.] Repealed by 82-12-078 (Order DE 82-12), filed 6/2/82. Statutory Authority: RCW 90.48.035.
173-201-030	Water use and quality criteria—General water use and criteria classes. [Order 73-4, § 173-201-030, filed 7/6/73.] Repealed by 78-02-043 (Order DE 77-32), filed 1/17/78. Statutory Authority: RCW 90.48.035.
173-201-040	Water use and quality criteria—General considerations. [Order 73-4, § 173-201-040, filed 7/6/73.] Repealed by 78-02-043 (Order DE 77-32), filed 1/17/78. Statutory Authority: RCW 90.48.035.
173-201-050	Characteristic uses to be protected. [Statutory Authority: RCW 90.48.035. 78-02-043 (Order DE 77-32), § 173-201-050, filed 1/17/78; Order 73-4, § 173-201-050, filed 7/6/73.] Repealed by 82-12-078 (Order DE 82-12), filed 6/2/82. Statutory Authority: RCW 90.48.035.
173-201-060	Water course classification. [Order 73-4, § 173-201-060, filed 7/6/73.] Repealed by 78-02-043 (Order DE 77-32), filed 1/17/78. Statutory Authority: RCW 90.48.035.
173-201-130	Definitions. [Order 73-4, § 173-201-130, filed 7/6/73.] Repealed by 78-02-043 (Order DE 77-32), filed 1/17/78. Statutory Authority: RCW 90.48.035.
173-201-140	Miscellaneous. [Statutory Authority: RCW 90.48-.035. 78-02-043 (Order DE 77-32), § 173-201-140, filed 1/17/78; Order 73-4, § 173-201-140, filed 7/6/73.] Repealed by 82-12-078 (Order DE 82-12), filed 6/2/82. Statutory Authority: RCW 90.48.035.

WAC 173-201-010 Introduction. (1) The purpose of this chapter is to establish water quality standards for surface waters of the state of Washington pursuant to the provisions of chapter 90.48 RCW and the policies and purposes thereof.

(2) This chapter shall be reviewed periodically by the department and appropriate revisions shall be undertaken.

(3) The water use and quality criteria set forth in WAC 173-201-035 through 173-201-085 are established in conformance with present and potential water uses of the surface waters of the state of Washington and in consideration of the natural water quality potential and limitations of the same. These shall be the sole criteria for said waters. [Statutory Authority: RCW 90-.48.035. 82-12-078 (Order DE 82-12), § 173-201-010, filed 6/2/82; 78-02-043 (Order DE 77-32), § 173-201-010, filed 1/17/78; Order 73-4, § 173-201-010, filed 7/6/73.]

WAC 173-201-025 Definitions. (1) Background conditions: The biological, chemical, and physical conditions of a water body, upstream from the point or nonpoint source of any discharge under consideration. Background sampling location in an enforcement action would be upstream from the point of discharge, but not upstream from other inflows. If several discharges to any water body exist, and enforcement action is being taken for possible violations to the standards, background sampling would be undertaken immediately upstream from each discharge.

(2) Department: State of Washington department of ecology.

(3) Director: Director of the state of Washington department of ecology.

(4) Fecal coliform: That portion of the coliform group which is present in the intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius.

(5) Geometric mean: The nth root of a product of n factors.

(6) Mean detention time: The time obtained by dividing a reservoir's mean annual minimum total storage by the 30-day ten-year low-flow from the reservoir.

(7) 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.

(8) pH: The negative logarithm of the hydrogen ion concentration.

(9) Primary contact recreation: Activities where a person would have direct contact with water to the point of complete submergence, including but not limited to skin diving, swimming and water skiing.

(10) Secondary contact recreation: Activities where a person's water contact would be limited (wading or fishing) to the extent that bacterial infections of eyes, ears, respiratory or digestive systems or urogenital areas would normally be avoided.

(11) Surface waters of the state: Include lakes, rivers, ponds, streams, inland waters, saltwaters, and all other

surface waters and water courses within the jurisdiction of the state of Washington.

(12) Temperature: Water temperature expressed in degrees Celsius (°C).

(13) Turbidity: The clarity of water expressed as nephelometric turbidity units (NTU) and measured with a calibrated turbidimeter.

(14) Upwelling: The annual natural phenomenon where the summer prevailing, northerly winds parallel to Washington's coast produce a seaward transport of surface waters. Cold, deeper more saline waters rich in nutrients and low in dissolved oxygen rise to replace the surface water. The cold, oxygen deficient water flows into Puget Sound and other coastal estuaries replacing the deep water with lower dissolved oxygen concentrations reaching the surface during late summer and fall.

(15) USEPA: United States Environmental Protection Agency.

(16) Wildlife habitat: Waters of the state used by fish, other aquatic life and wildlife for any life history stage or activity. [Statutory Authority: RCW 90.48.035. 82-12-078 (Order DE 82-12), § 173-201-025, filed 6/2/82; 78-02-043 (Order DE 77-32), § 173-201-025, filed 1/17/78.]

WAC 173-201-035 General considerations. The following general guidelines shall apply to the water quality criteria and classifications set forth in WAC 173-201-045 through 173-201-085 hereof:

(1) At the boundary between waters of different classifications, the water quality criteria for the higher classification shall prevail.

(2) In brackish waters of estuaries, where the fresh and marine water quality criteria differ within the same classification, the criteria shall be interpolated on the basis of salinity; except that the marine water quality criteria shall apply for dissolved oxygen when the salinity is one part per thousand or greater and for fecal coliform organisms when the salinity is ten parts per thousand or greater.

(3) The water quality criteria herein established shall not apply within an authorized dilution zone adjacent to or surrounding a waste-water discharge.

(4) Generally, waste discharge permits, whether issued pursuant to the National Pollutant Discharge Elimination System or otherwise, shall be conditioned in such manner as to authorize discharges which meet the water quality standards.

(a) However, persons discharging wastes in compliance with the terms and conditions of permits shall not be subject to civil and criminal penalties on the basis that discharge violates water quality standards.

(b) Permits shall be subject to modification by the department whenever it appears to the department the discharge violates water quality standards. Modification of permits, as provided herein, shall be subject to review in the same manner as originally issued permits.

(5) Nonpoint sources and water quality standards.

(a) It is recognized that many activities not subject to a waste discharge permit system are now being performed in the state, which result in conflicts with the water quality standards of this chapter. Further, the department has not developed a program which, in a reasonable or fully satisfactory manner, provides methods or means for meeting such standards. Persons conducting such activities shall not be subject to civil or criminal sanctions for violation of water quality standards if the activities are either:

(i) Conducted in accordance with management practices set forth by rules of the department.

For example, promulgation of regulations by the department which set forth approved management practices or other effluent limits shall be accomplished so that activities conducted within such regulations, (i.e., Forest Practices Rules and Regulations chapter 173-202 WAC and Title 222 WAC) will achieve compliance with water pollution control laws. When the regulations are violated, the water quality standard can be enforced as described in WAC 173-201-045 through 173-201-085; or,

(ii) Subject to a regulatory order issued by the department relating to specific activities as provided for in WAC 173-201-100(2).

(b) Management practices or regulatory orders described in WAC 173-201-035(5) hereof, shall be subject to modification by the department whenever it appears to the department that the discharge violates water quality standards. Modification of management practices or regulatory orders, as provided herein, shall be subject to review in the same manner as the originally issued management practices or regulatory orders.

(6) The water quality criteria herein established for total dissolved gas shall not apply when the stream flow exceeds the 7-day, 10-year frequency flood.

(7) The total area and/or volume of a receiving water assigned to a dilution zone shall be as described in a valid discharge permit as needed and be limited to that which will:

(a) Not cause acute mortalities of sport, food, or commercial fish and shellfish species of established biological communities within populations or important species to a degree which damages the ecosystem.

(b) Not diminish aesthetic values or other beneficial uses disproportionately.

(8) The antidegradation policy of the state of Washington, as generally guided by chapter 90.48 RCW, Water Pollution Control Act, and chapter 90.54 RCW, Water Resources Act of 1971, is stated as follows:

(a) Existing beneficial uses shall be maintained and protected and no further degradation which would interfere with or become injurious to existing beneficial uses will be allowed.

(b) No degradation will be allowed of waters lying in national parks, national recreation areas, national wildlife refuges, national scenic rivers, and other areas of national ecological importance.

(c) Whenever waters are of a higher quality than the criteria assigned for said waters, the existing water quality shall be protected and waste and other materials and substances shall not be allowed to enter such waters which will reduce the existing quality thereof, except, in those instances where:

(i) It is clear that overriding considerations of the public interest will be served, and

(ii) All wastes and other materials and substances proposed for discharge into the said waters shall be provided with all known, available, and reasonable methods of treatment before discharge.

(d) Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria.

(e) The criteria and special conditions established in WAC 173-201-045 through 173-201-085 may be modified for a specific water body on a short-term basis when necessary to accommodate essential activities, respond to emergencies, or to otherwise protect the public interest. Such modification shall be issued in writing by the director or his designee subject to such terms and conditions as he may prescribe. The aquatic application of herbicides which result in water use restrictions shall be considered an activity for which a short-term modification generally may be issued subject to the following conditions:

(i) A request for a short-term modification shall be made to the department on forms supplied by the department. Such request generally shall be made at least thirty days prior to herbicide application.

(ii) Such herbicide application shall be in accordance with state of Washington department of agriculture regulations.

(iii) Such herbicide application shall be in accordance with label provisions promulgated by USEPA under the Federal Insecticide, Fungicide, and Rodenticide Act, as amended. (7 U.S.C. 136, et seq.)

(iv) Notice, including identification of the herbicide, applicator, location where the herbicide will be applied, proposed timing and method of application, and water use restrictions shall be given according to the following requirements:

(A) Appropriate public notice as determined and prescribed by the director or his designee shall be given of any water use restrictions specified in USEPA label provisions.

(B) The appropriate regional offices of the departments of fisheries and game shall be notified twenty-four hours prior to herbicide application.

(C) In the event of any fish kills, the departments of ecology, fisheries, and game shall be notified immediately.

(v) The herbicide application shall be made at times so as to:

(A) Minimize public water use restrictions during weekends.

(B) Completely avoid public water use restrictions during the opening week of fishing season, Memorial Day weekend, July 4 weekend, and Labor Day weekend.

(vi) Any additional conditions as may be prescribed by the director or his designee.

(f) In no case, will any degradation of water quality be allowed if this degradation interferes with or becomes injurious to existing water uses and causes long-term and irreparable harm to the environment.

(g) No waste discharge permit will be issued which violates established water quality criteria, except, as provided for under WAC 173-201-035(8)(e).

(9) Due consideration will be given to the precision and accuracy of the sampling and analytical methods used as well as existing conditions at the time, in the application of the criteria.

(10) The analytical testing methods for these criteria shall be in accordance with the most recent editions of "Standard Methods for the Examination of Water and Wastewater," published by the American Public Health Association, American Water Works Association, and the Water Pollution Control Federation, and "Methods for Chemical Analysis of Water and Wastes," published by USEPA, and other or superseding methods published and/or approved by the department following consultation with adjacent states and concurrence of the USEPA.

