Colorado Department of Public Health and Environment
Water Quality Control Division

Colorado Mixing Zone Implementation Guidance

April 2002

Table of Contents

Introduction

Effluent that is discharged to surface waters in most cases does not mix fully with the receiving water at the point of discharge. When immediate mixing does not occur, the effluent will appear in the receiving water as a plume. At progressively greater distances from the point of discharge, the plume becomes less distinct, until finally it is mixed fully with the receiving water. The area over which an effluent plume can be distinguished from a receiving water is called a mixing zone.

Water quality standards in Colorado have been developed and applied in permitting with the simplifying assumption that effluent will be fully mixed with the receiving water at or very near the point of discharge. This assumption typically is incorrect; there often is a significant mixing zone below the point of discharge. In such a case, water quality standards may be exceeded within the mixing zone, even when the effluent discharge is in full compliance with the permit.

The practical significance of the exceedance of standards within a mixing zone depends on the area over which exceedance occurs. An area of exceedance that is very large compared to the size of the receiving water might be considered unacceptably harmful to beneficial uses, whereas an area of exceedance that is very small compared to the size of the receiving water might be considered consistent with the protection of beneficial uses because of its negligible overall effect on the receiving water. For this reason, the USEPA has argued that water-quality regulations for the protection of beneficial uses should include some meaningful limit on the area below a discharge where standards will be exceeded, and many states have adopted regulations that address this issue.

During 1999, the Colorado Department of Public Health and Environment formed a working group for the purpose of developing draft regulations related to mixing zones for permitted discharges to surface waters in Colorado. This working group, which included CDPHE staff as well as consultants, attorneys, and staff members of cities permitted for municipal discharges, reviewed EPA guidance, current practice in states other than Colorado, and the general goals of the State=s water quality protection program. The Committee recommended adoption of some specific policies for limiting the area below discharges within which standards can be exceeded. These policies were prepared by CDPHE staff in the form of a draft regulation, which was dispersed for comment several times and edited by CDPHE staff in response to comments. The draft regulation was forwarded, early in the year 2000, to the Colorado Water Quality Control Commission for consideration, but was sent back to the working group for revision. A revised version was approved by the Commission in October 2000, with the understanding that a guidance document would be prepared for subsequent review by the Commission.

The purpose of this guidance document is to explain how the mixing-zone regulation was developed and how it will be applied in the preparation of permits for the discharge of effluents to surface waters of Colorado. The guidance given here reflects as closely as possible the intent of the working group and CDPHE staff in preparing the regulation.

Explanation of Key Terms: Physical Mixing Zone, Regulatory Mixing Zone, and

Exceedance Zone

The area beyond a point of discharge within which the water from the discharge is not fully mixed with the receiving water is referred to here as the *physical mixing zone* (PMZ: Figure 1). The dimensions of the physical mixing zone reflect the site-specific characteristics of the effluent discharge and the receiving water.

The intent of regulatory policy on mixing zones is to set a limit on the area within a physical mixing zone where water quality standards can be exceeded. This area, which is site-specific, is called the *regulatory mixing zone* (RMZ), and is developed separately for acute (acute regulatory mixing zone) and chronic (chronic regulatory mixing zone) standards. The regulatory mixing zone is defined for the protection of uses, i.e., it is not a natural phenomenon.

For a given discharge, the regulatory mixing zone may be smaller than or larger than the physical mixing zone. These possibilities are shown in Figure 2. When the regulatory mixing zone is larger than the physical mixing zone, a discharge permit will not be restricted in any way by the mixing-zone regulation. In such a case, the permit writer can assume that the effluent is completely dispersed into the receiving water within an area that is smaller than the area that is allowed by regulation for exceedance of standards associated with mixing. If the regulatory mixing zone is smaller than the physical mixing zone, however, a discharge permit sometimes will be more restrictive than it would have been in the absence of mixing zone regulations.

A portion of the physical mixing zone within which a standard is exceeded for a given substance is called an *Exceedance Zone* (EZ) for that substance. For a given discharge, the sizes

