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**MIXING ZONE GUIDANCE  
FOR  
CHRONIC TOXICITY  
AND  
ZONES OF INITIAL DILUTION**

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Wisconsin Department of Natural Resources  
Modeling and Analysis Unit  
Bureau of Water Resources Management

## FORWARD

This document is meant to give guidance on the selection of the correct mixing zone size for chronic toxicity mixing zones and zones of initial dilution. Both of these types of mixing zones are integral to the implementation of the recently enacted toxic criteria and effluent limit regulations found in NR102, NR105 and NR106 of the Wisconsin Administrative Codes. This information is being provided by the Department to clarify the current interpretation that the Department is using to make decisions on mixing zones. It is hoped that by providing this guidance, the permitting process will be quicker and the information submitted by dischargers will be of maximum use to the Department in making the determinations. This will be of benefit for both the dischargers and the Department.

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## CHRONIC TOXICITY - MIXING ZONE REQUIREMENTS

This paper is intended to give guidance to WPDES discharge applicants on the procedures the Department will use to select an appropriate chronic toxicity mixing zone for use in calculating effluent limits based upon criteria established in NR105 for fish and aquatic life. This guidance will establish the procedures that applicants must complete to obtain a mixing zone flow that exceeds 1/4 of the design flow.

Chronic toxicity mixing zones are intended as areas used to dilute effluent discharges to levels protective of fish and aquatic organisms from chronic impacts due to prolonged exposure and are defined in a variety of ways depending on the type, size, physical and biological conditions of the receiving water. For toxic substances with fish and aquatic life chronic criteria listed in NR105.06, the implementation code, established in NR106, allows for the selection of a mixing zone based on 1/4 of the  $Q_{7,10}$  (or 1/4 of the "biologically based design flow") in flowing streams. The use of values up to the full  $Q_{7,10}$  (or "biologically based design flow") is allowed providing mixing is rapid and a determination is made by the Department that a higher flow value is appropriate. In most cases the hydrologically defined  $Q_{7,10}$  will be available at discharge locations. If the "biologically based design flow" is available, it should be used. A special case that needs to be addressed occurs at discharge sites where the discharge is going into a peaking dam or a dam that is influenced by an upstream peaking facility. These sites may have very low flows that occur on a daily basis but for only a few hours of the day. Such operation will have some impact on the low flow calculations if "harmonic means" are used. The harmonic mean is defined as the inverse of the daily average inverse flows. Each mixing zone case will present a unique situation requiring the best choice of low flow calculation appropriate to determine the dilution factor. From here on in this paper the "design flow" will refer to either the  $Q_{7,10}$ , the "biologically based design flow" or other low flow appropriate to the situation, since any of these could be used for mixing zone calculations.

### REGULATORY AUTHORITY FOR MIXING ZONES

The following list explains the legal requirements for the selection of a mixing zone for the application of chronic toxicity fish and aquatic life criteria.

- NR102.05(3)(a) Mixing zones shall be as small as practicable.
- NR102.05(3)(b) Mixing zones shall provide passage for fish and other mobile aquatic organisms.
- NR102.05(3)(c) Mixing zones shall be no larger than 25% of the cross sectional area or volume of flow nor wider than 50% of the stream width except as provided in NR106.
- NR102.05(3)(e) Mixing zones shall be no larger than 10% of a lake's surface area except as provided in NR106.
- NR102.05(3)(f) Mixing zones shall not interfere with spawning or nursery areas, migratory routes, nor mouths of tributaries.
- NR102.05(3)(g) Overlapping mixing zones must account for synergistic effects.
- NR102.05(3)(h) To protect indigenous species, the pH range in the mixing zone must be  $4su < pH < 11su$ .
- NR106.06(3)(b)2 Mixing zones on lakes shall not exceed an area greater than that where discharge induced mixing occurs or the limitation formula, whichever is smaller.
- NR106.06(3)(b)1 Mixing zone limitation formula for rivers.
- NR106.06(3)(c)4 Design flow shall be between 1/4  $Q_{7,10}$  (or 1/4 of the biologically based design flow) and 1.0 of the  $Q_{7,10}$  (or 1.0 of the biologically based design flow). The default value is 1/4 of the design flow. Any greater fraction of the design flow will require a showing of acceptability by the discharger.
- NR106.06(3)(c)1 Department shall determine the "zone of free passage" and mixing characteristics (see also second item above).
- NR106.06(3)(c)2 The Department may require the discharger to demonstrate the mixing and "zone of free passage" of their discharge.

NR106.06(3)(c)6 The design flow may be reduced below the  $Q_{7,10}$  under some conditions of flow regulation.

The items referred to above will be interpreted in the following sections for purposes of implementing these mixing zone requirements and in particular to give guidance on what is needed for a showing by a discharger to obtain a larger design flow than the default value.

#### **WHAT IS A CHRONIC CRITERIA MIXING ZONE?**

A chronic criteria mixing zone is intended to be a small area in the receiving water in which the discharge of an effluent is mixed with the receiving water to assure dilution of any toxicant in the effluent to concentrations such that no chronic impacts to fish and aquatic organisms will occur outside of the mixing zone. Since many criteria are sensitive to instream parameters such as pH, temperature and hardness, care must be taken to assure that criteria will be met outside the mixing zone if these factors are widely different in the discharge and receiving water. Inside the mixing zone, concentrations of effluent may exceed chronic criteria. (NOTE: Acute criteria applied at "end of pipe" or at the edge of a "zone of initial dilution" will assure no acute impacts occur inside the mixing zone. See "Zones of Initial Dilution" guidance paper for more information.) The mixing zone depends on ambient turbulence to provide the energy for mixing to occur except in special cases for lake discharges as cited above. Since mobile aquatic organisms can reside in or pass through the mixing zone, chronic impacts to those organisms can be avoided only if the length of time an organism is in the zone is smaller than the exposure period needed to observe a chronic impact. Therefore it is essential that the mixing zone be kept as small as possible. The impact period for chronic effects may range from 4 to 30 days. Since the mixing zone may have concentrations that exceed the chronic criteria, several precautions must be taken to minimize the potential impact on the receiving water.

#### **WHAT DETERMINES THE SIZE OF A MIXING ZONE?**

The method used to determine the size of the mixing zone depends upon whether the receiving water is flowing or non flowing.

##### Non Flowing Waters

Dischargers to non flowing waters (ie lakes or backwaters) will have the mixing zone limited by a number of considerations found in the Natural Resources codes. They are limited to no more than 10% of the total surface area of the lake. NR106.06(3)(b)2 further limits the mixing zone to either a 10:1 dilution or the dilution achieved at the edge of the "discharge induced mixing area". Discharge induced mixing occurs in the area where the energy and momentum of the discharge velocity exceeds that of the ambient receiving water.

##### Flowing Waters

Discharges to flowing streams will have the mixing zone calculated as a dilution ratio based on the stream and effluent design flows. The physical area and geometry of the mixing zone need not be explicitly determined unless the discharger is requesting a non standard mixing zone or the discharge presents a barrier to the migration of aquatic life. For substances that have chronic impacts to fish and aquatic organisms, the default stream design flow specified in NR106 is 1/4 of the  $Q_{7,10}$  or 1/4 of the "biologically based" design flow. This flow will assure that the mixing zone will not exceed 25% of the cross sectional area nor more than 50% of the stream width under critical low flow conditions. These factors provide for the "zone of free passage" of mobile aquatic organisms required by NR102.05.

The design flow will always be based on the entire hydrological period of record that is available applied on a non seasonal basis. The best available estimate of the  $Q_{7,10}$  will be obtained in this way. The design flow may change over time in response to more data. Any changes in the design flow would be incorporated into the permit at the next reissuance or permit modification.

Under some conditions of rapid and complete mixing, the stream design flow can be increased to 100% of the  $Q_{7,10}$  or 100% of the biologically based design flow. How the determination is made under these conditions and any needed studies to support the determination will be discussed in later sections of this paper.

If the discharge occurs on a flowing stream but is in a side channel or one of many channels that carry flow at that point on the river, then the design flow will be based on 1/4 of the portion of the  $Q_{7,10}$  that is carried by the channel that has the discharge. The mixing zone could be increased similar to non channelized streams if conditions allow. If the channel is non flowing during low flow periods or during certain operational conditions, then the non flowing mixing zone method will be used.