(11) Deleterious concentrations of radioactive materials for all classes shall be as determined by the lowest practicable concentration attainable and in no case shall exceed:

(a) 1/100 of the values listed in WAC 402-24-220 (Column 2, Table II, Appendix A, Rules and Regulations for Radiation Protection); or,

(b) USEPA Drinking Water Regulations for radionuclides, as published in the Federal Register of July 9, 1976, or subsequent revisions thereto.

(12) Deleterious concentrations of toxic, or other nonradioactive materials, shall be determined by the department in consideration of the Quality Criteria for Water, published by USEPA 1976, and as revised, as the authoritative source for criteria and/or other relevant information, if justified.

(13) Nothing in this chapter shall be interpreted to be applicable to those aspects of governmental regulation of radioactive wastes which have been preempted from state regulation by the Atomic Energy Act of 1954, as amended, as interpreted by the United States Supreme Court in the cases of Northern States Power Co. v. Minnesota 405 U.S. 1035 (1972) and Train v. Colorado Public Interest Research Group 426 U.S. 1 (1976).

(14) Nothing in this chapter shall be interpreted to prohibit the establishment of effluent limitations for the control of the thermal component of any discharge in accordance with Section 316 of the Federal Clean Water Act (P.L. 95-217 as amended). [Statutory Authority: RCW 90.48.035. 82-12-078 (Order DE 82-12), § 173-201-035, filed 6/2/82; 78-02-043 (Order DE 77-32), § 173-201-035, filed 1/17/78.]

WAC 173-201-045 General water use and criteria classes. The following criteria shall apply to the various classes of surface waters in the state of Washington:

(1) CLASS AA (EXTRAORDINARY).

(a) General characteristic. Water quality of this class shall markedly and uniformly exceed the requirements for all or substantially all uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (domestic, industrial, agricultural).

(ii) Stock watering.
(iii) Fish and shellfish:
Salmonid migration, rearing, spawning, and harvesting.
Other fish migration, rearing, spawning, and harvesting.
Clam, oyster, and mussel rearing, spawning, and harvesting.
Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting.
(iv) Wildlife habitat.
(v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).
(vi) Commerce and navigation.
(c) Water quality criteria.
(i) Fecal coliform organisms.
(A) Freshwater - Fecal coliform organisms shall not exceed a geometric mean value of 50 organisms/100 mL, with not more than 10 percent of samples exceeding 100 organisms/100 mL.
(B) Marine water - Fecal coliform organisms shall not exceed a geometric mean value of 14 organisms/100 mL, with not more than 10 percent of samples exceeding 43 organisms/100 mL.
(ii) Dissolved oxygen.
(A) Freshwater - Dissolved oxygen shall exceed 9.5 mg/L.
(B) Marine water - Dissolved oxygen shall exceed 7.0 mg/L . When natural conditions, such as upwelling, occur, causing the dissolved oxygen to be depressed near or below 7.0 mg/L, natural dissolved oxygen levels can be degraded by up to 0.2 mg/L by man-caused activities.
(iii) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.
(iv) Temperature shall not exceed 16.0° C (freshwater) or 13.0° C (marine water) due to human activities. Temperature increases shall not, at any time, exceed $t=23/(T+5)$ (freshwater) or $t=8/(T-4)$ (marine water).
When natural conditions exceed 16.0° C (freshwater) and 13.0° C (marine water), no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C.
For purposes hereof, "t" represents the permissive temperature change across the dilution zone; and "T" represents the highest existing temperature in this water classification outside of any dilution zone.
Provided that temperature increase resulting from nonpoint source activities shall not exceed 2.8° C, and the maximum water temperature shall not exceed 16.3° C (freshwater).
(v) pH shall be within the range of 6.5 to 8.5 (freshwater) or 7.0 to 8.5 (marine water) with a man-caused variation within a range of less than 0.2 units.
(vi) Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.
(vii) Toxic, radioactive, or deleterious material concentrations shall be less than those which may affect public health, the natural aquatic environment, or the desirability of the water for any use.
(viii) Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.
(2) CLASS A (EXCELLENT).
(a) General characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses.
(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:
(i) Water supply (domestic, industrial, agricultural).
(ii) Stock watering.
(iii) Fish and shellfish:
Salmonid migration, rearing, spawning, and harvesting.
Other fish migration, rearing, spawning, and harvesting.
Clam, oyster, and mussel rearing, spawning, and harvesting.
Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting.
(iv) Wildlife habitat.
(v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).
(vi) Commerce and navigation.
(c) Water quality criteria.
(i) Fecal coliform organisms.
(A) Freshwater - Fecal coliform organisms shall not exceed a geometric mean value of 100 organisms/100 mL, with not more than 10 percent of samples exceeding 200 organisms/100 mL.
(B) Marine water - Fecal coliform organisms shall not exceed a geometric mean value of 14 organisms/100 mL, with not more than 10 percent of samples exceeding 43 organisms/100 mL.
(ii) Dissolved oxygen.
(A) Freshwater - Dissolved oxygen shall exceed 8.0 mg/L.
(B) Marine water - Dissolved oxygen shall exceed 6.0 mg/L . When natural conditions, such as upwelling, occur, causing the dissolved oxygen to be depressed near or below 6.0 mg/L, natural dissolved oxygen levels can be degraded by up to 0.2 mg/L by man-caused activities.
(iii) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.
(iv) Temperature shall not exceed 18.0° C (freshwater) or 16.0° C (marine water) due to human activities. Temperature increases shall not, at any time, exceed $t=28/(T+7)$ (freshwater) or $t=12/(T-2)$ (marine water).
When natural conditions exceed 18.0° C (freshwater) and 16.0° C (marine water), no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C.
For purposes hereof, "t" represents the permissive temperature change across the dilution zone; and "T" represents the highest existing temperature in this water classification outside of any dilution zone.

Provided that temperature increase resulting from nonpoint source activities shall not exceed 2.8° C, and the maximum water temperature shall not exceed 18.3° C (freshwater).

(v) pH shall be within the range of 6.5 to 8.5 (freshwater) or 7.0 to 8.5 (marine water) with a man–caused variation within a range of less than 0.5 units.

(vi) Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vii) Toxic, radioactive, or deleterious material concentrations shall be below those of public health significance, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.

(viii) Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

(3) CLASS B (GOOD).

(a) General characteristic. Water quality of this class shall meet or exceed the requirements for most uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (industrial and agricultural).

(ii) Stock watering.

(iii) Fish and shellfish:

Salmonid migration, rearing, and harvesting.

Other fish migration, rearing, spawning, and harvesting.

Clam, oyster, and mussel rearing and spawning.

Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting.

(iv) Wildlife habitat.

(v) Recreation (secondary contact recreation, sport fishing, boating, and aesthetic enjoyment.

(vi) Commerce and navigation.

(c) Water quality criteria.

(i) Fecal coliform organisms.

(A) Freshwater – Fecal coliform organisms shall not exceed a geometric mean value of 200 organisms/100 mL, with not more than 10 percent of samples exceeding 400 organisms/100 mL.

(B) Marine water – Fecal coliform organisms shall not exceed a geometric mean value of 100 organisms/100 mL, with not more than 10 percent of samples exceeding 200 organisms/100 mL.

(ii) Dissolved oxygen.

(A) Freshwater – Dissolved oxygen shall exceed 6.5 mg/L.

(B) Marine water – Dissolved oxygen shall exceed 5.0 mg/L. When natural conditions, such as upwelling, occur, causing the dissolved oxygen to be depressed near or below 5.0 mg/L, natural dissolved oxygen levels can be degraded by up to 0.2 mg/L by man–caused activities.

(iii) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

(iv) Temperature shall not exceed 21.0° C (freshwater) or 19.0° C (marine water) due to human activities. Temperature increases shall not, at any time, exceed $t=34/(T+9)$ (freshwater) or $t=16/T$ (marine water).

When natural conditions exceed 21.0° C (freshwater) and 19.0° C (marine water), no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C.

For purposes hereof, "t" represents the permissive temperature change across the dilution zone; and "T" represents the highest existing temperature in this water classification outside of any dilution zone.

Provided that temperature increase resulting from nonpoint source activities shall not exceed 2.8° C, and the maximum water temperature shall not exceed 21.3° C (freshwater).

(v) pH shall be within the range of 6.5 to 8.5 (freshwater) and 7.0 to 8.5 (marine water) with a man–caused variation within a range of less than 0.5 units.

(vi) Turbidity shall not exceed 10 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 20 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vii) Toxic, radioactive, or deleterious material concentrations shall be below those which adversely affect public health during characteristic uses, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect characteristic water uses.

(viii) Aesthetic values shall not be reduced by dissolved, suspended, floating, or submerged matter not attributed to natural causes, so as to affect water use or taint the flesh of edible species.

(4) CLASS C (FAIR).

(a) General characteristic. Water quality of this class shall meet or exceed the requirements of selected and essential uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (industrial).

(ii) Fish (salmonid and other fish migration).

(iii) Recreation (secondary contact recreation, sport fishing, boating, and aesthetic enjoyment).

(iv) Commerce and navigation.

(c) Water quality criteria – marine water.

(i) Fecal coliform organisms shall not exceed a geometric mean value of 200 organisms/100 mL, with not more than 10 percent of samples exceeding 400 organisms/100 mL.

(ii) Dissolved oxygen shall exceed 4.0 mg/L. When natural conditions, such as upwelling, occur, causing the dissolved oxygen to be depressed near or below 4.0 mg/L, natural dissolved oxygen levels can be degraded by up to 0.2 mg/L by man–caused activities.

(iii) Temperature shall not exceed 22.0° C due to human activities. Temperature increases shall not, at any time, exceed $t=20/(T+2)$.

When natural conditions exceed 22.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C.

For purposes hereof, "t" represents the permissive temperature change across the dilution zone; and "T" represents the highest existing temperature in this water classification outside of any dilution zone.

(iv) pH shall be within the range of 6.5 to 9.0 with a man-caused variation within a range of less than 0.5 units.

(v) Turbidity shall not exceed 10 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 20 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vi) Toxic, radioactive, or deleterious material concentrations shall be below those which adversely affect public health during characteristic uses, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect characteristic water uses.

(vii) Aesthetic values shall not be interfered with by the presence of obnoxious wastes, slimes, aquatic growths, or materials which will taint the flesh of edible species.

(5) LAKE CLASS.

(a) General characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (domestic, industrial, agricultural).

(ii) Stock watering.

(iii) Fish and shellfish:

Salmonid migration, rearing, spawning, and harvesting.

Other fish migration, rearing, spawning, and harvesting.

Clam and mussel rearing, spawning, and harvesting.

Crayfish rearing, spawning, and harvesting.

(iv) Wildlife habitat.

(v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).

(vi) Commerce and navigation.

(c) Water quality criteria.

(i) Fecal coliform organisms shall not exceed a geometric mean value of 50 organisms/100 mL, with not more than 10 percent of samples exceeding 100 organisms/100 mL.

(ii) Dissolved oxygen – no measurable decrease from natural conditions.