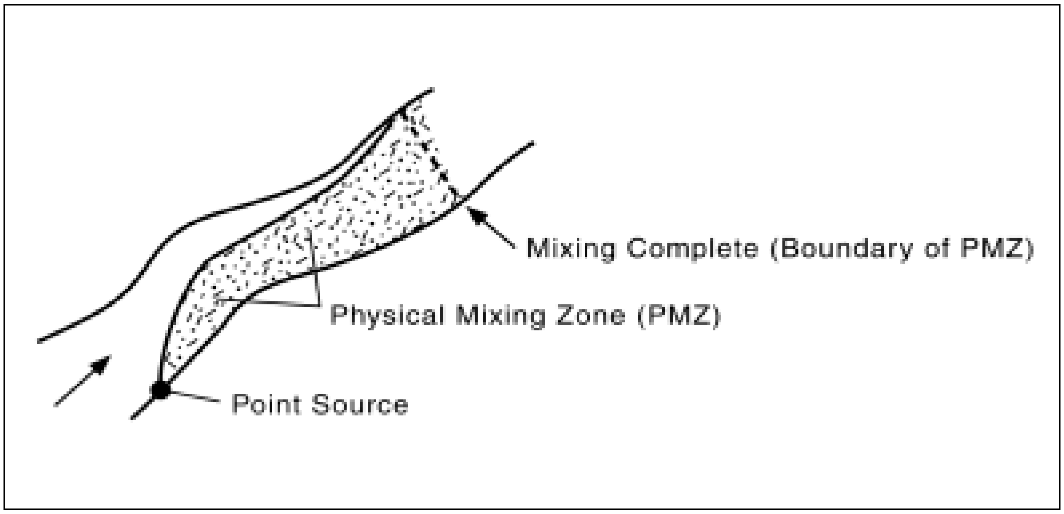


Figure 1 Diagram of a physical mixing zone (PMZ).

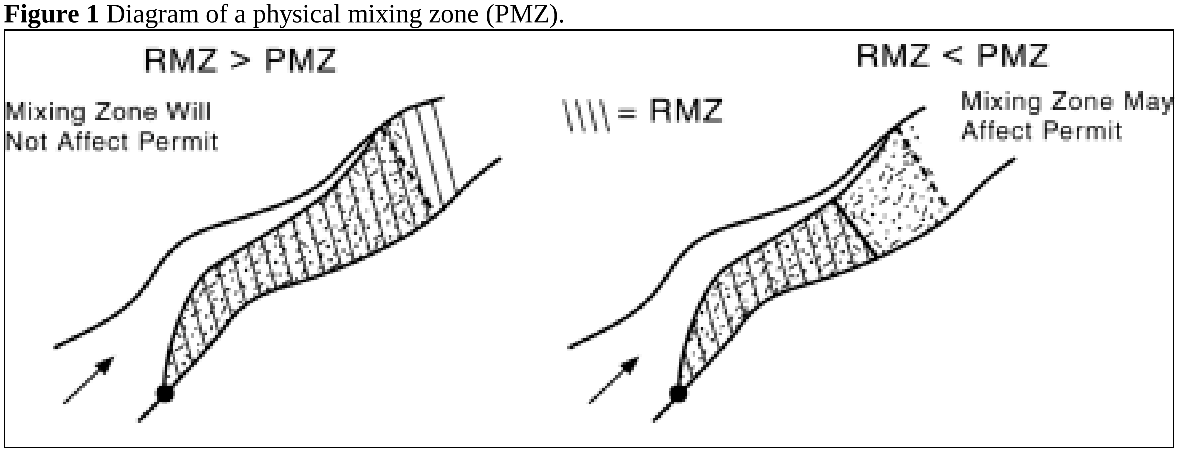


Figure 2 Diagram of a regulatory mixing zone (RMZ) superimposed on a physical mixing zone (PMZ) for two cases: RMZ > PMZ, RMZ < PMZ.