## WHAT OTHER FACTORS NEED TO BE CONSIDERED WITH MIXING ZONES?

Since chronic criteria can be exceeded in the mixing zone, the area included can represent a barrier to the migration of aquatic organisms. Such barriers block the spawning migration of anadromous and catadromous species. Resident species make local migrations for spawning or other reasons and barriers to their free movement can threaten their existence. The EPA "Green Book" explained it this way:

"It is essential that adequate passageways be provided at all times for the movement or drift of the biota. Water quality criteria favorable to the aquatic community must be maintained at all times in these passageways. It is recognized, however, that certain areas of mixing are unavoidable. These create harmfully polluted areas and for this reason it is essential that they be limited in width and length and be provided only for mixing."

Additional factors are discussed in EPA's "Water Quality Standards Handbook". It lists the following points that need to be considered in the determination of the allowable size of a mixing zone.

1. Location      Biologically important areas are to be identified and protected. Where necessary to preserve a zone of passage for migrating fish or other organisms in a water course, the standards should specifically identify the portion of the waters to be kept free from mixing zones.
2. Size            Various methods and techniques for defining the surface area and the volume of mixing zones for various types of waters have been formulated. Methods which result in quantitative measures sufficient for permit actions and which protect the designated uses of the water body as a whole are acceptable.
3. Shape           The shape of a mixing zone should be a simple configuration that is easy to locate in the body of water and that avoids impingement on biologically important areas.
4. Outfall          Prior to designating any mixing zone, it should be assured that the design and location of the existing or proposed outfall will avoid significant adverse aquatic resource and water quality impacts by the wastewater discharge.
5. In-zone          The mixing zone should be free of:
  - materials that cause acute toxicity;
  - objectionable deposits;
  - floating debris, oil or scum;
  - objectionable color, odor, taste or turbidity;
  - undesirable aquatic life or dominance by nuisance species.

## WHO DETERMINES THE MIXING ZONE SIZE?

The Department will make an initial determination of the size of the mixing zone and the dilution ratio to be used to calculate effluent limits for each discharge. This will be done at the District level through the use of on site inspection surveys, professional judgement and guidance contained in this document. The discharger will be informed of the results of the determination and what dilution factor the Department intends to use. If the discharger believes that their site can qualify for a greater dilution ratio than that determined by the Department, they must make a request to the Department by submitting material that supports their position. The Department will review the submitted material and determine if a change in the chronic criteria dilution ratio is warranted. The Department will normally use the default value for the initial mixing zone determination as outlined in NR106.06. Several case examples that could receive larger mixing zones are enclosed with this document.

## WHAT CASES QUALIFY FOR LARGER MIXING ZONES?

### Non Flowing Waters

As previously stated, discharges to non flowing water are limited to a dilution ratio of 10:1 or the dilution ratio at the edge of the discharge induced mixing area. The discharge induced mixing area could be measured with dye and hydrodynamic studies but is best demonstrated with well documented plume models such as those discussed in the Zones of Initial Dilution guidance. The dilution achieved in this zone may be greater or less than 10:1. If it is less than 10:1 then that is the limiting factor. If it is greater than 10:1 the Department must determine if the site is suitable for a dilution ratio greater than the default value. It is the intention of the Department to use the default value of 10:1 in most cases. Lake discharges that may not be eligible for a dilution value greater than the 10:1 default include:

- shoreline discharges;
- surface discharges;
- effluents that attract fish and aquatic life;
- discharge sites in shallow areas;
- areas with threatened or endangered aquatic species;
- mixing zones adjacent to spawning or nursery areas;
- mixing zones adjacent to swimming beaches.

In order for a discharger to obtain a dilution ratio greater than the 10:1 default value, the discharger will have to provide information to the Department to substantiate the request. For lake discharges this will usually require a plume modeling study to determine the edge of the discharge induced mixing area. Prior to submitting such a request, the discharger should obtain a determination from the Department that their site will not be excluded for one of the above reasons. Determination of whether a particular site qualifies will require some case by case analysis by the Department after a request has been received from a discharger.

#### Flowing Waters

Stream dischargers may also have dilution ratios increased from default values (up to the full  $Q_{7,10}$ ) if the discharge situation safely allows a higher factor. There are some situations in which a "mixing zone" does not exist since the mixing of the effluent with the receiving stream or with a significant portion of the receiving stream is essentially instantaneous. These discharges occur in such places as dam tailraces, spillway energy dissipaters, turbine power house and on small streams where the velocity of the discharge creates essentially instantaneous mixing with the entire stream cross section. These cases are prime candidates for increased design flows for the chronic criteria mixing zones. Instantaneous mixing can be created with the use of a properly designed diffuser as well.

Determination of allowable mixing zones is a site specific activity involving professional judgement. A site visit will be required by District staff to assure proper selection of a design stream flow other than the default flow. During the determination, emphasis should be placed on the critical condition. Usually, the low flow situation is most critical. The District reviewer should be looking for mixing rates under the low flow situation and the maintenance of adequate zones of free passage. Reference to the examples provided with this document should be used as a guide.

If the applicant disagrees with the Department's determination then the applicant can prepare a mixing study to support the discharger's request for a larger mixing zone. The Department will review the submitted information and make a determination as to whether the proposed design flow is protective of the environment and can be used in the calculation of chronic criteria effluent limits.

#### **WHAT SITUATIONS ARE EXCLUDED FROM INCREASED MIXING ZONES?**

Some circumstances can be clearly eliminated from consideration. The following cases represent situations in which the Department would disapprove of an increased chronic criteria mixing zone size:

- effluents that have a net attraction to fish or other mobile aquatic organisms;
- mixing zones that interfere with spawning or nursery areas, migratory routes or mouths of tributaries;
- mixing zones that overlap or are adjacent (within 5 stream widths) to one another;
- plumes that hug the shore line;
- mixing zones that do not provide for the free passage of fish and other mobile aquatic life;
- mixing zones that are not as small as possible or where ambient mixing is slow.

#### **DEMONSTRATION TO RECEIVE AN INCREASED MIXING ZONE**

##### Flowing Waters

Discharge applicants requesting an increased mixing zone size after the initial Department determination will need to submit a mixing zone study to the Department for review. Such a mixing zone study must include several key elements. First, it will require a demonstration of how the effluent plume will mix with the receiving water under a variety of conditions to demonstrate which condition is most critical. This must include either dye studies or



plume model results or both. Second, a discussion of stream flow variabilities that may affect the dilution ratio must be included. This will require such information as what fraction of the design flow will be available for instantaneous mixing under various flow conditions. This should also discuss what the discharger will do if river flow is diverted away from the mixing zone area by such things as dam dewatering or lowering of an impoundment for maintenance, shutting off a turbine or any other situation that could alter the flow in the vicinity of the outfall. Thirdly, the discharger should present information on all impeding factors such as spawning or nursery areas, other mixing zones (overlapping or adjacent) in the area or other factors as discussed in the above sections. Lastly, the discharger must demonstrate how the proposed mixing zone will provide a zone of free passage for fish and mobile aquatic organisms. In the case of complete and instantaneous mixing, the Department will assume that since the chronic criteria will be met instantly, the discharge will not present a blockage to migrating aquatic organisms.

#### Discharges to Peaking Dams

This represents a special case that must have the appropriate flow determined for use in the dilution calculation. Peaking dams or sites that are influenced by upstream peaking facilities often have flows that are below the  $Q_{7,10}$  for part of the day when the dam is being run in peaking mode. Under these circumstances, the normal low flow for use in the dilution calculation may not be appropriate. Each facility will have to be examined to determine what information is available. Low flows for use in the dilution calculation could come from Federal Energy Regulatory Commission (FERC) licenses or other minimum flow passage requirements from state laws. Flow records, especially hourly records during drought periods, could also be used to determine realistic low flow values. It is recommended that harmonic means be used if sufficient records are available and if they cover drought periods. For chronic toxicity calculations, a  $Q_{7,10}$  using harmonic means could then be used.

#### Non Flowing Waters

In the case of lake discharges using a diffuser, it will generally be necessary to demonstrate the expected size of the mixing zone by use of a plume model. Lake discharges have the option of a chronic mixing zone defined by a default dilution ratio of 10:1 as explained in NR106.06(3)(b)2 or a dilution ratio achieved at the edge of the discharge induce mixing area. It will be necessary to use a plume model to estimate the size of the "discharge induced mixing area" and the resulting dilution ratio. Several models that are available from EPA and are also described in the "Zones of Initial Dilution" paper are briefly described below.