(iii) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

(iv) Temperature – no measurable change from natural conditions.

(v) pH – no measurable change from natural conditions.

(vi) Turbidity shall not exceed 5 NTU over background conditions.

(vii) Toxic, radioactive, or deleterious material concentrations shall be less than those which may affect public health, the natural aquatic environment, or the desirability of the water for any use.

(viii) Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste. [Statutory Authority: RCW 90.48.035. 82-12-078 (Order DE 82-12), § 173-201-045, filed 6/2/82; 78-02-043 (Order DE 77-32), § 173-201-045, filed 1/17/78.]

WAC 173-201-070 General classifications. General classifications applying to various surface water bodies not specifically classified under WAC 173-201-080 or 173-201-085 are as follows:

(1) All surface waters lying within the mountainous regions of the state assigned to national parks, national forests, and/or wilderness areas, are classified Class AA or Lake Class.

(2) All lakes and their feeder streams within the state are classified Lake Class and Class AA respectively, except for those feeder streams specifically classified otherwise.

(3) All reservoirs with a mean detention time of greater than 15 days are classified Lake Class.

(4) All reservoirs with a mean detention time of 15 days or less are classified the same as the river section in which they are located.

(5) All reservoirs established on preexisting lakes are classified as Lake Class.

(6) All unclassified surface waters that are tributaries to Class AA waters are classified Class AA. All other unclassified surface waters within the state are hereby classified Class A. [Statutory Authority: RCW 90.48-.035. 82-12-078 (Order DE 82-12), § 173-201-070, filed 6/2/82; 78-02-043 (Order DE 77-32), § 173-201-070, filed 1/17/78; Order 73-4, § 173-201-070, filed 7/6/73.]

WAC 173-201-080 Specific classifications—Freshwater. Specific fresh surface waters of the state of Washington are classified as follows:

(1) American River.	Class AA
(2) Big Quilcene River and tributaries.	Class AA
(3) Bumping River.	Class AA
(4) Burnt Bridge Creek.	Class A
(5) Cedar River from Lake Washington to Landsburg Dam (river mile 21.6).	Class A
(6) Cedar River and tributaries from Landsburg Dam (river mile 21.6) to headwaters. Special condition – no waste discharge will be permitted.	Class AA
(7) Chehalis River from upper boundary of Grays Harbor at Cosmopolis (river mile 3.1, longitude 123°45'45" W) to Scammon Creek (river mile 65.8).	Class A
(8) Chehalis River from Scammon Creek (river mile 65.8) to Newaukum River (river mile 75.2). Special condition – Dissolved oxygen shall exceed 5.0 mg/L from June 1, to September 15. For the remainder of the year, the dissolved oxygen shall meet Class A criteria.	Class A
(9) Chehalis River from Newaukum River (river mile 75.2) to Rock Creek (river mile 106.7).	Class A

(10) Chehalis River, from Rock Creek (river mile 106.7) to headwaters. Class AA
(11) Chehalis River, south fork. Class A
(12) Chewack River. Class AA
(13) Chiwawa River. Class AA
(14) Cispus River. Class AA
(15) Clearwater River. Class A
(16) Cle Elum River. Class AA
(17) Cloquallum Creek. Class A
(18) Clover Creek from outlet of Lake Spanaway to inlet of Lake Steilacoom. Class A
(19) Columbia River from mouth to the Washington–Oregon border (river mile 309.3). Special conditions – Temperature shall not exceed 20.0° C due to human activities. When natural conditions exceed 20.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C; nor shall such temperature increases, at any time, exceed 0.3° C due to any single source or 1.1° C due to all such activities combined. Dissolved oxygen shall exceed 90 percent of saturation. Class A
(20) Columbia River from Washington–Oregon border (river mile 309.3) to Grand Coulee Dam (river mile 596.6). Special condition from Washington–Oregon border (river mile 309.3) to Priest Rapids Dam (river mile 397.1). Temperature shall not exceed 20.0° C due to human activities. When natural conditions exceed 20.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C; nor shall such temperature increases, at any time, exceed $t=34/(T+9)$. Class A
(21) Columbia River from Grand Coulee Dam (river mile 596.6) to Canadian border (river mile 745.0). Class AA
(22) Colville River. Class A
(23) Coweeman River from mouth to Mulholland Creek (river mile 18.4). Class A
(24) Coweeman River from Mulholland Creek (river mile 18.4) to headwaters. Class AA
(25) Cowlitz River from mouth to base of Riffe Lake Dam (river mile 52.0). Class A
(26) Cowlitz River from base of Riffe Lake Dam (river mile 52.0) to headwaters. Class AA
(27) Crab Creek and tributaries. Class B
(28) Decker Creek. Class AA
(29) Deschutes River from mouth to boundary of Snoqualmie National Forest (river mile 48.2). Class A
(30) Deschutes River from boundary of Snoqualmie National Forest (river mile 48.2) to headwaters. Class AA
(31) Dickey River. Class A
(32) Dosewallips River and tributaries. Class AA
(33) Duckabush River and tributaries. Class AA
(34) Dungeness River from mouth to Canyon Creek (river mile 10.8). Class A
(35) Dungeness River and tributaries from Canyon Creek (river mile 10.8) to headwaters. Class AA
(36) Duwamish River from mouth south of a line bearing 254° true from the NW corner of berth 3, terminal No. 37 to the Black River (river mile 11.0) (Duwamish River continues as the Green River above the Black River). Class B
(37) Elochoman River. Class A
(38) Elwha River and tributaries. Class AA
(39) Entiat River from Wenatchee National Forest boundary (river mile 20.5) to headwaters. Class AA
(40) Grande Ronde River from mouth to Oregon border (river mile 37). Special condition – Temperature shall not exceed 20.0° C due to human activities. When natural conditions exceed 20.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C; nor shall such temperature increases, at any time, exceed $t=34/(T+9)$. Class A
(41) Grays River from Grays River Falls (river mile 15.8) to headwaters. Class AA
(42) Green River (Cowlitz County). Class AA
(43) Green River (King County) from Black River (river mile 11.0 and point where Duwamish River continues as the Green River) to west boundary of Sec. 27–T21N–R6E (west boundary of Flaming Geyser State Park at river mile 42.3). Class A
(44) Green River (King County) from west boundary of Sec. 27–T21N–R6E (west boundary of Flaming Geyser State Park, river mile 42.3) to west boundary of Sec. 13–T21N–R7E (river mile 59.1). Class AA
(45) Green River and tributaries (King County) from west boundary of Sec. 13–T21N–R7E (river mile 59.1) to headwaters. Special condition – No waste discharge will be permitted. Class AA
(46) Hamma Hamma River and tributaries. Class AA
(47) Hanaford Creek from mouth to east boundary of Sec. 25–T15N–R2W (river mile 4.1). Special condition – Dissolved oxygen shall exceed 6.5 mg/L. Class A
(48) Hanaford Creek from east boundary of Sec. 25–T15N–R2W (river mile 4.1) to headwaters. Class A
(49) Hoh River and tributaries. Class AA
(50) Hoquiam River (continues as west fork above east fork) from mouth to river mile 9.3 (Dekay Road bridge) (upper limit of tidal influence). Class B
(51) Humptulips River and tributaries from mouth to Olympic National Forest boundary on east fork (river mile 12.8) and west fork (river mile 40.4) (main stem continues as west fork). Class A

(52) Humptulips River, east fork from Olympic National Forest boundary (river mile 12.8) to headwaters. Class AA

(53) Humptulips River, west fork from Olympic National Forest boundary (river mile 40.4) to headwaters. Class AA

(54) Issaquah Creek. Class A

(55) Kalama River from lower Kalama River Falls (river mile 10.4) to headwaters. Class AA

(56) Klickitat River from Little Klickitat River (river mile 19.8) to headwaters. Class AA

(57) Lake Washington Ship Canal from Government Locks (river mile 1.0) to Lake Washington (river mile 8.6). Special condition – Salinity shall not exceed one part per thousand (1.0 ppt) at any point or depth along a line that transects the ship canal at the University Bridge (river mile 6.1). Lake Class

(58) Lewis River, east fork, from Multon Falls (river mile 24.6) to headwaters. Class AA

(59) Little Wenatchee River. Class AA

(60) Methow River from mouth to Chewack River (river mile 50.1). Class A

(61) Methow River from Chewack River (river mile 50.1) to headwaters. Class AA

(62) Mill Creek from mouth to 13th street bridge in Walla Walla (river mile 6.4). Special condition – Dissolved oxygen concentration shall exceed 5.0 mg/L. Class B

(63) Mill Creek from 13th Street bridge in Walla Walla (river mile 6.4) to Walla Walla waterworks dam (river mile 25.2). Class A

(64) Mill creek and tributaries from city of Walla Walla waterworks dam (river mile 25.2) to headwaters. Special condition – No waste discharge will be permitted. Class AA

(65) Naches River from Snoqualmie National Forest boundary (river mile 35.7) to headwaters. Class AA

(66) Naselle River from Naselle "Falls" (cascade at river mile 18.6) to headwaters. Class AA

(67) Newaukum River. Class A

(68) Nisqually River from mouth to Alder Dam (river mile 44.2). Class A

(69) Nisqually River from Alder Dam (river mile 44.2) to headwaters. Class AA

(70) Nooksack River from mouth to Maple Creek (river mile 49.7). Class A

(71) Nooksack River from Maple Creek (river mile 49.7) to headwaters. Class AA

(72) Nooksack River, south fork, from mouth to Skookum Creek (river mile 14.3). Class A

(73) Nooksack River, south fork, from Skookum Creek (river mile 14.3) to headwaters. Class AA

(74) Nooksack River, middle fork. Class AA

(75) Okanogan River. Class A

(76) Palouse River from mouth to south fork (Colfax, river mile 89.6). Class B

(77) Palouse River from south fork (Colfax, river mile 89.6) to Idaho border (river mile 123.4). Special condition – Temperature shall not exceed 20.0° C due to human activities. When natural conditions exceed 20.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C; nor shall such temperature increases, at any time, exceed $t=34/(T+9)$. Class A

(78) Pend Oreille River from Canadian border (river mile 16.0) to Idaho border (river mile 87.7). Special condition – Temperature shall not exceed 20.0° C due to human activities. When natural conditions exceed 20.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C; nor shall such temperature increases, at any time, exceed $t=34/(T+9)$. Class A

(79) Pilchuck River from city of Snohomish waterworks dam (river mile 26.8) to headwaters. Class AA

(80) Puyallup River from mouth to river mile 1.0. Class B

(81) Puyallup River from river mile 1.0 to Kings Creek (river mile 31.6). Class A

(82) Puyallup River from Kings Creek (river mile 31.6) to headwaters. Class AA

(83) Queets River and tributaries. Class AA

(84) Quillayute River. Class AA

(85) Quinault River and tributaries. Class AA

(86) Salmon Creek (Clark County). Class A

(87) Satsop River from mouth to west fork (river mile 6.4). Class A

(88) Satsop River, east fork. Class AA

(89) Satsop River, middle fork. Class AA

(90) Satsop River, west fork. Class AA

(91) Skagit River from mouth to Skiyou Slough–lower end (river mile 25.6). Class A

(92) Skagit River and tributaries (includes Baker, Suak, Suiattle, and Cascade Rivers) from Skiyou Slough–lower end, (river mile 25.6) to Canadian border (river mile 127.0). Class AA

(93) Skokomish River and tributaries. Class AA

(94) Skookumchuck River from Bloody Run Creek (river mile 21.4) to headwaters. Class AA

(95) Skykomish River from mouth to May Creek (above Gold Bar at river mile 41.2). Class A

(96) Skykomish River from May Creek (above Gold Bar at river mile 41.2) to headwaters. Class AA

(97) Snake River from mouth to Washington–Idaho–Oregon border (river mile 176.1). Special condition

(a) Below Clearwater River (river mile 139.3). Temperature shall not exceed 20.0° C due to human activities. When natural conditions exceed 20.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than

0.3° C; nor shall such temperature increases, at any time, exceed t=34/(T+9).