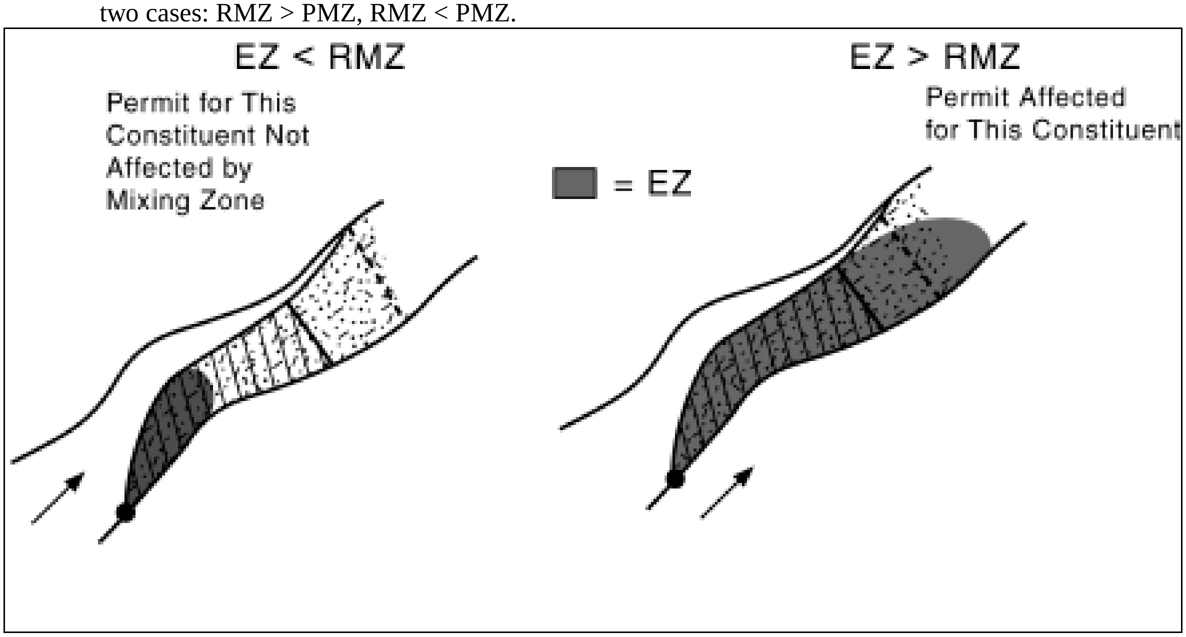


Figure 3 Diagram of an exceedance zone (EZ) superimposed on a physical and regulatory mixing zone for two cases: EZ < RMZ, EZ > RMZ.

of exceedance zones may differ from one substance to another, and will differ in size for chronic and acute standards applicable to any given substance. An exceedance zone may occupy a small, moderate, or large portion of the physical mixing zone, depending on the site-specific circumstances. The mixing-zone regulations require a comparison of the size of any exceedance zone with the size of the regulatory mixing zone (Figure 3). If the exceedance zone is larger than the regulatory mixing zone, the permit limit for the substance in question must be reduced until the exceedance zone is no larger than the regulatory mixing zone. In such a case, the mixing zone regulation restricts the permit limit.

The practical difficulties for preparation of permits by the State or anticipation of permit requirements by dischargers are as follows: (1) estimation of the size of the physical mixing zone for a given site, (2) estimation of the size of the regulatory mixing zone for a given site, and (3) calculation of restrictions, if any, that may be necessary to bring exceedance zones to a size no greater than that of the regulatory mixing zone. These topics are addressed in the following sections of this guidance.

Explanation of the Mixing-Zone Regulation

The mixing-zone regulation applies to both lakes and streams, but the form of the regulation differs somewhat for these two types of aquatic environments. For both lakes and streams, the rationale for the regulation is that potential impairment of an aquatic environment by unmixed effluent should be limited to a small proportion of the total area of the environment.

For both lakes and streams, separate but complementary acute (1-day) and chronic (30-day) limitations are imposed by the mixing-zone regulation. The regulatory mixing zone for chronic exposure encompasses an area within which the chronic standards may be exceeded. Within this zone, at times when critical conditions exist (e.g., low flow for streams), organisms occupying or passing through the zone may experience reduced growth rate, behavioral alterations, or other consequences of stress. If the condition persists for intervals of many weeks, organisms in this zone may even experience mortality if they are incapable of moving to avoid stress. Such a condition would be unusual, however, in that it would occur only under the most extreme circumstances that would be consistent with the development of permit limitations.

The regulatory mixing zone for acute exposure encompasses an area within which the acute standards for protection of aquatic life may be exceeded. Organisms occupying this zone, if unable to move from it, may experience mortality under critical conditions.

Streams

Streams and rivers, which are referred to collectively here as streams, have regulatory mixing zones that are directly scaled to channel width. The chronic regulatory mixing zone has an area equal to 6 times the square of the channel width at bankfull flow (see following sections for further explanation of bankfull flow). This regulatory convention is based on the concept of geomorphic units in streams. For streams that show pool and riffle structure, one sequence of pools and riffles is approximately 6 times the bankfull width. The channel area corresponding to this geomorphic sequence is length (6 times the bankfull width) times width (bankfull width). Thus the regulatory mixing zone for chronic exposures corresponds to 6 times the square of the bankfull width. This geomorphic scaling is applied to all streams, even though some do not show well-developed pool and riffle structure. The scaling convention allows the regulatory mixing zone to reflect the habitat size of the receiving water. Because the regulation is based on area rather than length, dischargers need not be concerned about the shape of the mixing zone that forms below a point of discharge. In this sense, application of the regulation is as equitable as possible across sites.

The size of regulatory mixing zones for individual discharges may be reduced if multiple discharges occur in a single stream reach or segment. The regulation states that the sum of all chronic mixing zones in a stream reach or segment may occupy no more than 10% of the area of that stream reach or segment. Further restrictions may be placed on individual dischargers if the Division finds that two or more mixing zones overlap each other. The boundaries of a reach or segment for purposes of this aspect of regulation generally will be as given by the most recent segmentation of waters that have been adopted by the Colorado Water Quality Control Commission, unless the Division concludes that such segments should be subdivided for purposes of mixing zone evaluation because of close spatial clustering of discharges.