- CORMIX 1** This model allows simulation of single port diffusers of positively or negatively buoyant plumes and can handle plumes that attach to the bottom, hit the surface or cause recirculation. This model is preferred for dilution calculations were it is applicable.
- CORMIX 2** This model is similar to CORMIX 1 but allows the use of multiple ports. Again this model is preferred for dilution calculations were it is applicable.
- UPLUME** This model is used for a single port discharge in a deep area with no ambient current. The discharge angle may range from -5° to 90° (0° is horizontal). An arbitrary density profile in the ambient water is allowed. Multiple ports are allowed but the calculations ignore merging although the point at which merging occurs is output.
- UOUTPLM** This model is similar to UPLUME except that a constant current speed with depth is allowed and assumed to be perpendicular to the diffuser pipe (i.e. parallel to the port velocity). Merging is again ignored although the point is identified.
- UDKHDEN** This model allows multiple ports and calculates merging effects. Port angles are increased from -5° to 130°. An arbitrary density and flow field are allowed. The flow field may range from 45° to 135° (90° is parallel to the port velocity).
- UMERGE** This model is similar to UOUTPLM except that current velocities may be arbitrary with depth and that merging is considered in the calculations. Current is assumed to be perpendicular to the diffuser.
- ULINE** This model assumes either a slotted diffuser or very closely spaced ports. Discharge angle is fixed at 90°. Density and current velocity are arbitrary with depth and current angle may range from 0° to 180°.

Other well documented plume mixing models may also be used provided the discharger has a copy of the documentation of the model and the model clearly calculates the edge of the discharge induced mixing area. All of the above models are meant to be used with positively buoyant plumes (except CORMIX which can handle either case) which is nearly always the case with an industrial discharge. The applicant will have to choose the

appropriate model to use for their particular situation. Various configurations will have to be explored to identify the critical conditions to be tested. The size of the mixing zone is generally determined by the distance identified in the model output as the edge of the "discharge induced mixing" area.

A number of model runs using various water depths, density gradients and velocity profiles should be considered. The results should include calculations that indicate the dilution achieved as a function of horizontal distance from the diffuser port and the distance to the edge of the discharge induced mixing. The dilution ratio achieved in the model results will be used as the dilution factor for calculation of chronic toxicity limits provided the Department concurs with the modeling results and no other limiting factors are present.

#### Field Studies

Field studies or demonstrations will usually be required to establish the mixing zone in cases where the discharge is on a flowing stream. Under certain conditions, field studies may be the best way to demonstrate the mixing achieved near a particular outfall. Field studies should be conducted as close to the expected design conditions as possible. Field results must be extrapolated to the design conditions whenever necessary. Results of field studies, after extrapolation to the design conditions can be used to establish the dilution ratio for calculation of chronic toxicity limits provided the field test results are approved by the Department. Field studies will be the responsibility of the applicant although the Department will attempt to make available Water Resources or Waste Water staff to be on site during the tests if the applicant requests it. Department employees on site during the field studies will not constitute approval of the field tests.

Results of the field studies should be submitted to the Department (Bureau of Water Resources Management) for review and approval. The submittal must include sufficient information to describe the field study procedure, initial concentrations measured in the effluent pipe throughout the tests, the horizontal gradients measured at various stations, the type of current meter used, the type of dye used and the type of equipment used to measure the dye. If more than one dye measuring device is used for the field studies, calibration of all of the devices to a common response over the observed concentration range of the tests must be included in the submittal.

#### **OTHER INFORMATION THAT MAY BE NEEDED**

In some instances, the description of the discharge site may be sufficient to determine the size of the mixing zone. Discharges to small streams where mixing is extremely rapid or discharges in the tailrace of a dam are examples. These situations may only need some detailed information on the discharge location and characteristics for the Department to be able to determine mixing zone size. Information that will be needed may be site specific but should include such items as the dimensions of the outlet pipe, receiving stream morphology, stream velocity, discharge velocity, percentage of stream flow at the outfall site during various flow conditions (especially low flows) and potential "lack of stream flow" situations. Consideration of impeding factors must also be included.

#### **APPROVAL OF THE MIXING ZONE FOR USE IN THE PERMIT**

The results of the model runs or field tests along with the other required information should be submitted to the Water Quality Modeling Unit in the Bureau of Water Resources Management for review and approval. Following review of the submitted information, the Department will either approve the requested mixing zone for use in the calculation of chronic toxicity limits or state the reason for denial of the request to the applicant. All submittals and subsequent approval/denials will become part of the permit issuance briefing package sent to EPA for final permit concurrence. A record of the submittals and correspondence will be made a part of the applicants permit file as well.

## CHRONIC MIXING ZONE - REFERENCES

- U.S. EPA "Initial Mixing Characteristics of Municipal Ocean Discharges - Volume I - Procedures and Applications", EPA-600/3-85-073a, Newport, OR, November, 1985.
- U.S. EPA "Initial Mixing Characteristics of Municipal Ocean Discharges - Volume II - Computer Programs", EPA-600/3-85-073b, Newport, OR, November, 1985.
- U.S. EPA "Technical Support Document for Water Quality Based Toxics Control", EPA-440/4-85-032 Athens, GA, September, 1985.
- U.S. EPA "Mixing Zones" chapter in Water Quality Standards Criteria Summaries: A Compilation of State/Federal Criteria Volume II. Athens, GA, September, 1980.
- U.S. EPA Water Quality Standards Handbook. Athens, GA, Draft September, 1984.
- U.S. EPA Water Quality Criteria (Green Book), April, 1968.
- U.S. EPA Water Quality Criteria 1972 (Blue Book), EPA-r3-73-033, Athens, GA, March, 1973.
- Webb,P.W. "Hydrodynamics and Energetics of Fish Propulsion", Bulletin of the Fisheries Research Board of Canada, Bulletin 190, Ottawa Canada, 1975.

## CHRONIC MIXING ZONE - CHECKLIST

The following checklist provides quick answers to many of the questions concerning the proper size of the mixing zone to be used for calculation of chronic toxicity effluent limits. This checklist should be used as a starting point to determine if a mixing zone larger than the default size could be allowed. This checklist will give an indication of whether an increased mixing zone size is possible, but added analysis will be required prior to a final determination. The initial analysis will be done by Department staff. The discharger may submit additional studies and information to the Department before and after the initial mixing zone determination.

### 1. Type of receiving water?

non flowing	Mixing zone either 10:1 or based on "discharge induced mixing" from an approved plume model study.
flowing stream: single channel	Mixing zone based on 1/4 of design stream flow or may be eligible for up to 100% of design flow under approved conditions.
flowing stream: multi channel	Mixing zone based on 1/4 of the portion of the design flow carried by the channel receiving the effluent. May be eligible for up to 100% of that flow under approved conditions.
flowing stream: regulated flow from dam operation	Mixing zone based on 1/4 of the "frequently observed" or Federal Energy Regulatory Commission required minimum flow or up to 100% of that flow under approved conditions.
flowing stream: peaking facility	Mixing zone based on 1/4 to 100% of the low flow. The low flow could be based on harmonic means for 7 day, 10 year lows, FERC or State requirements or other appropriate low flow.

### 2. What conditions exclude larger mixing zones?

general	<ul style="list-style-type: none"> <li>-- effluent plumes that attract fish</li> <li>-- mixing zone adjacent to spawning or nursery area</li> <li>-- adjacent to swimming beach</li> <li>-- mixing zones that overlap</li> </ul>
non flowing water	<ul style="list-style-type: none"> <li>-- shoreline discharge</li> <li>-- surface discharge</li> <li>-- threatened or endangered species present</li> <li>-- shallow areas (&lt; 10 feet)</li> </ul>
flowing waters	<ul style="list-style-type: none"> <li>-- plumes that hug the shore</li> <li>-- mixing zones that do not provide a zone of free passage</li> </ul>

### 3. Conditions where larger mixing zones are allowed.

non flowing water	All stated requirements are met and "discharge induced mixing" results in greater than 10:1 dilution (a plume model is required to demonstrate this).
flowing water	<p>Up to full design flow can be used, as determined by a site visit, if immediate complete mixing occurs such as:</p> <ul style="list-style-type: none"> <li>-- through a turbine</li> <li>-- dam tailrace</li> </ul> <p>Note: The number of turbines and the location of the effluent pipe will determine if the full design flow can be used.</p> <ul style="list-style-type: none"> <li>-- other high turbulence area</li> </ul>

- effluent plume mixed from shore to shore in less than one stream width downstream (for use when stream width at  $Q_{7,10}$  is less than 100 feet).