(b) Above Clearwater River (river mile 139.3). Temperature shall not exceed 20.0° C due to human activities. When natural conditions exceed 20.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C; nor shall such temperature increases, at any time, exceed 0.3° C due to any single source or 1.1° C due to all such activities combined. Class A

(98) Snohomish River from mouth and east of longitude 122°13'40"W upstream to latitude 47°56'30"N (southern tip of Ebey Island river mile 8.1). Special condition: Fecal coliform organisms shall not exceed a geometric mean value of 200, organisms/100 mL. with not more than 10 percent of samples exceeding 400 organisms/100 mL. Class A

(99) Snohomish River upstream from latitude 47°56'30"N (southern tip of Ebey Island river mile 8.1) to confluence with Skykomish and Snoqualmie River (river mile 20.5). Class A

(100) Snoqualmie River and tributaries from mouth to west boundary of Twin Falls State Park on south fork (river mile 9.1). Class A

(101) Snoqualmie River, middle fork. Class AA

(102) Snoqualmie River, north fork. Class AA

(103) Snoqualmie River, south fork, from west boundary of Twin Falls State Park (river mile 9.1) to headwaters. Class AA

(104) Soleduck River and tributaries. Class AA

(105) Spokane River from mouth to Idaho border (river mile 96.5). Special condition – Temperature shall not exceed 20.0° C due to human activities. When natural conditions exceed 20.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C; nor shall such temperature increases, at any time, exceed t=34/(T+9). Class A

(106) Stehekin River. Class AA

(107) Stillaguamish River from mouth to north and south forks (river mile 17.8). Class A

(108) Stillaguamish River, north fork, from mouth to Squire Creek (river mile 31.2). Class A

(109) Stillaguamish River, north fork, from Squire Creek (river mile 31.2) to headwaters. Class AA

(110) Stillaguamish River, south fork, from mouth to Canyon Creek (river mile 33.7). Class A

(111) Stillaguamish River, south fork, from Canyon Creek (river mile 33.7) to the headwaters. Class AA

(112) Sulphur Creek. Class B

(113) Sultan River from mouth to Chaplain Creek (river mile 5.9). Class A

(114) Sultan River and tributaries from Chaplain Creek (river mile 5.9) to headwaters. Special condition – No waste discharge will be permitted above city of Everett diversion dam (river mile 9.4). Class AA

(115) Sumas River from Canadian border (river mile 12) to headwaters (river mile 23). Class A

(116) Tieton River. Class AA

(117) Tolt River, south fork and tributaries from mouth to west boundary of Sec. 31-T26N-R9E (river mile 6.9). Class AA

(118) Tolt River, south fork from west boundary of Sec. 31–T26N–R9E (river mile 6.9) to headwaters. Special condition – No waste discharge will be permitted. Class AA

(119) Touchet River, north fork from Dayton water intake structure (river mile 3.0) to headwaters. Class AA

(120) Toutle River, north fork, from Green River to headwaters. Class AA

(121) Toutle River, south fork. Class AA

(122) Tucannon River from Umatilla National Forest boundary (river mile 38.1) to headwaters. Class AA

(123) Twisp River. Class AA

(124) Union River and tributaries from Bremerton waterworks dam (river mile 6.9) to headwaters. Special condition – No waste discharge will be permitted. Class AA

(125) Walla Walla River from mouth to Lowden (Dry Creek at river mile 27.2). Class B

(126) Walla Walla River from Lowden (Dry Creek at river mile 27.2) to Oregon border (river mile 40). Special condition – Temperature shall not exceed 20.0° C due to human activities. When natural conditions exceed 20.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C; nor shall such temperature increases, at any time, exceed t=34/(T+9). Class A

(127) Wenatchee River from Wenatchee National Forest boundary (river mile 27.1) to headwaters. Class AA

(128) White River (Pierce–King Counties) from Mud Mountain Dam (river mile 29.6) to headwaters. Class AA

(129) White River (Chelan County). Class AA

(130) Wildcat Creek. Class A

(131) Willapa River upstream of a line bearing 70° true through Mailboat Slough light (river mile 1.8). Class A

(132) Wishkah River from mouth to river mile 6 (SW 1/4 SW 1/4 NE 1/4 Sec. 21–T18N–R9W). Class B

(133) Wishkah River from river mile 6 (SW 1/4 SW 1/4 NE 1/4 Sec. 21–T18N–R9W) to west fork (river mile 17.7). Class A

(134) Wishkah River from west fork of Wishkah River (river mile 17.7) to south

boundary of Sec. 33-T21N-R8W (river mile 32.0). Class AA

(135) Wishkah River and tributaries from south boundary of Sec. 33-T21N-R8W (river mile 32.0) to headwaters. Special condition - No waste discharge will be permitted. Class AA

(136) Wynoochee River from mouth to Olympic National Forest boundary (river mile 45.9) Class A

(137) Wynoochee River from Olympic National Forest boundary (river mile 45.9) to headwaters. Class AA

(138) Yakima River from mouth to Sunnyside Dam (river mile 103.8). Class B

(139) Yakima River from Sunnyside Dam (river mile 103.8) to Cle Elum River (river mile 185.6). Special condition - Temperature shall not exceed 21.0° C due to human activities. When natural conditions exceed 21.0° C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° C; nor shall such temperature increases, at any time, exceed $t=34/(T+9)$. Class A

(140) Yakima River from Cle Elum River (river mile 185.6) to headwaters. Class AA

[Statutory Authority: RCW 90.48.035. 82-12-078 (Order DE 82-12), § 173-201-080, filed 6/2/82; 78-02-043 (Order DE 77-32), § 173-201-080, filed 1/17/78; Order DE 73-22, § 173-201-080, filed 11/16/73; Order 73-4, § 173-201-080, filed 7/6/73.]

WAC 173-201-085 Specific classifications—Marine water. Specific marine surface waters of the state of Washington are classified as follows:

(1) Budd Inlet south of latitude 47°04'N (south of Priest Point Park). Class B

(2) Coastal waters: Pacific Ocean from Ilwaco to Cape Flattery. Class AA

(3) Commencement Bay south and east of a line bearing 258° true from "Brown's point" and north and west of line bearing 225° true through the Hylebos waterway light. Class A

(4) Commencement Bay, inner, south and east of a line bearing 225° true through Hylebos Waterway light except the city waterway south and east of south 11th Street. Class B

(5) Commencement Bay, city waterway south and east of south 11th Street. Class C

(6) Drayton Harbor, south of entrance. Class A

(7) Dyes and Sinclair Inlets west of longitude 122°37'W. Class A

(8) Elliott Bay east of a line between Pier 91 and Duwamish head. Class A

(9) Everett Harbor, inner, north and east of a line bearing 121° true from light "4" (Snohomish River mouth). Class B

(10) Grays Harbor west of longitude 123°59'W. Class A

(11) Grays Harbor east of longitude 123°59'W to longitude 123°45'45"W (Cosmopolis Chehalis River, river mile 3.1). Special condition - Dissolved oxygen shall exceed 5.0 mg/L. Class B

(12) Guemes Channel, Padilla, Samish and Bellingham Bays east of longitude 122°39'W and north of latitude 48°27'20"N. Class A

(13) Hood Canal. Class AA

(14) Mukilteo and all North Puget Sound west of longitude 122°39' W (Whidbey, Fidalgo, Guemes and Lummi Islands and state highway 20 bridge at Deception Pass), except as otherwise noted. Class AA

(15) Oakland Bay west of longitude 123°05'W (inner Shelton harbor). Class B

(16) Port Angeles south and west of a line bearing 152° true from buoy "2" at the tip of Ediz Hook. Class A

(17) Port Gamble south of latitude 47°51'20"N. Class A

(18) Port Townsend west of a line between Point Hudson and Kala point. Class A

(19) Possession Sound, south of latitude 47°57'N. Class AA

(20) Possession Sound, Port Susan, Saratoga Passage, and Skagit Bay east of Whidbey Island and state highway 20 bridge at Deception Pass between latitude 47°57'N (Mukilteo) and latitude 48°27'20"N (Similk Bay), except as otherwise noted. Class A

(21) Puget Sound through Admiralty Inlet and South Puget Sound, south and west to longitude 122°52'30"W (Brisco Point) and longitude 122°51'W (northern tip of Hartstene Island). Class AA

(22) Sequim Bay southward of entrance. Class AA

(23) South Puget Sound west of longitude 122°52'30"W (Brisco Point) and longitude 122°51'W (northern tip of Hartstene Island, except as otherwise noted). Class A

(24) Strait of Juan de Fuca. Class AA

(25) Willapa Bay seaward of a line bearing 70° true through Mailboat Slough light (Willapa River, river mile 1.8). Class A

[Statutory Authority: RCW 90.48.035. 82-12-078 (Order DE 82-12), § 173-201-085, filed 6/2/82; 78-02-043 (Order DE 77-32), § 173-201-085, filed 1/17/78.]

WAC 173-201-090 Achievement considerations. To fully achieve and maintain the foregoing water quality in the state of Washington, it is the intent of the department to apply the various implementation and enforcement authorities at its disposal, including participation in the programs of the Federal Clean Water Act (P.L. 95-217) as appropriate. It is also the intent that cognizance will be taken of the need for participation in cooperative programs with other state agencies and private groups with respect to the management of related problems. The department's planned program for water pollution control will be defined and revised annually in accordance with section 106 of said federal act. Further, it shall be required that all activities which discharge wastes into waters within the state, or otherwise adversely affect the quality of said waters, be in compliance with the waste treatment and discharge provisions of state or federal law. [Statutory Authority: RCW 90-.48.035. 82-12-078 (Order DE 82-12), § 173-201-090, filed 6/2/82; 78-02-043 (Order DE 77-32), § 173-201-090, filed 1/17/78; Order 73-4, § 173-201-090, filed 7/6/73.]

WAC 173-201-100 Implementation. (1) **Discharges from municipal, commercial, and industrial operations.** The primary means to be used for controlling municipal, commercial, and industrial waste discharges shall be through the issuance of waste disposal permits, as provided for in RCW 90.48.160 and following.