The size of an acute regulatory mixing zone for a given location is scaled to the size of the chronic regulatory mixing zone for the same location. Because acute standards are designed to be protective against more extreme forms of damage (e.g., mortality in aquatic life) than chronic standards, the area of an acute mixing zone should be considerably smaller than that of a chronic mixing zone. At the same time, acute mixing zones that are excessively small would deny dischargers the benefit of rapid mixing that occurs very near a point of discharge. Consideration of the balance between these factors suggests that the acute mixing zone should fall generally between 10 and 25% of the size of the chronic mixing zone. For reviewable waters, the upper limit for the size of an acute mixing zone is 25% of the size of the chronic mixing zone, but 10% will be the default limit, and will be applied unless the CDPHE staff perceives specific reasons for adopting a zone of different size (but always $\leq$25% of the chronic zone) in a specific case. For waters designated as use-protected, the upper limit for the size of an acute mixing zone is 25% as large as the chronic regulatory mixing zone, and this upper limit is treated as a default in the sense that it will be applied unless the Division perceives reasons for adopting a smaller size in a specific case. Dischargers may present arguments against any specific proposal by the Division for the size of a mixing zone. Arguments must be based on economic reasonableness, ecological risk, and other related factors as listed in the regulation. The Division then will weigh the arguments of the discharger against the requirements of the regulation and reach a determination as to the appropriate size of the acute mixing zone, which will in no case exceed 25% of the size of the chronic mixing zone.

Lakes

For lakes, the regulatory mixing zone for chronic exposure cannot exceed 3% of the area of the lake for any specific point of discharge. In addition, the regulation restricts the area of chronic exposure for all dischargers combined to 10% of the area of a lake. Acute mixing zones for lakes are scaled to chronic mixing zones for lakes in exactly the same manner and by the same rationale as described above for streams. An acute mixing zone cannot be more than 25% as large as a chronic mixing zone at the same site (except in the special case of lakes with potable water supplies, as described below). For reviewable waters, 10% is taken as a default value, and for use-protected waters 25% is taken as a default value. The CDPHE staff may set a limit below these default values for specific reasons. Dischargers may present arguments against any specific size proposed by the Division that is <25% of the size of the chronic mixing zone.

These arguments must be related to economic reasonableness, ecological risk, and other factors as listed in the regulation. The Division will consider these arguments along with the intent of the regulation in making a final decision concerning the size of the acute mixing zone.

Because lakes (including reservoirs) in Colorado often are subject to large fluctuations in area and volume, the mixing-zone regulations require that computation of the area for regulatory mixing zones be based on the monthly or other appropriate seasonal characteristic areas for the lake. The regulation also states that distinct arms of individual lakes may be treated as separate receiving waters for purposes of computing the sizes of regulatory mixing zones.

Other Considerations

The mixing zone regulation allows CDPHE to restrict or deny a permittee any benefit from a mixing zone in certain instances where the existence of a mixing zone of any size might pose unusual risks or harm to beneficial uses. A list of the most likely conditions under which such restrictions or denials might occur is given in the regulation.

Restrictions or denials may be based either on numeric standards or narrative standards. The Division's index for applying narrative standards for toxic substances for aquatic life is based on whole effluent testing (WET). Effluents that meet the requirements of WET testing will be considered to have complied with the narrative standards for toxic substances for aquatic life within the mixing zone. Compliance with numeric standards within the mixing zone must be judged according to a procedural flow chart that is given in the next section of these guidelines.

The need to provide a zone of passage for aquatic life, as specified in the regulation, will be judged on the basis of the size and location of the acute mixing zone. An acute mixing zone that extends across an entire channel or arm of a water body is inconsistent with the requirement to provide a zone of passage, and will be the basis for restriction of the mixing zone as necessary to allow space that prevents the outer boundary of the acute mixing zone from encompassing the entire width of a channel or arm. The dimensions of an acute mixing zone with respect to channel width will be judged on the basis of field data collected by methods described in this guidance document. For discharges that are excluded from mixing zone analysis by other criteria, or where the mixing zone requirements are within regulatory size limits further restrictions may also be required when field information and/or modeling supplied by the Division or other parties indicate an inadequate zone of passage. In addition, diffusers such as those that may be used to promote mixing cannot extend across the full low flow width of a channel or a lake arm at characteristic lake level, because of the risk that such installations would be inconsistent with the need to maintain a zone of passage.