More than 1/4 of the design flow can be used if the effluent pipe uses a diffuser to obtain complete mix with a significant portion of the design flow.

4. Who makes the determination on mixing zone size?

Department's role

The Department will make an initial determination, based most often on a site visit and professional judgement, as to what mixing zone size should be used. The District will perform the site visit to view the existing or proposed discharge situation. They will make a determination and submit it to the Bureau of Water Resources Management along with supporting information. The initial determination will be used when calculating chronic toxicity effluent limits for the permit that is publicly noticed.

Discharger's role

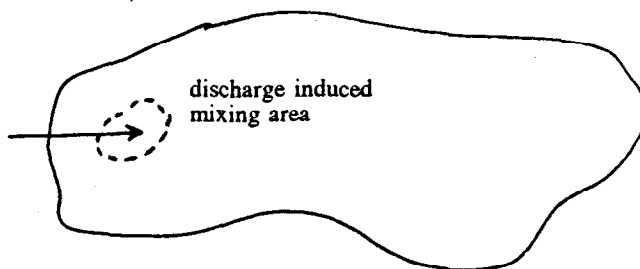
The discharger may wish to supply additional information to support a larger mixing zone especially if they disagree with the Departments determination or to aid in the initial determination. They can begin gathering this information whenever they desire and submit it prior to the end of the public noticed comment period to the Bureau of Water Resources Management. The Bureau of Water Resources Management will review the submitted information and adjust the mixing zone size if appropriate.

## CHRONIC MIXING ZONE - EXAMPLES

The best way to illustrate the determination of the design flow for mixing zone determinations is with the use of several examples. Six types of discharge situations are illustrated below. In all examples except number 1, the design flow refers to either the  $Q_{7,10}$  or the biologically based design flow.  $Q_c$  refers to the flow used to calculate the dilution ratio.

1. Non flowing receiving waters (ie lakes and backwaters)

default dilution  
ratio = 10:1

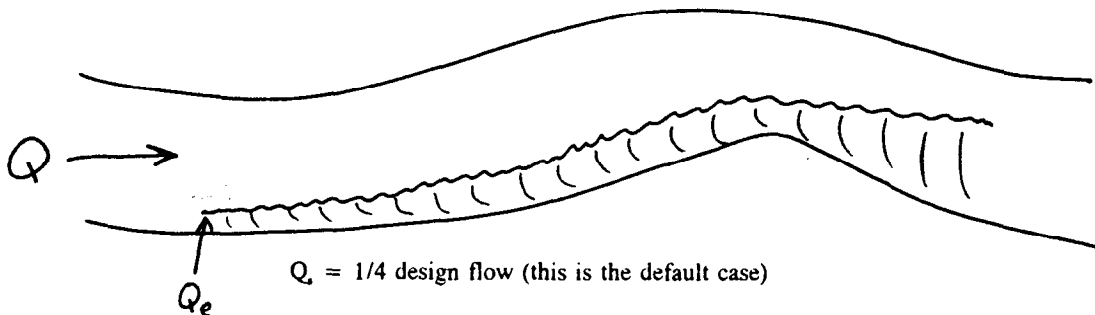


submerged diffuser  
in 10 feet of water

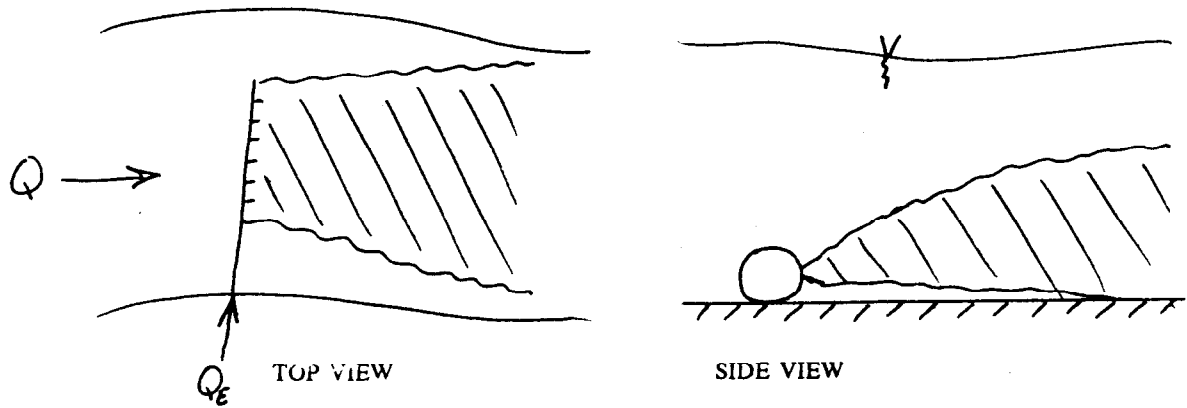
dilution ratio = 17:1 from a plume model  
study submitted by the discharger

This case shows a lake discharge in 10 or more feet of water that is off shore and submerged. The site visit would have to determine if spawning, nursery or swimming areas will touch or overlap the mixing zone and if threatened or endangered aquatic species are present. If the site passes these tests, than the 17:1 dilution ratio could be applied instead of the default 10:1.

2. Flowing stream with a shoreline discharge that hugs the shore.



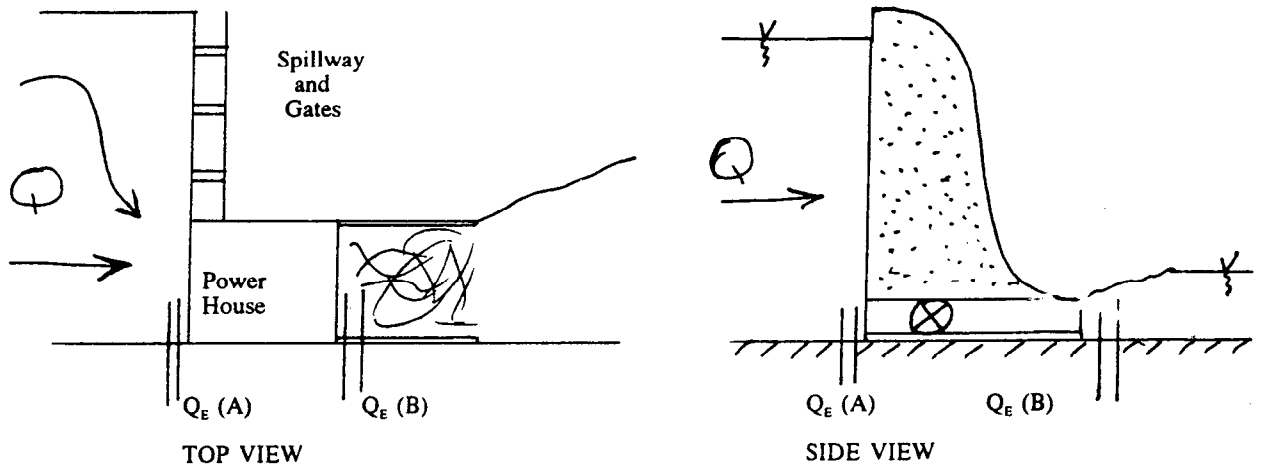
3. Flowing stream with effluent plume dispersed from a multiport diffuser with ports that cover up to 1/2 of the stream width. NOTE: The diffuser ports should not go beyond 1/2 of the stream width to allow for a "zone of free passage".



$$1/4 \text{ design flow} < Q_e < 1/2 \text{ design flow or more}$$

Up to 1/2 or more of the design flow could be used depending on the ratio of flow over the diffuser to flow in the whole channel. The site visit determination will be based on this factor and judgement. A more exact determination will require a plume model or dye study by the discharger.