(2) Miscellaneous waste discharge or water quality effect sources. The director shall, through the issuance of regulatory permits, directives, and orders, as are appropriate, control miscellaneous waste discharges and water quality effect sources not covered by WAC 173-201-100(1) hereof. It is noted that, from time to time, certain short-term activities which are deemed necessary to accommodate essential activities or to otherwise protect the public interest may be specially authorized by the director as indicated in WAC 173-201-035(8)(e), under such conditions as the director may prescribe, even though such activities may result in a reduction of water quality conditions below those criteria and classifications established by this regulation. [Statutory Authority: RCW 90.48.035. 78-02-043 (Order DE 77-32), § 173-201-100, filed 1/17/78; Order 73-4, § 173-201-100, filed 7/6/73.]

WAC 173-201-110 Surveillance. A continuing surveillance program, to ascertain whether the regulations, waste disposal permits, orders, and directives promulgated and/or issued by the department are being complied with, will be conducted by the department staff as follows:

(1) Inspecting treatment and control facilities.

(2) Monitoring and reporting waste discharge characteristics.

(3) Monitoring receiving water quality. [Statutory Authority: RCW 90.48.035. 78-02-043 (Order DE 77-32), § 173-201-110, filed 1/17/78; Order 73-4, § 173-201-110, filed 7/6/73.]

WAC 173-201-120 Enforcement. To insure that the provisions of chapter 90.48 RCW, the standards for water quality promulgated herein, the terms of waste disposal permits, and other orders and directives of the department are fully complied with, the following enforcement tools will be relied upon by the department, in cooperation with the attorney general as it deems appropriate:

(1) Issuance of notices of violation and regulatory orders as provided for in RCW 90.48.120. Under this section, whenever in the opinion of the department a person is violating or about to violate chapter 90.48 RCW, the department shall notify said person of its determination. Within thirty days said person shall notify the department of the action taken or being taken in response to the department's determination, whereupon the department may issue a regulatory order as it deems appropriate. Whenever the department deems immediate action is necessary to accomplish the purposes of chapter 90.48 RCW, it may issue a regulatory order without first giving notice and thirty days for response.

(2) Initiation of actions requesting injunctive or other appropriate relief in the various courts of the state, as provided for in RCW 90.48.037.

(3) Levying of civil penalties as provided for in RCW 90.48.144. Under this section, the director may levy a civil penalty up to five thousand dollars per day against a person who violates the terms of a waste discharge permit, or who discharges without such a permit when the same is required, or violates the provisions of RCW 90.48.080. If the amount of the penalty, which is subject to mitigation or remission by the department, is not paid within thirty days after receipt of said notice, the attorney general, upon request of the director, shall bring an action in superior court to recover the same.

(4) Initiation of a criminal proceeding by the appropriate county prosecutor, as provided for in RCW 90.48.140.

(5) Issuance of regulatory orders or directives as provided for in RCW 90.48.240. [Statutory Authority: RCW 90.48.035. 82-12-078 (Order DE 82-12), § 173-201-120, filed 6/2/82; 78-02-043 (Order DE 77-32), § 173-201-120, filed 1/17/78; Order 73-4, § 173-201-120, filed 7/6/73.]

SECTION 2

BASIS OF CRITERIA FOR SPECIFICATION OF VEGETATED FILTER AREAS

2.01. Basis of Criteria for Feasibility of Vegetated Filter Areas

The sensitive water criteria represent the principal basis on which to determine the need for pollutant mitigation. These criteria can be applied at a very early stage of highway project development. The impact assessment guide can provide a more detailed level of analysis but requires more complete information, such as would be available at a later stage. If the analysis indicates a need for runoff treatment, vegetated drainage is recommended because of its demonstrated effectiveness in removing various types of pollutants, its adaptability to highway design at low cost, and its low maintenance requirements.

Important mechanisms in pollutant removal in a vegetated drainage course are sedimentation and filtration of solids and plant uptake of dissolved quantities. Operation of these mechanisms is promoted by intimate and extended contact between the flow and the vegetation. This contact requires a close-growing cover of water-resistant grassy, rather than woody, species. Almost all of the previous experience with overland flow treatment has been on slopes in the 2-8 percent range. As long as hydraulic transport is sufficient and safety and roadway stability are not endangered, a minimum slope specification is not required in the case of highway runoff. If these conditions are met, ponding of the flow would not be detrimental and would increase the residence time for treatment. With a slope greater than 8 percent, excessive velocity and insufficient detention time may occur. Slope variation up to 8 percent does not appear to affect performance appreciably.

The appended literature review covers each of these subjects in greater detail.

2.02. Basis of Criteria for Design of Vegetated Filter Areas

Over-the-shoulder versus distribution from a collection point is determined by the highway design characteristics. The use of a broad vegetated slope versus a channel is based on overall drainage system design and the geometry of the slope. Broad vegetated drainage courses are generally 100-200 ft in length, shorter than channel requirements. However, broad slopes need considerably more width to allow sheet flow of the drainage. Other than length, dimensions and construction of the channel configuration are determined more by hydraulic considerations than by water quality requirements.

The appended literature review discusses hydraulic loading rate specifications. Although most experience is with advanced treatment of secondary municipal effluents by overland flow, these effluents typically have pollutant concentrations the same order of magnitude as highway runoff (Mar et al., 1982). Hydraulic loading rates of 2.5-5.5 in/week are specified for these systems. Although overland flow systems in municipal service usually operate 1-3 shifts each day, five or six days a week, while runoff is more intermittent, equivalent treatment capacity is required during the period of flow. Therefore, the rates specified in this criterion were determined from the weekly rates given in the literature divided by 5 days/week.

2.03. Basis of Criteria for Maintenance of Vegetated Filter Areas

The maintenance recommendations are based on experience gained during the Highway Runoff Water Quality research project, as well as that reported by other observers. The vegetated channels studied in the Seattle area had not been scraped in the recorded past. In one case the adjacent freeway had been in operation approximately 20 years. The recommendations follow the principle of basing drainage course maintenance on a demonstrated need to guard hydraulic performance, as well as the runoff treatment function.

SECTION 3

BASIS OF CRITERIA FOR

SPECIFICATION OF DETENTION FACILITIES

3.01. Basis of Criteria for Requirement of Detention Facilities

The first two conditions represent use of a detention device for hydrologic control. The first depends on the existence of specific regulations that have been passed by certain jurisdictions to maintain stream flow rate patterns equivalent to those in an undeveloped watershed. The second condition refers to a situation where no regulation exists but a stream has been found to be potentially sensitive to the effects of peak discharge increase as a result of use for salmonid or other fish rearing, spawning, and/or harvesting.

As pointed out above, vegetated drainage courses generally are superior to detention facilities in reducing runoff contaminants of various types. However, a vegetated drainage course may not be warranted where large solids loadings occur but other pollutants are minimal, e.g. on a lightly traveled mountain highway. Where solids loadings are high and a vegetated drainage course is required for other pollutants, deposition may increase the maintenance requirement of the vegetated drainage course excessively and cause its removal from service if not preceded by a sedimentation basin.

3.02. Basis of Design Criteria and Considerations for Detention Facilities

The criteria and considerations represent current WSDOT practice, supplemented by the results of some recent studies on the performance of detention facilities. The mathematical criteria were derived from recommendations by Sylvester and DeWalle (1972). The appended literature review presents more detail on detention device performance and design.

SECTION 4

BASIS OF CRITERIA
FOR HANDLING OF SPOILS

4.01. Basis of Criteria for Spoils Disposal

Roadside sweepings, catch basin sediments, and ditch cleaning spoils consist of relatively large particles, which are not as erosive and do not contain quantities of contaminants as great per unit volume as do finer particles. Nevertheless, these sediments have some erosion and contamination potential. Surface waters can be protected from these potentials by limiting contact with large volumes of runoff water through disposal on slightly sloped areas not in major drainage paths. The maximum slope is the same as recommended for vegetated drainage courses. The spacing from a water body is the recommended length of a vegetated drainage channel to receive essentially the maximum treatment of runoff (Mar et al., 1982).

Wang et al. (1982) found that lead, zinc, copper, and other metals in highway runoff tend to accumulate in the top two inches of soils and in the first 30 and 150 ft of mud and vegetated drainage ditches, respectively. The difference in the accumulation in the two types of ditches is due to the relatively small capability of bare, compacted soil to capture pollutants relative to organic soils and vegetation. Removal occurs in a mud channel only where large particles are deposited near the beginning of the ditch. Once captured, metals have little tendency to move either vertically or longitudnally, even after a long period of highway operation without ditch cleaning. Toxic effects appeared in bioasssays only when aquatic organisms were exposed to runoff from highways transporting more than 10,000 ADT (Portele et al., 1982). Therefore, these more contaminated sediments can be dealt with separately from other sediments, both saving costs and providing environmental protection. The greater level of portection recommended for these sediments involves isolation from both the public and the surface environment.

SECTION 5

BASIS OF CRITERIA FOR WOODWASTE FILL LEACHATE CONTROL

5.01. Basis of Criteria for Woodwaste Fill Leachate Control

In laboratory and field experimentation, Vause et al. (1980) found that woodwaste leachate pollutant concentrations declined exponentially with time. Within one year they reached levels not considered to create a significant impact potential if leachate enters surface water or groundwater. The same level of protection offered by weathering of woodwaste can be provided by measures designed to prevent the formation of leachate, treat it, and/or dilute it sufficiently.

SECTION 6

BASIS OF CRITERIA FOR HIGHWAY SANDING

6.01. Basis of Criteria for Highway Sanding

The effectiveness of particle transport by flowing water is inversely related to particle size and density. The use of relatively large and/or dense sand particles can prevent transport in runoff. A precise analysis of the necessary particle characteristics depends on data on runoff velocity. The WSDOT Headquarters Hydraulic Section can assist with this analysis.

SECTION 7

BASIS OF CRITERIA FOR HIGHWAY RUNOFF DILUTION

7.01. Basis of Criteria for Highway Runoff Dilution

The general criterion is identical to Level I of the impact assessment guide procedure (Horner and Mar, 1982). To ensure protection of the receiving water ecosystem, it requires that the highway consume a minimal fraction of the total receiving water catchment and either provide runoff treatment by vegetation, or equivalent, or transport a relatively low traffic volume.

The criterion for specific cases is derived from the physical principle of conservation of mass.

SECTION 8

BASIS OF CRITERIA FOR HIGHWAY CLEANING

8.01. Basis of Criteria for Highway Cleaning

Sweeping is relatively effective in capturing large particles but less effective with smaller particles. Vacuuming along with sweeping improves the capture of smaller particles. All of the possible conditions listed generally introduce relatively large particles. Some of these conditions are continuing, while others are intermittent or isolated incidents. Highway cleaning is best suited to the latter types, but a permanent installation, such as a detention basin, may be warranted with a continuing pattern.

Flushing is a fairly slow process, requires equipment that may not be easily available, and uses a large volume of water, which becomes a waste product. Therefore, it is best suited for nonroutine use on a small scale when the wastewater will not create secondary problems.