Bioaccumulation of toxins in fish or wildlife also is a consideration for the application of the mixing zone regulation. Bioconcentration (BCF) factors already in use for antidegradation reviews will be used in screening substances that may require special evaluation. If bioassay of organisms indicates significant bioaccumulation of such substances, the mixing zone may be denied or restricted to the extent necessary to prevent excessive bioaccumulation.

The Division will consider the special importance of certain habitat such as fish spawning or nursery areas or habitat that supports threatened and endangered species. The Division will use any lists or other information of special habitat features or special spawning areas maintained by the Division of Wildlife as its basis for evaluating any necessity to deny or restrict mixing zones for these purposes. Evaluation of mixing zones with respect to threatened and endangered species involves collaboration with the U.S. Fish and Wildlife Service through procedures and protocols that are outlined in Appendix IV of this guidance.

Potential for human exposure to pollutants through drinking water and recreation will be identified through inclusion of a routine requirement in the permit application to identify any drinking water intakes or recreational facilities such as docks, beaches, swimming areas, or kayak courses downstream of the discharge either 12 times the bankfull width on the bank opposite the discharge point or 24 times the bankfull width on the same side as the discharge point. If any such facilities are identified within these distances, and no site specific information exists to indicate that complete mixing occurs prior to the facility(ies), discharge limits will be set to meet the appropriate standards based on the amount of mixing at that location as shown by field data or, lacking such data, water quality standards for appropriate parameters must be met at the end-of-pipe.

The possible attraction of aquatic life to an effluent plume may be reason for further mixing zone restrictions by the Division in applying mixing zone regulations if there is field evidence of harm to aquatic life within the mixing zone, such as evidence of fish mortality. Where field studies or modeling show that surface water is likely to pass from the mixing zone into groundwater at a point where the groundwater is withdrawn for use prior to being adequately diluted by other waters the mixing zone will be restricted. Acute mixing zones in particular may be restricted for substances that are known to cause mortality over very short exposures, and substances that are likely to accumulate near the site of discharge to such an extent as to impair uses may be cause for requirement of special studies leading to restriction or denial of a mixing zone for the substance in question.

As explained in the statement of basis and purpose for the mixing zone regulation, analysis of anti-degradation as required by Subsection 31.8 must be conducted outside the boundaries of any mixing zone that is authorized by a discharge permit, and any assessment of impairment must also be conducted by use of data that are collected outside the boundaries of any mixing zone that is authorized by permit. Also, the mixing zone regulation does not apply to whole effluent toxicity (WET). When guidance for the WET regulation is revised, the applicability of mixing zone regulations to WET regulations will be specified.

As indicated by the mixing zone regulation and its statement of basis and purpose, the Commission has authorized the use of both exclusions and simplifications in the application of mixing zone regulations. These exclusions and simplifications, which are explained in the next section of this guidance document, are intended to make the application of the mixing zone more practicable, without incurring significant risk that the intended effect of the regulation will be compromised.

The mixing zone regulation contains provisions for special treatment of water bodies receiving water primarily from potable sources subject to treatment for disinfection purposes. For such water bodies, mixing zones are required to be as small as practicable, but may be allowed to exceed the size of mixing zones that would otherwise be allowed, because of the unusual nature of the source water.

Application of Mixing Zone Regulations to Streams

Mixing of an effluent discharge with a stream is affected by the volume of the effluent discharge and the velocity with which it reaches the stream. In addition, mixing will be affected by the width, depth, and shape of the stream channel. Other factors, such as dispersion devices, discharge to the middle rather than the edge of the stream, or the presence of low-head dams or tributaries, also may have an influence in certain situations.