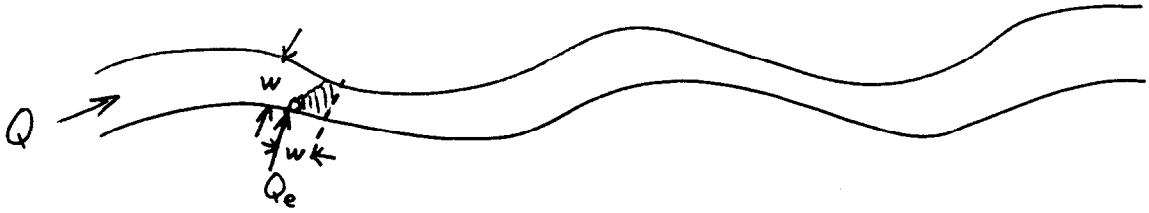
4. Discharge pipe directly in front of a turbine inlet or in the dam tailrace.



$$Q_e = 1.0 \text{ design flow}$$

The design flow may need to account for the operation of more than one turbine, leakage through the dam gates or other flow diversions. Dams operated or influenced by peaking operations may need to have low flow estimates based on regulatory requirements or harmonic means if data is available.

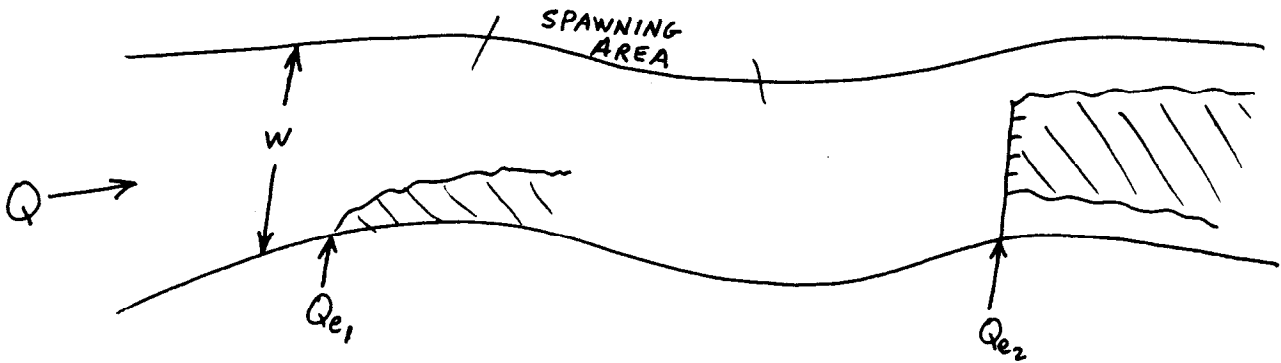
5. Discharge is on a stream that is less than 100 feet wide.



If mix point (shore to shore) is less than 1 stream width downstream and all other conditions are met than:

$$Q_i = 1.0 \text{ design flow}$$

6. Discharge from a multiport diffuser on a flowing stream with another mixing zone nearby.



If mixing zone is adjacent to a spawning, nursery or swimming area or near (less than 5 stream widths) from another mixing zone than:

$$Q_i = 1/4 \text{ design flow}$$



## ACUTE TOXICITY - ZONES OF INITIAL DILUTION

This document is meant to be used to give guidance to discharge permit applicants on how to apply for the use of a Zone of Initial Dilution or ZID. Chapter NR106 allows the use of a ZID for rapidly mixing a discharge plume with the receiving water so as to prevent acute toxicity to fish and aquatic life as specified in NR105.05. The guidance contained herein is meant to be advisory only, and reflects the current thinking of the Bureau of Water Resources Management on which cases merit the use of a ZID and which don't. In developing this document, protection of the receiving water for fish and aquatic life was the primary consideration. A ZID checklist is attached to the end of this paper that can be used by a discharger to quickly determine if a ZID option is worth pursuing.

### REGULATORY AUTHORITY FOR ZONES OF INITIAL DILUTION

The following list explains the legal requirements for zones of initial dilution. This list only includes items that are covered in the Natural Resources codes. To better understand the following regulations two definitions are needed:

Acute Toxicity Criteria or "ATC" means the maximum daily concentration of a substance which ensures adequate protection of sensitive species of aquatic life from acute toxicity of that substance.

Final Acute Value or "FAV" is meant to approximate the concentration equivalent of an  $LC_{50}$  or  $EC_{50}$ . An adverse effect including mortality will occur to 50% of the exposed organisms at this concentration in a given time period.

- NR102.05(3)(d) FAV not to be exceeded anywhere in the chronic mixing zone. This implies that acute toxicity that is related to water quality parameters must be accounted for as the water quality parameters are diluted inside the chronic mixing zone.
- NR106.06(2)(b) FAV at "end of pipe" except for ZID area.
- NR106.06(2)(c) FAV can be exceeded if the ATC is met at the edge of the ZID.
- NR106.06(2)(c)1 Discharges at the shoreline or water surface cannot have a ZID.
- NR106.06(2)(c)2 The discharge cannot be a dominant portion of the stream flow.
- NR106.06(2)(c)3 Discharge velocity must exceed 3 meters per second (10 feet/second).
- NR106.06(2)(c)4 ZID must be no more than 10% of chronic mixing zone distance.
- NR106.06(2)(c)5 ZID must be no more than 50 times the square root of the cross sectional area of the port.
- NR106.06(2)(c)6 ZID must be no more than 5 times the local water depth.
- NR105.05(2)(f)6 ATC equals 1/2 of the FAV for chemical specific aquatic life criteria.
- NR106.09(1)(c)1 No lethality at edge of ZID for whole effluent limits.
- NR106.09(1)(c)2 Whole effluent concentrations must not exceed  $1/3 LC_{50}$  at the edge of the ZID.

### WHAT IS A ZONE OF INITIAL DILUTION?

A zone of initial dilution or ZID is defined as a small area in the immediate vicinity of an outfall structure in which turbulence from the effluent velocity is high and causes rapid mixing with the surrounding water. Turbulence for rapid mixing can be provided in three ways. The most common way is with the use of an effluent diffuser. This method assures adequate velocities and mixing if it is properly designed for the discharge area. The second method makes use of instream conditions in special cases where very high velocities can be guaranteed under all conditions. The third way makes use of a direct discharge into the inlet of a turbine. Rapid and complete mixing will occur as the water goes through the turbine to satisfy the ZID requirements. Flow dilution under these circumstances will be limited to use of 1/2 of the design low flow appropriate for that site. The low flow will be determined similarly to the design flow determined for a chronic mixing zone. This can include  $Q_{7,10}$ , legally mandated minimum flow passage at the dam or harmonic mean low flow if sufficient data is available.

The Acute Toxicity Criteria (ATC) must be met everywhere outside the ZID. For substances identified in Chapter NR105.05, the ATC is 1/2 of the Final Acute Value (FAV) as defined in NR105. For whole effluent limits, the ZID must dilute the effluent to 1/3 of the whole effluent acute toxicity defined in NR106.09. In simple terms, the edge of the ZID must achieve sufficient dilution to be no greater than an  $LC_1$ . The FAV in NR105 is intended to represent the  $LC_{50}$  and is assumed to be two times the  $LC_1$  for chemical specific and three times the  $LC_1$  for whole effluent limitations.

The velocity of the discharge must be high enough in the ZID to provide sufficient energy for rapid mixing to occur and also to prevent aquatic organisms from prolonged exposure in the ZID. EPA guidance in the Technical Support Document for Water Quality-based Toxics Control supports a minimum velocity of 3 meters/sec (10 ft/sec) for ZIDs that are based on the use of a diffuser outfall. This requirement was made a part of NR106 as well. Ten feet per second should impart sufficient momentum to the effluent to provide for the creation of intense turbulence that is needed to enhance rapid mixing. It should also be sufficient to prevent fish from being able to hold position in the ZID where acute toxicity may be exceeded. In setting the recommended effluent velocity, the maximum burst speed and maximum sustainable speeds of fish were considered.

For ZIDs based on instream velocity, the maximum sustainable swimming speed is the most important factor. Five feet per second receiving water velocities are suggested for this requirement. The discharger will need to demonstrate that the site specific situation will assure minimal organism exposure time as required under NR106.06(2)(c)3. The discharger will further have to demonstrate the dilution rate and ZID radius achieved through the use of field studies since plume models are not applicable for these circumstances.