SECTION 9

BASIS OF CRITERIA FOR STREAM CHANNEL MODIFICATION

9.01. Basis of Criteria for Stream Channel Modification

Even with relatively careful design and construction adhering to the criteria, unavoidable environmental impacts attend stream channel modification. First, a period of time is required for recovery of a natural substrate and favorable benthic habitat. During this period, the overall smaller-than-normal particle size distribution introduces a degree of instability that is particularly evident in the event of highly elevated flow. Second, riparian vegetation loss is practically unavoidable, is aesthetically detrimental, and may result in increased water temperatures and reduced fish productivity if extensive. Therefore, channel modification should be regarded as a last resort.

Due to the energy relations in flowing water, natural streams tend to a meandering pattern (Horner and Welch, 1978). Maintenance of this pattern and the original gradient assists in maintaining a current velocity distribution similar to the undisturbed channel and in preventing erosion, biotic habitat alteration, and downstream flooding. Current velocity is an important determinant of the habitats for aquatic life (Horner and Welch, 1978) and also of the erosive potential of the flow. Also due to energy considerations, natural streams tend toward an alternating pattern of pools and riffles, both of which are important habitats for aquatic life (Horner and Welch, 1978).

Reconstructed banks require rip-rap and revegetation to prevent erosion. Revegetation should also be concerned with reestablishing lost shading, which is apparently one of the impacts of channel modification of longest duration. Lack of shading can raise summer water temperatures, especially in small streams, to the potential detriment of salmonid fish.

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APPENDIX

REVIEW OF THE LITERATURE

Retention and Detention Facilities

Preceding the concern with runoff water quality, the problem of runoff quantity and receiving stream peak flow increase had begun to receive attention. Retention and detention of stormwater in holding basins, followed by release at relatively slow rates, was prescribed as the solution to the quantity problem, and a large number of new R/D facilities was installed throughout the nation. Considering the particulate settling potential offered by such devices, public works personnel soon began to regard them as at least a partial solution to runoff quality problems as well.

The research record on R/D devices primarily concerns flow attenuation. Some work has been accomplished to investigate their performance in improving runoff water quality, mostly within the last five years. Speaking both generally and in regard to highway applications, however, the available knowledge has been insufficient to design, build, and operate the facilities with regard to specific conditions. This review will cite work that has advanced the knowledge of R/D treatment effectiveness, design, and operations and maintenance in various applications and will highlight concepts that contributed to the proposed work plan development. It will concentrate on operating urban and highway sites, rather than construction sites experiencing soil erosion.

The terms retention and detention are often used interchangeably. Technically, detention basins are small impoundments having short holdup times and ungated outlets. Retention basins, on the other hand, store water longer under the control of outlet structures (Dally et al., 1983). Except where these distinctions matter in the discussion or where a reference has reported one or the other, this proposal will use the general term R/D facilities.

removal. Employing the same data as Davis et al. (1978), McCuen (1980) found sediment removal efficiency to vary between 2 and 98% over different storms, with the highest efficiencies associated with the smallest storms and longest detention times. One aspect of the U.S. Environmental Protection Agency's (1982) Nationwide Urban Runoff Program involved detention basin effectiveness. This study established the following typical pollutant removal efficiencies for detention: TSS--65%; Pb--19%; Cu--41%; total phosphorus (TP)--25%. Dally et al. (1983) investigated the performance of two urban detention facilities and documented negative efficiencies at times due to resuspension of sediment.

Design of R/D Facilities:

Various protocols exist to design R/D facilities with respect to hydrologic considerations. Common methods include that of Yrjanainen and Warren (1973) for watersheds under 200 acres in size and the Soil Conservation Service and Colorado Urban Hydrograph methods for larger catchments. These procedures generally employ the Rational Method to estimte runoff volume from the smallest watersheds (less than 50 acres) and the Unit Hydrograph otherwise.

R/D design based on water quality considerations is less standardized. Those procedures available fall into two broad categories: (1) theoretically based methods, generally relying on particle settlement according to Stokes Law, and (2) mechanistic models or statistical treatments derived from empirical data. Methods of the first type are usually based on textbook treatments (e.g. Linsley et al., 1975) but have not been widely checked for accuracy in actual use. The National Cooperative Highway Research Program (1980) produced a design manual for construction site sedimentation basins that bases hydrologic design on the Rational Method and sediment trapping on Stokes Law. Empirical treatments include that of Driscoll (1982), who proposed an equation relating detention basin solids removal with particle settling velocity, flow rate, basin area, and turbulence. Mays and Bedient (1982) constructed a model using a dynamic programming scheme that optimizes cost, size, and location of a detention basin in urban watersheds. Davis et al. (1978) developed a model that illustrates the difference in R/D design criteria for flow rate control versus water quality control and aids a user in finding a design best suited to achieving selected objectives. The approaches cited represent a range of possibilities that will be considered in analyzing the results of the proposed research to fulfill the stated objectives.

In most R/D applications water output is primarily surface discharge. However, highway agencies have employed such designs as groundwater recharge basins (Weaver, 1971) and ponded storage in interchange areas (Johnson, Personal communication), where evapotranspiration or outflow to groundwater predominate. R/D facilities frequently are employed for temporary water pollution control during highway construction, and there has been recent consideration of converting some of these installations to permanent service during highway operations (Conroy, Personal communication). Determining features required for compatible dual service is a subject that will be addressed in the proposed research.

R/D devices are generally conceived as holding areas excavated or constructed off the vehicular lanes. Porous pavement is a special category of holding capacity established within or beneath the roadway. This subject also will be given attention in the review. In-line catch basins will be eliminated from consideration because they offer no significant detention and may add to pollutant concentrations in the "first-flush" (Lager et al., 1977), although Aronson et al. (1983) have observed pollutant removal in such devices if maintained well.

Performance of R/D Facilities:

The use of R/D facilities as treatment devices has been supported by both laboratory and field research, although an insufficient record is available to predict performance over a wide range of conditons or to serve as a strong foundation for design and operating criteria. Whipple and Hunter (1981) quantified pollutant settleability in laboratory water columns and applied the data to estimate detention basin pollutant removal capabilities. They concluded that 32 hr residence time in an undisturbed pond six feet (1.83 m) deep would reduce various stormwater constituents as follows: total suspended solids (TSS)--70%; lead (Pb)--60%; Zinc (Zn)--17-36%; hydrocarbons--65%; biochemical oxygen demand (BOD), copper (Cu), and nickel (Ni)--20-50%. In a similar study Randall et al. (1982) found that a 48 hr settling period removed 90, 86, and 64% of the TSS, Pb, and BOD, respectively, from parking lot runoff.

Basing their work on field data, Davis et al. (1978) analyzed treatment efficiency of R/D processes by a series of regression analyses. Curtis and McCuen (1977), through the same process, identified storage volume, basin length, and detention time as significant predictor variables of pollutant

In addition to devising formal design procedures, some investigators have published design guidelines based on observation of operating R/D facilties. For example, Kathuria et al. (1976) recommended the following, based on study of surface mine sedimentation ponds:

Minimum 10 hr detention time for design storm
Maximum 2×10^{-5} m/s overflow velocity
Maximize basin surface area to the extent possible
Install trash barriers, velocity checks at the inlet, and non-perforated risers

Data gathered in the proposed work will be analyzed to determine the cost-effectiveness of design criteria of this nature.

Operation and maintenance of R/D Facilites:

R/D facilities in urban runoff service often have operating control capability, e.g. by changing orifices or adjusting outlet depths. Such capability is not as appropriate in highway locations because of their relative remoteness.

Assuming proper design for service conditions, R/D performance depends to a large extent on maintenance (Kathuria et al., 1976). These investigators also provided maintenance recommendations, including regular sediment removal, cleaning of outflow pipes, and repair of spillways and embankments when necessary. Kamedulski and McCuen (1979) added cutting of vegetation in the spillway as a concern. Cost-effective maintenance strategies for R/D facilities in highway service will be a matter to be investigated specifically in the proposed research.

Porous Pavements:

Stormwater holdup could be provided in open-grated concrete or asphalt or in the subbase beneath pavements (Thelan et al., 1972). Porous concrete and asphalt and concrete lattice blocks have been used in parking lots to reduce stormwater drainage offsite but, apparently, have been applied for this purpose on a street of highway only once (Field et al., 1982a, b). Most state highway agencies have tried open-graded pavements to improve skid resistance and achieve other operating advantages, but there has been little thought or study given to their potential hydrological and water quality benefits in highway service or the possible problems associated with such applications. Day et al. (1982) have tested concrete grid pavements and have found them to affect both the quantity and quality of stormwater runoff favorably.

The subject of porous pavements will be studied further during Task A of the proposed work. Following this study, a decision will be made on the allocation of resources to retention/detention basins versus porous pavements during Task B. The allocation may be split between the two subjects, most likely emphasizing R/D basins, or may be devoted totally to R/D basins. The laboratory work plan developed during Task B will present and defend the decision.

Overland Flow

Land treatment of wastewater can take three fundamentally different forms: (1) rapid infiltration, (2) slow-rate infiltration, and (3) overland flow. The three are distinguished by the mode and rate of application of wastewater, the soils and vegetation involved, and the ultimate disposition of the renovated water. Overland flow processes are those in which the majority of the effluent is surface discharge after treatment through interaction with surface soils and vegetation. Unlike the other two processes, soils in the overland flow case tend to be of relatively low permeability. Because of their dependence on distribution of the water under pressure via spray equipment, rapid and slow-rate infiltration generally are not feasible for highway applications and will not be discussed further.

Overland flow systems can be in either of two configurations: (1) sheet flow over a broad, vegetated surface area or (2) passage through a vegetated channel. There are no inherent features of either configuration that limit their use in the highway setting, but the long experience in channeling highway drainage may favor the second in practice. Over-the-shoulder drainage across grass exemplifies the first approach and may have cost-effectiveness advantages of avoiding regular ditch maintenance and concentrated discharge to a receiving water at a single point, however. The following discussion will consider both configurations.

Overland flow offers potentially important environmental advantages in cases of high pollution potential (e.g. high traffic highways) and sensitive receiving waters, with relatively low installation and operation and maintenance costs (Mar et al., 1982). Depending on hydrologic and treatment requirements, land availability, climate, and other factors, a highway drainage system could be designed to incorporate both R/D facilities and overland flow. One specific goal of the proposed research will be to develop guidelines relating recommended application of the various technologies alone or in combination to circumstances prevalent on existing and yet-to-be-built highways.

Previous Applications of Overland Flow:

Most previous applications of overland flow have been in the area of polishing pretreated municipal sewage, although two installations have treated food processing wastewater (Hinrichs et al., 1980). Melbourne, Australia, has operated a municipal wastewater polishing overland flow system for many years (McPherson, 1979). All of these systems utilize broad surfaces over which water is distributed in sheet flow. Table 2 summarizes the characteristics of U.S. overland flow systems and provides ranges of the key design, operating, and performance variables.

Highway runoff frequently drains over vegetation, and there has been some consideration of the environmental value of such practices in highway agencies (Conroy, Personal communication). However, informed design of systems to meet specific environmental protection goals is essentially nonexistent, probably because there is little knowledge on which to base such design. Research data on overland flow application to stormwater runoff treatment are scarce, although two investigations in the highway realm have been completed (Bell and Wanielista, 1979; Wang et al., 1982; Little et al., 1983). The following discussion will summarize those aspects of the overall research record that have some relevance to highway applications and have influenced the Work Plan.