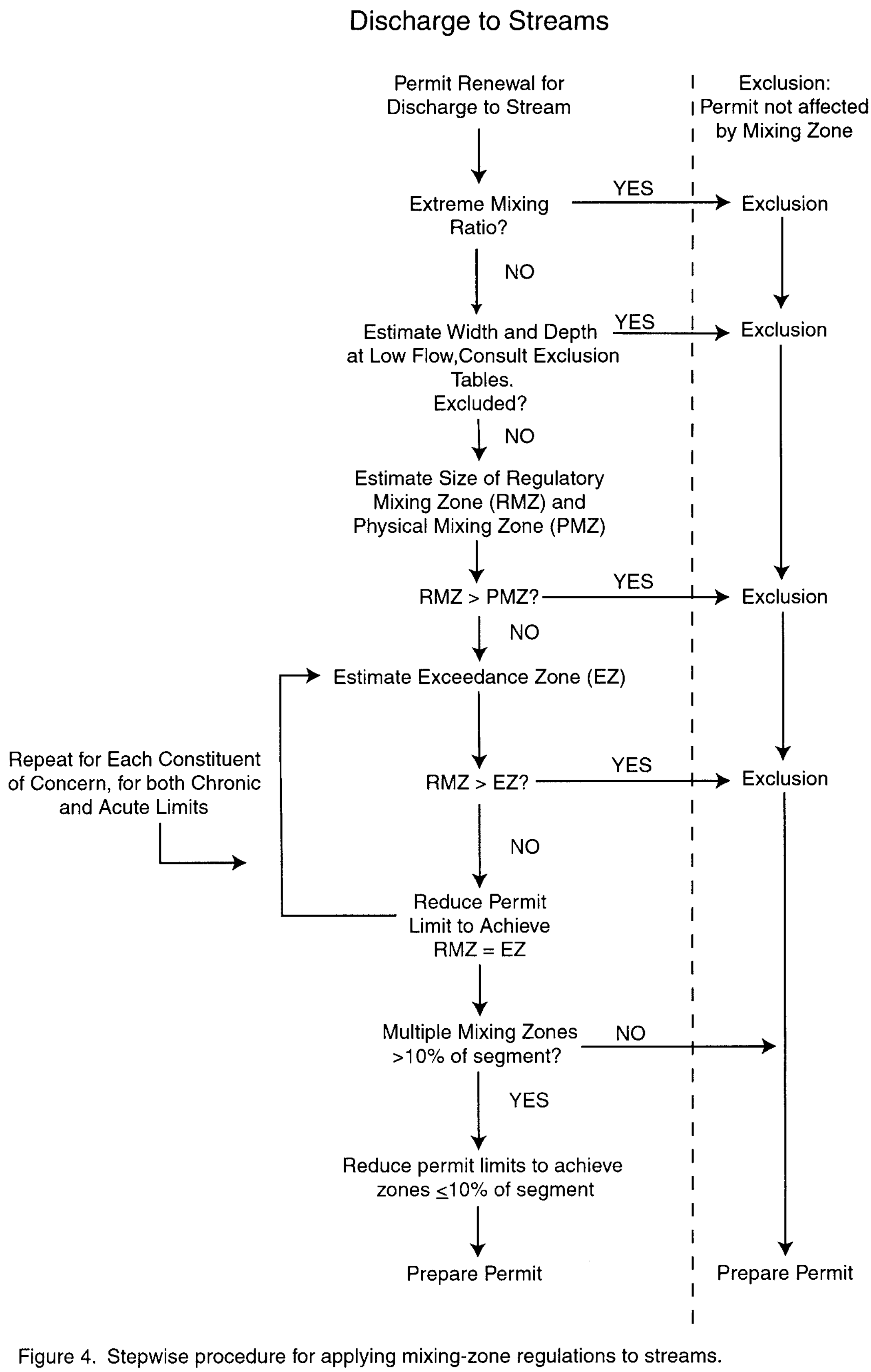
The volume and velocity of flow for a stream typically vary seasonally in Colorado. Variations in volume of flow are accompanied by variations in width and depth. Thus it is necessary to identify the most critical conditions for analysis of mixing, i.e., the conditions under which the size of the exceedance zone is likely to be greatest. Critical conditions will generally occur when the quantity of flow in the stream is lowest. For purposes of applying the mixing-zone regulations to permits, all calculations and estimates will be based on low-flow conditions (biologically-based low flow), unless there is clear evidence that critical conditions occur under other circumstances. The low flows for purposes of mixing zone analysis are as determined from the protocols for estimating biologically-based low flows for chronic exposures, as would be typical for determination of permit limits related to a fully mixed flow. No separate treatment of the acute low flow is necessary because the size of the regulatory mixing zone for acute exposures is taken as a percentage of the size of the chronic regulatory mixing zone.

The sequential steps for development of permit limits that are consistent with the mixing zone regulation are as follows (Figure 4): (1) application of the exclusion rule for extreme mixing ratios, (2) application of exclusion tables, (3) determination of size for the regulatory and physical mixing zones, (4) comparison of sizes for the regulatory mixing zone and physical mixing zones, (5) determination of the size of the exceedance zones for specific constituents of concern, and (6) adjustment of permit limits to bring the exceedance zones to the same size as the regulatory mixing zone. Only a few permit analyses will pass through all of these steps. As shown by Figure 4, a number of the intermediate steps in the analysis lead to an endpoint for which there is no effect of the mixing zone regulation on the establishment of permit limits. Appendix III gives sample calculations for each step shown in Figure 4.