#### **HOW IS THE SIZE OF A ZID DETERMINED?**

The size of the ZID is limited by several restrictions in NR106 as well as other common sense considerations that may be revealed by plume models or field tests such as dye studies. Most ZIDs will be on the order of a few meters in radius which is many times smaller than the chronic mixing zone used to protect fish and aquatic life from chronic impacts. Since acute toxicity criteria may be exceeded inside the ZID it is important to limit the size to a very small area. NR106 sets up three factors that directly limit the radius of the ZID.

The first factor that limits the radius of a ZID is related to the size of the discharge ports. The ZID is restricted to 50 times the discharge length scale in any direction. The discharge length scale is defined as the square root of the cross sectional area of the discharge port. The length scale is determined for each port on a multi-port diffuser. This calculation is frequently the limiting factor as can be illustrated. A diffuser with 6" ports will have a ZID limited to 22 feet or roughly 7 meters. It is likely that many dischargers will have even smaller port diameters to maintain discharge velocity at ten feet per second at all times.

The second factor is dependant on the local water depth. The ZID radius must be no larger than 5 times the local water depth. The local water depth should be determined prior to construction of the diffuser outfall. The depth should be adjusted to correspond to the low flow condition when  $Q_{7,10}$  is occurring. For lake or impoundment discharges, the local water depth should be based on a low water datum if it is available. The low water datum is normally not the lowest observed water level but rather some statistically defined exceedence level such as the 90% level or the 10 year low water level. If none of these levels are available then the Department will choose a low water level based on the known range of water levels and the lowest known water mark.

The third factor requires that the radius of the ZID be less than one tenth of the distance to the nearest edge of the chronic mixing zone. This criteria has been difficult to interpret especially in situations where the diffuser used for a ZID application is also used to substantiate the use of more than 1/4  $Q_{7,10}$  for the chronic mixing zone. For future submittals the Department will interpret this criteria in the following way:

When the chronic mixing zone uses the default value of 1/4 of the  $Q_{7,10}$ , then the ZID radius must be no more than 10% of 1/4 of the stream width.

When the chronic mixing zone uses between 1/4 and 1/2 of the  $Q_{7,10}$ , then the ZID radius must be no more than 10% of whatever percent of the stream width is used for the chronic mixing zone.

When the chronic mixing zone uses more than 1/2 of the  $Q_{7,10}$ , then the ZID radius must be no more than 10% of 1/2 of the stream width.

ZID radius calculation examples:

Stream width = 300 feet  
Chronic mixing zone uses default flow

Port Diameter = 3 inches  
Water Depth = 4 feet  
ZID radius: 50 times length scale = 11.1 feet  
5 times local depth = 20 feet  
10% criteria = 1/10 of 1/4 of 300 feet or 7.5 feet  
Limiting ZID radius is therefore 7.5 feet.

Stream width = 300 feet  
Chronic mixing zone uses  $1/2 Q_{7,10}$  based on 100 ft diffuser  
Port Diameter = 3 inches  
Water depth = 4 feet  
ZID radius: 50 times length scale = 11.1 feet  
5 times local depth = 20 feet  
10% criteria = 1/10 of 1/2 of 300 feet or 15 feet  
Limiting ZID radius is therefore 11.1 feet.

Stream width = 800 feet  
Chronic mixing zone uses default flow  
Port Diameter = 6 inches  
Water Depth = 6 feet  
ZID radius: 50 times length scale = 22.2 feet  
5 times local depth = 30 feet  
10% criteria = 1/10 of 1/4 of 800 feet or 20 feet  
Limiting ZID radius is therefore 20.0 feet.

Stream width = 800 feet  
Chronic mixing zone uses  $1/3 Q_{7,10}$  based on 200 ft diffuser  
Port Diameter = 6 inches  
Water Depth = 6 feet  
ZID radius: 50 times length scale = 22.2 feet  
5 times local water depth = 30 feet  
10% criteria = 1/10 of 1/3 of 800 feet or 26.7 feet  
Limiting ZID radius is therefore 22.2 feet

Stream width = 50 feet  
Chronic mixing zone uses default flow  
Port Diameter = 1 inches  
Water Depth = 3 feet  
ZID radius: 50 times length scale = 3.7 feet  
5 times local depth = 15 feet  
10% criteria = 1/10 of 1/4 of 50 feet or 1.25 feet  
Limiting ZID radius is therefore 1.25 feet.

Stream width = 50 feet  
Chronic mixing zone uses  $3/4 Q_{7,10}$  based on 20 ft diffuser  
Port Diameter = 1 inches  
Water depth = 3 feet  
ZID radius: 50 times length scale = 3.7 feet  
5 times local depth = 15 feet  
10% criteria = 1/10 of 1/2 of 50 feet or 2.5 feet  
Limiting ZID radius is therefore 2.5 feet.

Note: Diffusers are limited to no more than 50% of the stream width to maintain zones of free passage as required under NR102.05(3)(c).

For comparison, the ZID radius for common port sizes using the discharge length scale (50 times the square root of the port cross sectional area) are as follows:

Port Diameter Inches	ZID Radius Feet
.5	1.85
1	3.70
2	7.4
3	11.1
4	14.8
5	18.5
6	22.2
8	29.5
10	36.9
12	44.3

This type of calculation can also be applied to receiving waters that do not exhibit a unidirectional flow. In those cases, the chronic mixing zone is defined as the point at which a 10 to 1 dilution is achieved or at the edge of the discharge induced mixing area. The ZID would then be limited to one tenth of that distance. ZIDs in these situations may be limited for other reasons discussed later.

Additional factors not mentioned in NR106 may also limit the radius of the ZID. These factors are derived through the use of a plume model. It will be necessary to predict the performance of the ZID by the use of a plume model especially if a diffuser is used. Several models are available and are demonstrated in EPA document 600/3-85/073a and b. These models can be used for a variety of conditions ranging from zero velocity to an ambient current and can account for multi port diffusers in stratified or unstratified receiving waters. The results of the models can be scanned for limiting factors such as when the plumes intersect the surface of the water, interact with the bottom or when plumes merge in a multi port diffuser. These conditions all limit the effective size of immediate mixing and will therefore also limit the radius of the ZID.

After all of the above factors have been calculated, the most restrictive distance will determine the size of the ZID for a given situation. That ZID size must then be used with models or field studies to estimate the rate of dilution achieved. The dilution rate must be designed to account for the critical design conditions that may be encountered as discussed below.

#### WHAT OTHER RESTRICTIONS LIMIT THE USE OF A ZID?

A few other restrictions need to be considered before use of a ZID can be approved. NR106 restricts the use of a ZID in cases where the discharge is on shore or at the surface of the receiving water. Furthermore the effluent should not dominate the flow in the receiving water. As a rule of thumb, the effluent should be no more than 10% of the  $Q_{7,10}$  measured upstream of the discharge site. (Note: The TSD recommends 1% as effluent dominated)

The use of a ZID will also not be allowed in situations where the receiving water exhibits frequent periods of very low or no velocity. This condition is usually encountered with lake discharges. This restriction does not apply when the point of discharge is sufficiently deep that a stable thermocline is normally found during summer months. The rationale for these restrictions are based on the likelihood of concentration buildups in the vicinity of the discharge point if no ambient flow field is present to bring in new water. This will be especially true in the vicinity of discharges in shallow water and may even be cause to limit such discharges to the ATC at end of pipe to prevent the buildup of acute toxicity. This restriction can be removed when sufficient depth is present. The rule of thumb is based on sufficient depth to support a stable thermocline. Under these conditions, plumes which are nearly always buoyant (especially in the hypolimnion) will have sufficient vertical mixing to prevent the buildup of acute concentrations as the plume rises. These factors can be demonstrated by the use of the above mentioned plume models. Modeling studies would therefore be required for such a design.

ZIDs cannot under any circumstances be used to reduce effluent restrictions for substances which bioaccumulate or are persistent in the environment. ZIDs are most effective for dealing with acutely toxic substances that degrade, transform or otherwise leave the aquatic environment. In general, if a substance is of concern in the "far field" in the aquatic environment, then a ZID can not be used to reduce effluent restrictions for that substance.

Many substances display toxicity that varies depending on the condition of the receiving water. In particular, hardness, temperature and pH may be directly related to the toxicity of some substances. If a ZID is used, care must be taken to assure that background parameters in combination with more dilution outside of the ZID will not recreate acute toxicity in a region away from the ZID. Dilution calculations that include the background water

quality parameters must be made to demonstrate that this will not happen.