Design and Construction:

Soils underlying overland flow systems generally are of relatively low permeability, so that the majority of the applied water discharges as surface runoff. The range of desirable permeability rate is 0.006-0.6 inch/hr (0.015-1.52 cm/hr) (Moser, 1978). With wastewater concentrated at the influent end of overland flow fields, excessive infiltration would reduce contact between contaminants and the treatment media. Common soil textural classes are clay, clay loam, and silty clay. It is preferable to have a soil of at least one foot (0.30 m) depth (Moser, 1978) capable of supporting a

Table 2. Summary of Existing Overland Flow Treatment Systems in the United States (After Hinrichs et al., 1980).

Location	Scale	Waste	Pretreatment	Soils	Vegetation	Slope (%)	Length (m)	Area (ha)	Application	Avg. Flow (m^3/d)	Loading rate (cm/wk)	Timing (hr/d)	Kg BOD/ha-d	Kg N/ha-d	Runoff (% Appl.)	Percent Removal BOD	TSS	N	P
Davis, CA	Research, Pilot	Municipal	Oxidation pond	Clay	Rye grass	2	30	0.05	Spray nozzles	15	20	2-12	16	-	87	70	69	-	-
Hunt-Wesson, Davis, CA	Full	Food	Screening	Silty clay	Fescue, Trefoil, Reed canary, Rye grass	2.5	30	97	Solid-set sprinklers	12,000	9	6-10	166	8.1	21	97	99	84	-
Ada, OK	Research	Municipal	Screening Primary Oxidation pond	Clay	Fescue Rye Bermuda grasses	2 2 2	36 36 36	2.4 0.8 0.8	Rotating spray	510 260 260	10-20 15-20 25-40	8-12 8-12 8-12	61-68 9-14 4.3-7.4	12-13 5-6 4.1-4.6	47 50 50	98 98 98	98 98 98	90 90 90	50 50 50
Utica, MS	Research	Municipal	Oxidation pond	Silty clay loam	Reed canary Fescue, Rye, Bermuda grasses	2-8	46	0.5	Perforated trough	46 130	6.5 18	6-24	2.2 6.2	2.0 5.6	-	55 -	57 -	90 75	50 30
Carbondale, IL	Full	Municipal	Oxidation pond	Glacial till	Natural grass	7-12	60	0.06	Perforated pipe	38	44	0-24	26	13	83	76	-	64	64
Hanover, NH	Research	Municipal	Primary Secondary	Silt loam	Orchard, Fescue, Reed canary, Rye grasses	5 5	30 30	0.03 0.03	Perforated pipe	2.1 2.1	5 5	7	6.0 3.7	2.6 2.3	25 25	91/58[a] 95/80[a]	97/84[a] 96/88[a]	94/25[a] 87/32[a]	89/39[a] 80/30[a]
Easley, SC	Full	Municipal	Screening Oxidation pond	Clay	Kentucky 31, Tall fescue grasses	6 6	55 47	0.53 1.4	Fan nozzles	91 290	12 15	6-8	32 15	3.7NH_3-N 0.7NH_3-N	70 70	84 59	76 48	77 74	45 52
Campbell Soup, Paris, TX	Full	Food	Screening Grease removal	Clay loam	Reed canary grass	2-8	60-75	285	Sprinklers	17.2	4.2	6	42	0.44	87	99	93	90	58

[a]Summer/Winter

Note: gal/d = m^3/d x 264.2; inches/wk = cm/wk x 0.39; lb/ac-d = Kg/ha-d x 0.89

close-growing cover of water resistant grasses (Sutherland and Myers, 1982). Favorable soil properties are pH = 5.5-8.4, cation exchange capacity (CEC) > 20 meq/100 g, sodium $\leq$ 5% of CEC, calcium = 60-70% of CEC, and potassium = 5-10% of CEC (Metcalf and Eddy, Inc., 1977). Where soils of high permeability or otherwise poor properties are present in a highway setting requiring runoff treatment, two strategies are available: import better soil or use a R/D device exclusively, particularly a groundwater recharge basin. The research will consider the economic and environmental implications of these strategies, expecially the potential threat to groundwater quality.

Surface preparation is an important determinant of performance in the case of sheet-flow overland flow systems. Proper grading is required to prevent ponding. The recommended sequence is coarse and fine grading, followed by hand planing (Sutherland and Myers, 1982).

Most engineered, sheet-flow overland flow systems have been seeded with specific grasses. The vegetated highway drainage channels investigated by Wang et al. (1982) and Little et al. (1983) exhibited high pollutant removal efficiencies with naturally occurring growth. Common grasses established on overland flow slopes are rye, fescue, reed canary, and Bermuda (Hinrichs et al., 1980). Sutherland and Myers (1982) reported that Kentucky 31 tall fescue and reed canary grasses have provided high levels of performance in both cold and warm climates. Palazzo et al. (1980) investigated various grasses and found that tall fescue and orchard grasses were best able to germinate under low nutrient conditions and on a slope. On the other hand, reed canary grass needed relatively large nutrient and water supplies, and perennial rye grass experienced winter kill. Invaders included Kentucky bluegrass and quackgrass, which served well to remove the nutrients from wastewater, and barnyard grass, which was aggressive but died off in the fall. The proposed research will not seek to investigate differences in performance resulting from different vegetation but will employ specific grasses shown to be usable under a range of conditions, as well as natural mixtures.

The geometry of overland sheet-flow plots is generally rectangular on a slope of 2-8 percent (Bouwer, 1976). Reported slope lengths almost always have been in the range 100-200 ft (approximately 30-60 m) (Hinrichs et al., 1980). Sutherland and Myers (1982) noted that little improvement in effectiveness has been seen with longer slopes. Widths are selected to treat the design flow at the recommended hydraulic loading rate (discussed below).

Sutherland and Myers (1982) concluded that slope and length are tolerant variables within the ranges cited, i.e. variation within these ranges affects performance little. Wang et al. (1982) discovered that pollutant concentrations in vegetated channels declined exponentially with length. Typically, 50 percent reduction of suspended solids and lead occurred within 60 ft (18.3 m) and 80 percent within 180 ft (54.9 m). The cross-section of such a channel depends on the hydraulic requirements of transporting a design flow without flooding. The proposed experiments will hold slope and length constant in the case of sheet-flow surfaces and will investigate the hydraulic requirements and pollutant removal as a function of length for vegetated channels.

Table 2 indicates a number of different means of applying wastewater to overland flow systems. Only the perforated trough and pipe are appropriate to gravity flow highway runoff. No special applicator is needed to introduce flow to vegetated channels.

Table 2 reports hydraulic loading rates of 4.2-44 cm/wk (1.7-17.3 inches/wk) for sheet-flow sites, but 6.4-14 cm/wk (2.5-5.5 inches/wk) is the usual range. Metcalf and Eddy, Inc. (1977) recommended a selection low in that range if slope exceeds 6 percent, slope length is less than 45 m (148 ft), or the location has a harsh winter climate; and a choice high in the range if the evapotranspiration or percolation rate is relatively high. Municipal and industrial overland flow treatment plants usually have operated a portion of each day for 5-6 days of the week, but storm runoff would be more intermittent. Thus, the hydraulic loading recommendations are not necessarily applicable to the case at hand and will be investigated further in the research.

A final design issue is overland flow effluent collection and transport to the receiving water. The tailwater ditch should be engineered for hydraulic efficiency and prevention of erosion and may itself be grass-lined. For such ditches Metcalf and Eddy, Inc. (1977) recommended 0.3-1 percent side slopes and less than 1 percent longitudnal slopes.

Operation and Maintenance:

A major advantage of overland flow compared to alternative treatment processes is that relatively little operating attention is needed. Although the municipal wastewater facilities representing the bulk of the reported experience generally are attended daily, the only operating requirement at highway sites should be occasional maintenance.

Potential maintenance activities include harvesting vegetation, removing sediment, and cleaning distribution equipment. Harvesting has been the norm at the municipal and industrial sites, but the highway channels studied by Wang et al. (1982) and Little et al. (1983) never were cut. Harvesting is more likely to be a necessity on sheet-flow surfaces than in channels, where the need would depend on climate, vegetation, and ditch capacity. Regarding sediments, the best strategy would appear to be prevention of the delivery of large solids loadings to the overland flow systems through preliminary settling. Sediment removal then should be based on hydraulic necessity, rather than an inflexible timetable, and should be performed to minimize disruption of vegetation growth.

A natural question concerning maintenance of land treatment facilities is the need to deal with pollutant accumulation in soils and vegetation. The evidence, presented below, is that pollutants generally are tightly bound and do not tend toward mobility either vertically or longitudnally. Soils in a channel draining runoff from a heavily traveled Seattle freeway had not been disturbed in 20 years of operation, and there was no evidence of pollutant break-through either to lower soil horizons or toward the end of the channel (Wang et al., 1982). Lee et al. (1976) noted that heavy metals in the Vicksburg system tended to be concentrated in soils near the point of application, indicating that any removal that might eventually be necessary would be localized. They also suggested that surface soils, if ever saturated, could be plowed under to fix pollutants in the subsoils, although the need for this action seems unlikely in the absence of highly contaminated waste streams. As discussed later, plant uptake of potentially toxic material does occur, opening the question of use or disposal of harvested crops.

Based on the above discussion, operating and maintenance questions for the proposed research are the necessity of harvesting, the degree of contamination of vegetation and its disposition, and rates of sediment deposition.

Mechanisms Operating in Overland Flow Treatment:

Successful design and operation of any treatment system depends on understanding of the physical, chemical, and biological mechanisms operating to fulfill its functions. Overland flow systems affect runoff hydrology and remove solids, metals, organics, microorganisms, and nutrients from the wastewater. This section will consider the mechanisms associated with each of these functions.

Most fundamentally, the design of an overland flow system depends on the hydraulic and pollutant loading rates in relation to the capacity of the site to transport water and remove pollutants and the discharge requirements. Figure 1 is a common representation of overland flow hydrology, which can also be expressed by the water balance equation:

Wastewater application + Precipitation =
Evapotranspiration + Percolation + Discharge

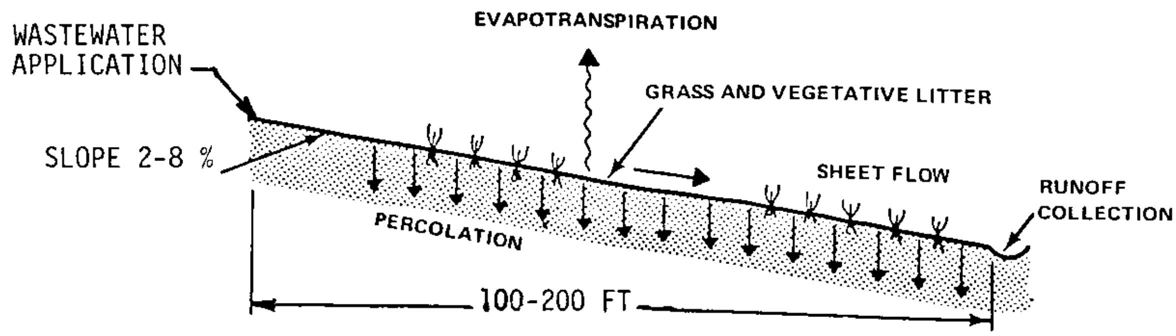

Figure 1: Overland Flow

A common distribution among the output quantities is approximately 20% evapotranspiration, < 20% percolation, and > 60% discharge. Hydrologic design of sheet-flow systems is according to the water balance, selected hydraulic loading rate, and a detention time of 20-45 minutes (Reed et al., 1979). In the case of channels, the hydrologic design depends on the water balance and hydraulic transport requirements. Design for treatment effectiveness is separate from hydrologic design, although the two must be reconciled.