Use of Field Data and Modelling

Mixing of effluent or other water that is introduced into a stream can be modelled by the use of widely available software if the stream shows constant flow characteristics. The application of any mixing model requires, however, considerable amount of data on field conditions, as well as some calibration and validation, in order to provide reliable results. In some cases, the appropriate calibration and validation of such a model may be feasible or desirable. In most instances, however, a simplified approach that does not require site-specific calibration of a model will be more practical. The approach for implementation of mixing-zone regulations as described in this guidance document involves a combination of field studies and use of some general equations and principles that are directly linked to the collection of field data. In this way, the more complex process of full calibration and validation for models is circumvented. As explained below, some general equations are used in separating conditions for which mixing zone regulations may be restrictive from conditions not likely to show such restrictions.

Figure 4 Stepwise procedure for applying mixing-zone regulations to streams.



Further consideration of discharges for which permit limits may be affected by mixing zone regulations is achieved by simple numerical analysis of field data, rather than modeling. This combination of approaches retains a close tie to specific information from field studies and avoids some of the expense and complication that accompany full-scale application of mixing models.

Exclusion for Extreme Mixing Ratios

Extreme mixing ratios for effluent are defined for present purposes as those in which either the effluent or the receiving water is strongly dominant in volume at the point of discharge. There are two types of extreme mixing ratios: (1) large amounts of effluent discharge to small amounts of low flow, and (2) small amounts of effluent discharge to high amounts of low flow. Both of these types of extremes generate circumstances leading to exclusion of discharges from the necessity of calculations and estimates related to mixing zones.

Discharges that exceed the volume of the receiving water by a significant margin force their way across the channel at low flow, thus achieving full mixing virtually at the point of discharge. Furthermore, discharges of this type have permit limits that are very little different from the stream standards, because they receive minimal benefit from dilution under low-flow conditions. For these two reasons, discharges that are large relative to the volume of flow in the receiving water are excluded from the analysis of mixing zones. The threshold for exclusion, according to the mixing zone regulations, is a ratio of 2:1 for effluent to receiving water: when the effluent is more than twice the volume of the receiving water at chronic low flow, permits can be prepared on the basis of a fully mixed condition.

The opposite extreme also generates exclusions, but for other reasons. An effluent discharge that is only a few percent of the volume of the combined flow below the point of discharge will show more than 90% dilution at the downstream margin of the physical mixing zone. If computed on the basis of >90% dilution (fully mixed condition), a permit limit in this situation would typically be so high as to be totally unrestrictive for the discharger (e.g., 100 mg/L total ammonia). In such cases, the permit writer typically would waive or minimize monitoring requirements, or would apply limits based on standard treatment technology rather than using the unnecessarily high allowance that would be dictated by dilution alone. In either case, the issue of mixing would be moot because the very high dilution would restrict any zone of exceedance to a very small area close to the discharge, and a mixing zone analysis would be unnecessary. The threshold for exclusion is a ratio of effluent to stream of 1:20 under conditions of low flow, i.e., effluents equal to or less than 4.75% of the combined flow are excluded from mixing-zone analysis, provided that such discharges are classified by CDPHE as “minor”, and that CDPHE finds no reason to expect that the discharge might raise special issues of environmental concern.

Application of the Mixing Zone Exclusion Tables

Because the mixing of a discharge with a stream follows certain well-known physical principles, equations can provide some rough estimates of the amount of distance downstream from a discharge that would be required for full incorporation of the discharge into the receiving water (i.e., complete mixing). These estimates are subject to considerable uncertainty, and therefore are not a substitute for field studies of mixing. In some situations, however, the general principles of mixing will show that it is highly unlikely for the physical mixing zone of an effluent to extend outside the size limits for the regulatory mixing zone. In these cases, field data on the mixing zone will not be needed, and the permit will not be restricted by the mixing zone regulation.

The CDPHE has established exclusion tables that can be used in determining whether or not the physical conditions of a particular site are such that the regulatory mixing zone will almost certainly be greater in area than the physical mixing zone. These exclusion tables are given in Appendix I.

Use of the exclusion tables requires site-specific information on the channel width and mean depth at the appropriate (eg. annual, seasonal, or monthly) low flow unless width and depth can be calculated based on published data. Stream width and mean depth at low flow must be determined by field observation unless calculated as described above. For both stream width at low flow and mean depth at low flow, six sets of measurements should be taken; these should be spaced equally at intervals of one bankfull width beginning at the point of discharge and extending downstream. Because critical low-flow conditions (i.e., biologically-based low flows) occur very seldom, field measurements can be taken for use of the exclusion tables at any flow within the lowest 15th percentile of flows, i.e., a low flow but not necessarily an actual critical low flow. Low flows suitable for measurements leading to application of the exclusion tables typically occur during fall and winter in most Colorado streams.