#### **HOW IS THE ZID DILUTION FACTOR CALCULATED?**

ZID dilution ratios will be limited to no more than 1/2 of the design low flow at the site of the discharge to dilute acute toxicity. This will assure that under the worst case river flow and discharge situation, the whole river can not approach the acute toxicity threshold. In addition, acute toxicity can have impacts on as little as a 1 hour exposure period (Technical Support Document). For practical purposes, daily composite concentration measurements and daily river flows make daily averages the shortest period that can be used for compliance purposes. However, effluent concentrations are known to vary on short time scales. Therefore, limiting use of only 1/2 of the design low flow for dilution calculations seems prudent to protect against short period acute toxicity exposures.

The dilution factor calculated for a ZID will be determined by the type of ZID being designed. Modeling studies will be required for ZID's using a high rate diffuser in either river or lakes. For river situations, the model will need to have a river flow rate over the diffuser specified. This flow rate must reflect only the flow of the river that passes over the diffuser for the design low flow situation and in no case can it be more than 1/2 of the design low flow at the site of the diffuser. Effluent flow rate should be the 2% exceedance flow from the discharger. For ZID's using a turbine inlet or dam tailrace to obtain rapid mixing, the dilution ratio will be calculated using 1/2 of the specified design low flow and the 2% exceedance flow from the discharger. For lake situations, the dilution factor will be calculated by the model. The results will need to be reviewed to assure they are realistic and do not over estimate dilution due to model assumptions of infinite amounts of water available when large scale recirculations might be occurring. The CORMIX 1 and 2 models may be best for these calculations.

#### **WHAT FACTORS MUST BE CONSIDERED DURING USE OF A ZID?**

If a permit holder has successfully obtained a ZID, they must demonstrate that the ZID will be functional during all potential conditions of discharge. For the use of a diffuser, this will mean the use of a design such that the minimum discharge port velocity can be maintained at all times. This may require special considerations to handle shutdowns and start up periods in the plant and periods of partial production. In general, the best situation will have infrequent starts and stops of the use of the diffuser.

For the case where the ZID depends on the river flow, the minimum velocity must be exceeded for all flows above the  $Q_{7,10}$  and all conditions of turbine or dam operation in the case of a tailrace discharge. Contingencies for stopping discharge or meeting limits that do not incorporate the ZID if sufficient velocity is not maintained must be considered.

#### **Effluent Velocity Requirements**

The use of a high rate diffuser to obtain a ZID requires that the discharger maintain a minimum port velocity of 10 feet per second. This requirement is interpreted as "all times" that the diffuser is in operation. Operation of the diffuser does allow for "infrequent" starts and stops that may occur over the course of a year such as for holiday shut downs and plant maintenance. Velocities during these short periods can be below 10 feet per second. Most diffusers operate as a series of fixed port areas so the port velocity is a direct result of the flow rate divided by the total port cross sectional area. The flow rate that results in 10 feet per second port velocity determines the minimum flow for ZID use. The ZID application must demonstrate that the effluent flow will exceed this minimum rate 98% of the time.

The Department will require a flow distribution analysis with future ZID applications to determine the minimum ZID design flow. This analysis should cover a sufficient period of time to overlap all configurations of the plants operations. A period of 2 years or more is suggested as a sufficient period of time. Shorter periods should be used only if plant modifications have taken place that have substantially altered the flow distribution of the plant. The flow distribution should establish the total daily discharge flow that will be expected on a percent exceedance basis. The diffuser must be designed to maintain 10 feet per second for the 98% exceedance flow (flow that is exceeded 98% of the time) or other appropriate flow determined by the Department on the basis of the flow distribution data submitted by the discharger.

Modifications to the plant during the life of a permit may require a permit modification on the use of the ZID if the flow distribution is altered. Continued use of a ZID will at a minimum require a review of the most current flow distribution during the permit reissuance which occurs at least every five years.

Discussions between the Bureaus of Water Resources Management and Wastewater Management have concluded an agreement that permittees who qualify for the use of a zone of initial dilution (ZID) should be required to maintain a minimum wastewater discharge velocity of 10 feet per second (ft/s). The permit language will contain the following concepts:

- o That the daily average discharge velocity not fall below 10 ft/s.
- o That exceptions to the daily average discharge velocity limitation be allowed under the following circumstances:
  - o The total daily flow is zero;
  - o During shutdown and start-up of production if production is completely curtailed;
  - o During scheduled maintenance or emergency repairs of the wastewater treatment system; or
  - o If the permittee demonstrates compliance with all water quality based effluent limitations that are necessary in the absence of a ZID.
- o That the permittee be required to report the total time (minutes per day) that the instantaneous discharge velocity falls below 10 ft/s, or, alternately, the instantaneous discharge flow (gpm) falls below that value which corresponds to a discharge velocity of 10 ft/s. This information will be used by the Bureau of Water Resources Management to reevaluate the permittee's qualification for use of a ZID.

#### DEMONSTRATIONS NEEDED TO RECEIVE A ZID

A permit holder or new applicant should include the request for a ZID as part of the permit application. This request will alert permit drafters of the expected ZID study that may have impacts on the calculated requirements for acute toxicity limits. The permit applicant will receive this guidance paper to evaluate their particular discharge circumstances and make a determination whether they want to pursue a ZID modeling or field study. Specific questions can be referred to the Water Quality Modeling and Analysis Unit in the Bureau of Water Resources Management by calling (608-267-7610).

A permit holder or applicant must demonstrate to the Department that the use of a ZID will be environmentally acceptable for their discharge site. This could require the use of plume models, field studies or both. Also, if an alternative discharge velocity is requested or the ZID depends upon instream velocities, the discharger must demonstrate that the proposed ZID will cause minimal organism exposure. These demonstrations must clearly identify the critical conditions under which the ZID must operate and identify how the ZID will operate during periods of shutdown and startup as described in the previous section.

#### Modeling Dilution Studies

In the case of ZIDs using a diffuser, it will generally be necessary to demonstrate the expected performance of the ZID by use of a plume model. In many cases this will be essential since construction of the diffuser may be contingent on approval of the ZID. The documents referred to above make available 5 different plume models that may be selected for the appropriate conditions. The models are briefly described below.

- CORMIX 1** This model allows simulation of single port diffusers of positively or negatively buoyant plumes and can handle plumes that attach to the bottom, hit the surface or cause recirculation. This model is preferred for dilution calculations were it is applicable.
- CORMIX 2** This model is similar to CORMIX 1 but allows the use of multiple ports. Again this model is preferred for dilution calculations were it is applicable.
- UPLUME** This model is used for a single port discharge in a deep area with no ambient current. The discharge angle may range from -5° to 90° (0° is horizontal). An arbitrary density profile in the ambient water is allowed. Multiple ports are allowed but the calculations ignore merging although the point at which merging occurs is output.
- UOUTPLM** This model is similar to UPLUME except that a constant current speed with depth is allowed and assumed to be perpendicular to the diffuser pipe (ie parallel to the port velocity). Merging is again ignored although the point is identified.
- UDKHDEN** This model allows multiple ports and calculates merging effects. Port angles are increased from -5° to 130°. An arbitrary density and flow field are allowed. The flow field may range from 45° to 135° (90° is parallel to the port velocity).
- UMERGE** This model is similar to UOUTPLM except that current velocity may be arbitrary with depth

and that merging is considered in the calculations. Current is assumed to be perpendicular to the diffuser.

ULINE This model assumes either a slotted diffuser or very closely spaced ports. Discharge angle is fixed at 90°. Density and current velocity are arbitrary with depth and current angle may range from 0° to 180°.

Except for CORMIX 1 and 2, all of the above models are meant to be used with positively buoyant plumes which is nearly always the case with an industrial discharge. The applicant will have to choose the appropriate model to use for their particular situation. Various configurations will have to be explored to identify the critical conditions to be tested. The size of the ZID to be considered should be established by considering the factors that were identified above. During the model test, any surface, bottom or merging that further limits the size of the ZID will have to be identified and used as a limiting factor.

A number of model runs using various density gradients and velocity profiles must be considered. The results should include calculations that indicate the dilution achieved as a function of horizontal distance from the diffuser port. At the edge of the most limiting ZID size, the lowest dilution achieved in the model results will be used as the dilution factor for calculation of acute toxicity limits.