Solids removal in overland flow is very straightforward, occurring as a result of sedimentation and filtration by the vegetation (Bouwer, 1976; Metcalf and Eddy, Inc., 1977). In stormwater runoff in general and highway runoff in particular, majorities of other important classes of pollutants, including organics, nutrients, and metals, are present in particulate form or are associated with general particulate matter through adsorption or other surface processes (Gupta et al., 1981; Mar et al., 1982). In both our Washington State studies (Portele et al, 1982; Wang et al., 1982) and the Envirex work (Gupta et al., 1981), dissolved metal fractions were found to be an extremely small proportion of the total metals. Zawlocki et al. (1982) found that an average of 80 percent of the extractable organics in Washington highway runoff was particulate. As a consequence, effective solids would also yield efficient reductions of other pollutants of interest.

Overland flow has exhibited highly efficient metal removal in general (particulate and dissolved), primarily as a result of the adsorptive capacity of the organic layer on the soil surface (Peters et al., 1981). Other metal removal mechanisms of lesser importance are precipitation, ion exchange, and plant uptake (Spyridakis and Welch, 1976). The degree of uptake depends primarily on the plant species and the metal, with cadmium and zinc shown to be most mobile in uptake (Olson et al., 1983).

There is evidence of two processes operating to immobilize metals in plant tissue following uptake: (1) complexation by free ions in root cell walls, and (2) enzyme-mediated incorporation into shoot tissue (Bradshaw et al., 1978). Heavy metals are toxic to plants, in general, although tolerance is commonly observed and has been well-studied. Apparently, some members of a given species have genes producing metal tolerance, and the development of tolerant populations in exposed environments is a result of natural selection (Bradshaw et al., 1978).

Organic contaminants, whether solid or dissolved, can be reduced by bacterial decomposition if they are biodegradable and if they come into contact with the soil organic layer. Adsorption of soluble organics in that layer is another important removal mechanism (Spyridakis and Welch, 1976).

Highway runoff has been found consistently to exhibit sizeable concentrations of bacteria regarded as indicators of the presence of pathogens (Horner et al., 1977; Gupta et al., 1981). Overland flow processes can remove microorganisms, primarily through entrapment of the solids harboring them (Bouwer, 1976).

Because of their roles in influencing algal growth in surface waters, nitrogen (N) and phosphorus (P) are the nutrients of greatest interest in runoff. Nakano et al. (1981) listed the mechanisms important in N removal as:

(1) adsorption of ammonium ions by the soil surface, (2) nitrification of ammonium to nitrite and nitrate, (3) transport of nitrate to the anaerobic zone in the saturated soil pores, (4) denitrification of nitrate to gaseous forms in the anaerobic zone, and (5) plant uptake. They expressed the view that nitrate transport is the step most limiting to the rate of N removal. Nitrification is reduced as pH declines since the process produces hydrogen ions. Therefore, neutralization (e.g. with calcium carbonate) would promote this mechanism. Alternate wetting and drying, as generally occurs in practice in overland flow, provides opportunity for both the aerobic oxidation (nitrification) and anaerobic reduction (denitrification) steps. Scott and Fulton (1979) observed that plant uptake was most important in the system they studied, exceeding 1 Kg N/ha/day during vigorous plant growth. Plants appeared to serve as ammonia strippers, taking up ammonium and then evolving ammonia gas. Khalid et al. (1981) concurred, finding uptake to account for 23-62 percent of the applied ammonia-nitrogen while Palazzo et al. (1979) found uptake was responsible for 64 percent of the total N removal.

Primary P removal mechanisms are adsorption, precipitation, and plant uptake of the soluble fraction (Metcalf and Eddy, Inc., 1977; Spyridakis and Welch, 1976). Precipitation of phosphorus has been promoted in overland flow processes by aluminum sulfate addition (Lee et al., 1976; Lee and Peters, 1979). Palazzo et al. (1979) observed plant uptake to account for 54 percent of the total P removal. It should be noted that nutrients taken up by plants may be released and escape in the effluent if the plants are left to die and decay in the field or channel, rather than being harvested.

With the proposed research primarily having an applied interest, investigation of mechanisms will not be a primary objective. Nevertheless, the data gathered for other purposes will be analyzed to reveal any insights that will add to the knowledge of mechanisms.

Performance of Overland Flow Treatment:

Substantial data are available on the treatment efficiency of existing overland flow processes. Besides the reductions reported for BOD, TSS, N and P in Table 2, McPherson (1979) has provided efficiencies for these constituents realized at the Melbourne, Australia, overland flow plant. Median values during warm weather operations follow:

BOD -- 95%	Total N -- 87%
TSS -- 95.5%	Total P -- 50%

McPherson (1979) analyzed differentials in removals of the individual constituents comprising the total N. The plant averaged 80 percent reduction of organic N but only 20 percent removal of ammonia-N, for an overall 45 percent N reduction, among the lowest reported. Widely varying success in P removal has been reported, ranging from 30-89 percent. The Vicksburg experimental plant achieved consistent reductions exceeding 80 percent (maximum 98 percent) by applying stoichiometric amounts of aluminum sulfate to the field (Lee et al., 1976; Lee and Peters, 1979).

Other efficiency data have been reported for heavy metals, as follows:

	McPherson (1979)	Peters et al. (1981)
Cu	90%	86%
Cr	85	--
Fe	40	92
Pb	95	--
Hg	85	--
Ni	60	95
Zn	--	88

In our study of the performance of grass-lined channels in highway drainage service (Wang et al., 1982), we observed consistent 80 percent reductions of TSS and Pb in a 180 ft (54.9 m) length. More soluble metals, such as Cu and Zn, were reduced by approximately 60 percent in this distance. Little et al. (1983) collected limited data on nutrient and oil and grease removals in one of these channels and observed the following:

	Removal Range (%)	No. Storms
Total P	5-85	9
Soluble Reactive P	< 0-73	6
Nitrate+Nitrite-Nitrogen	40-85	5
Oil and Grease	67-93	3

tion, as well as locations where snow remains for a period of time and then releases accumulated pollutants upon melting.

Analysis and Design of Overland Flow Systems:

The development of definitive design protocols for land treatment systems has lagged as a result of the lack of coordinated studies aimed at gathering data to support such development. Progress also has been retarded by differing site conditions. Experience gained operating a number of experimental and full-scale overland flow systems in recent years, however, has begun to yield generalized information that can be applied elsewhere (Smith and Schroeder, 1983). These points have been emphasized in the foregoing discussion.

Overcash and Pal (1979) have presented a thorough, systematic approach to design of land treatment systems for industrial wastes that is adaptable to other applications. The procedure depends upon identification of the land-limiting constituent (LLC), the quantity (including water) that will determine the system design features for given treatment goals in relation to the assimilative capacity of the natural treatment media. Relating specific waste characteristics to site conditions permits designing on the basis of site-specific factors. Since assimilative capacities usually are not available, application of the method does require study to establish them. The authors have presented three assimilation models for: (1) quantities that decompose or are taken up by plants, (2) quantities that accumulate without decomposing or migrating, and (3) conservative quantities that migrate. Overcash and Kendall (1981) demonstrated the application of the technique for textile industry waste.

Application of the Overcash and Pal (1979) procedure to highway runoff treatment by overland flow would require definition of runoff characteristics and assimilative capacities. The former category of information is available as a result of studies such as performed by Envirex (Gupta et al., 1981c), our University of Washington group (Mar et al., 1982) and CALTRANS (Racin et al., 1982). In the latter case the research need is to establish LLC assimilative capacity for typical soils and vegetation types, along with an efficient protocol designating how the necessary experiments should be performed in other circumstances.

In two late fall storms, soluble reactive P at the channel outlet exceeded that at the inlet, probably because of release from dead plant material.

These results and those reported for the Hanover plant in Table 1 indicate that reduced overland flow system performance must be expected in the winter. Jenkins and Martel (1979) observed high TSS removals all winter at Hanover, but efficiency in BOD reduction declined at temperatures below $4^{\circ}C$. N removals decreased below $14^{\circ}C$, and ammonia-N reduction was nil. P removal of 80 percent in summer declined to zero in the winter. Honachefsky (1978) observed that natural vegetation performed better than less diverse seeded growth in the winter and that ice build-up was beneficial to performance. Storage has been prescribed for small municipal overland flow systems in cold climates but would not be practical in the case of highways. Further research is required to establish the best winter management strategy for overland flow slopes or channels in highway runoff service.

Several workers have investigated the movements of pollutants in overland flow systems. Scott and Fulton (1979) found that removals of TSS, BOD, and total organic carbon in a sheet-flow field were exponential functions of flow distance, while organic N and heavy metals losses increased directly with length. Wang et al. (1982) observed TSS and metals to decline exponentially with length in highway runoff channels. Lee et al. (1976) found that heavy metals accumulated in soils close to the point of application, suggesting an exponential rather than a linear model. David and Williams (1979), Wang et al. (1982), and Olson et al. (1983) studied captured metal mobility in overland flow field soils. All agreed that metals concentrated in the upper soil layers (top 4 cm) and have shown little tendency to move vertically over long time spans. Wang et al. (1982) also were concerned about longitudinal transport to the end of the channels and "break-through" resulting from saturation of binding capacity. They saw no evidence of such movement, even in a channel that had been transporting runoff from a heavily traveled freeway for 20 years.

The major research question associated with overland flow performance in the highway setting concerns wintertime effectiveness and how it might limit the usefulness of the process or require special management. There should be comprehensive performance checks for the major runoff constituents in climates that experience winter die-back of vegetation but little or no snow accumula-

Economic analysis and costs of overland flow systems have been presented by Christensen (1978), Reed et al. (1979), Hinrichs et al. (1980), U.S. Environmental Protection Agency (1980), Overcash and Kendall (1981), and Roy F. Weston, Inc. (1982). Derived from the municipal experience, specific construction and operation and maintenance costs are not applicable to the highway case. Research should give attention to cost-effectiveness analysis to develop design guidance on this basis. Analogous to the evaluation of municipal land treatment cost-effectiveness presented by Christensen (1978), this analysis should compare costs versus performance for different size applications and various alternatives (e.g., dual R/D-overland flow systems, as well as stand-alone systems).

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