The model results should be submitted to the Department for review and approval. The submittal should include the results of all discharge configurations simulated, the depth, flow and temperature fields assumed for various conditions, the critical design condition, and calculated dilution rates with distance from the discharge point for several conditions including the critical condition. At least one model run should have the design low flow specified such that the flow over the diffuser represents the portion of the river covered by the diffuser and in no case should that exceed 50% of the design low flow. In addition, the type of model used, the input data set used for all runs and all assumptions in the model parameters must be justified and documented.

#### Field Dilution Studies

ZIDs that depend on instream velocity rather than a diffuser must be demonstrated through the use of field studies. Certain situations where a diffuser already exists may also be demonstrated with field studies rather than model results if the applicant so chooses. Extension of field studies to untested discharge configurations, locations or diffuser designs will not be accepted. New or proposed configurations must be studied with plume models.

Field studies should be conducted as close to the expected design conditions as possible and must be extrapolated to the critical design conditions whenever necessary. Results of field studies, after extrapolation to the design conditions can be used to establish the dilution ratio for calculation of acute toxicity limits provided the field test results are approved by the Department. Field studies will be the responsibility of the applicant although the Department will attempt to make available Water Resources or Waste Water staff to be on site during the tests if the applicant requests it. Department employees on site during the field studies will not constitute approval of the field tests.

Field studies should be conducted using appropriate dye techniques using continuous injection for steady state analysis during the test. Initial concentrations should be measured after mixing with the effluent at the site that will be used for normal discharge monitoring if possible. Continuous measurement of the receiving water should be made at the calculated most limiting ZID size, .7 times that size and 1.3 times that size to demonstrate the presence of continued mixing. The continuous monitoring should be mobile and moved until maximum concentrations are found at each distance. The depth of the monitor should be at the maximum concentration established by measuring at the surface and continuously downward to just off the bottom. Maximum concentration at the calculated ZID size is used to establish the dilution ratio.

Results of the field studies should be submitted to the Department for review and approval. The submittal must include sufficient information to describe the field study procedure, initial concentrations measured in the effluent pipe throughout the tests, the vertical and horizontal gradients measured at each of the required distances, the type of dye used and the type of equipment used to do the measurements. If more than one measuring device is used for the field studies, calibration of all of the devices to a common response over the observed concentration range of the tests must be included in the submittal. Finally, the results of the tests must be compared and extrapolated to the critical design condition for calculation of the dilution rate for the ZID.

#### **APPROVAL OF THE ZID FOR USE IN THE PERMIT**

The results of the model runs or field tests should be submitted to the Water Quality Modeling and Analysis Unit in the Bureau of Water Resources Management for review and approval. Following review of the submitted information, the Department will either approve the requested ZID, modify the study results and approve an

alternate ZID or state the reason for denial of the request to the applicant. If a ZID is approved, any acute toxicity effluent limits will be recalculated based on the approved dilution rate. All submittals and subsequent approval/denials will become part of the permit issuance briefing package sent to EPA for final permit concurrence. A record of the submittals and correspondence will be made a part of the applicants permit file as well.



## ZONES OF INITIAL DILUTION - REFERENCES

- U.S. EPA "Initial Mixing Characteristics of Municipal Ocean Discharges - Volume I - Procedures and Applications", EPA-600/3-85-073a, Newport, OR, November, 1985.
- U.S. EPA "Initial Mixing Characteristics of Municipal Ocean Discharges - Volume II - Computer Programs", EPA-600/3-85-073b, Newport, OR, November, 1985.
- U.S. EPA "Technical Support Document for Water Quality Based Toxics Control", EPA-440/4-85-032 Athens, GA, September, 1985.
- Webb, P.W. "Hydrodynamics and Energetics of Fish Propulsion", Bulletin of the Fisheries Research Board of Canada, Bulletin 190, Ottawa Canada, 1975.

## ZONES OF INITIAL DILUTION - CHECKLIST

By working through the following checklist, a discharger can quickly determine if they should pursue a request for a ZID for use in diluting acute toxicity.

### 1. Present or planned effluent pipe configuration.

shoreline discharge

no ZID allowed

discharge at water surface

no ZID allowed

submerged pipe or diffuser with port velocity less than 10 feet per second

ZID may be allowed under some conditions. Will require field dilution studies and an organism exposure study.

submerged pipe or diffuser with port velocity greater than 10 feet per second at all times

ZID is allowed in flowing streams and some non flowing situations. Dilution must be demonstrated with a plume model or field studies.

discharge into dam head or tailrace

ZID is allowed using 1/2 design flow if discharge is very close to turbine inlet. Contingencies must deal with turbine shutdown.

### 2. What type of receiving water will receive the effluent?

flowing stream:

ZID allowed if effluent does not dominate at  $Q_{7,10}$ .

flowing stream with stream velocity always above 5 feet per second near effluent pipe:

ZID allowed if effluent does not dominate at  $Q_{7,10}$  and dilution demonstrated with field studies and an organism exposure study is done.

non flowing waters:

ZID may be allowed only if depth of water is sufficient to allow thermocline to develop and discharge is through a diffuser at 10 feet per second.

dam head or tailrace

ZID allowed if effluent does not dominate design low flow. Design flow may be less than  $Q_{7,10}$  for peaking dams.

3. If an organism exposure study is needed for the effluent pipe configuration or receiving water type, what must be included?
- |  |  |
|--|--|
| effluent velocity less than 10 feet per second:          | study must show that drift through time for non swimming organisms does not exceed maximum exposure time. Also must show that fastest swimming fish (type and year class) in the receiving water could not hold position in the ZID longer than maximum exposure time regardless of whether or not the fish will tend to avoid the effluent plume. |
| receiving water velocity always above 5 feet per second: | same as above  |
4. Determine the maximum radius of the ZID.
- |   |   |
|---|---|
| choose the smallest of the following factors: | --10% of distance to edge of chronic mixing zone.   |
|   | --5 times the minimum local water depth.  |
|   | --50 times the discharge length scale.  |
|   | --distance where a plume model or field studies show that the plume interacts with the bottom, surface or merges with plumes from adjacent ports. |
5. Establish the dilution ratio.
- |   |   |
|---|---|
| diffuser in place and port velocity exceeds 10 feet per second: | use appropriate plume model to calculate critical condition and dilution ratio but limited to ratio of 1/2 of design low flow of receiving water divided by 2% exceedance flow from the discharger. |
| diffuser proposed for the site:                                 | use appropriate plume model as above.   |
| discharge into head or tailrace of a dam:                       | dilution is limited to 1/2 low flow of receiving water divided by 2% exceedance flow from the discharger.   |
| receiving water above 5 feet per second:                        | conduct dye studies (and plume models as needed).   |
6. Determine contingencies for diffuser shutoff and start up or flow velocities.
- |  |   |
|--|---|
| shutdown and start up:   | should be rapid and infrequent.   |
| receiving water flow diverted, turbine not operating or below minimum ZID velocity (for ZIDs dependant on receiving water velocity above 5 feet per second): | discharger should be prepared to meet limits as if no ZID was in place. |

**Effluent Flows to use for ZID and Chronic Mixing Zone Calculations**

The submittal made by a discharger for either a ZID or an increased chronic mixing zone must establish which effluent flows are evaluated when calculating dilution ratios. At present, the Department recommends the following flows be considered in the analysis.

**ZID submittals:**

<b>Industrial Dischargers</b>	-->	for 10 ft/sec for dilution ratio	98% exceedence flow 2% to 98% exceedence flows
<b>Municipal Dischargers</b>	-->	for 10 ft/sec for dilution ratio	98% exceedence flow design flow or 2% exceedence flow to 98% exceedence flow

**Chronic Mixing Zone submittals:****Flowing receiving waters:**

<b>Industrial Dischargers</b>	-->	for dilution ratio	mean flow last 2 years
<b>Municipal Dischargers</b>	-->	for dilution ratio	design flow

**Nonflowing receiving water:**

<b>Industrial Dischargers</b>	-->	mixing zone size (edge of discharge induced mixing)	4 day average 98% exceedence flow
		for dilution ratio	mean flow last 2 years
<b>Municipal Dischargers</b>	-->	mixing zone size	4 day average 98% exceedence flow
		for dilution ratio	design flow