Mean depth under low-flow conditions should be determined from equidistant measurements of depth over the stream cross-section at a number of points ($\geq$12 for large streams, 6 - 12 for streams of intermediate size, 4 - 6 for small streams) at each of the six sampling sites below the point of discharge. Stream width can be determined by direct measurement at the same time. For streams with divided channels, mean width and depth at low flow are taken from the channel division into which effluent is discharged or, if the discharge occurs well upstream of the channel division, mean width and depth are taken from the combined channels, but excluding any exposed substrate.

When the information on mean stream width and mean depth at low flow are available, the exclusion tables can be used (Appendix I). There are three tables, each of which corresponds to a general category of conditions (plains, montane, transition). Within each table, columns correspond to mean depth at low flow and rows correspond to mean width at low flow. Each cell within the table contains one of two designations: Y or N. Y indicates exclusion of the site from further site-specific analysis of the mixing zone; the permit will be prepared on the basis of full chronic and acute low flows for calculation of water quality standards-based effluent limits. The designation N indicates that further steps are needed to establish whether or not the mixing zone regulations will restrict permit limits.

When specific sites fall within a border area for cells in an exclusion table, they should be placed within a cell that has the closest numerical relation to the site. For example, a stream that has a width of 65 ft falls between rows that are designated for streams of width 50 ft and 75 ft, but is closest to 75 ft. In this case, for purposes of applying the exclusion table, the stream is assigned to the cell for streams of width 75 ft.

Determination of Size for the Regulatory Mixing Zone

If a discharge does not fall under the exclusions for extreme mixing ratios, and is not excluded by use of the exclusion tables, the discharger must determine the size of the regulatory mixing zone for the discharge. This is a site-specific determination, but it is relatively easy to make.

The size of the regulatory mixing zone for chronic exposures is determined from field measurements of channel width. The relevant channel width for determining the size of the regulatory mixing zone is the width that corresponds to the bankfull condition. The bankfull width of the channel can be observed and measured under any flow condition, because it corresponds to the abrupt change in slope that occurs where a stream leaves its banks and enters the lowest level of the floodplain (Figure 5). For headwaters, determination of the bankfull condition may be complicated by the absence of a floodplain. At such sites, geomorphic indicators of the width of the stream at high flow can be obtained at the site (e.g., exposure of rock caused by removal of soil at high flow). Also, such a stream could be observed at spring runoff, which typically would approach bankfull width, for measurement of bankfull channel width.

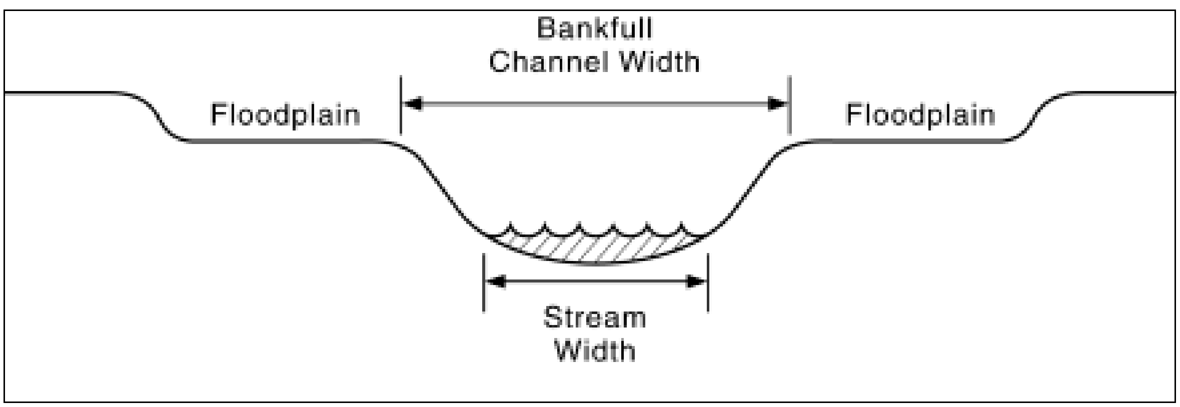


Figure 5 Illustration of stream width and bankfull width.

The bankfull width of a stream will vary from one location to another. For purposes of determining the size of the regulatory mixing zone, the bankfull width should be measured at six locations beginning at the point of discharge and extending downstream at intervals equal to the bankfull channel width near the discharge. The channel widths obtained at these six locations are then averaged, and the average is used in determining of the size of the regulatory mixing zone: 6 $\times$ (mean bankfull channel width)^2.

Determination of Size for the Physical Mixing Zone

If extreme mixing ratios or application of the exclusion tables do not lead to exclusion of a particular site from further analysis, a site-specific determination must be made of the dimensions of the physical mixing zone under low-flow conditions. Because it is impractical for field studies to be restricted to times coinciding with critical low flows, any field determination that is made at the time of a flow in the lowest 15th percentile can be used in field studies of the physical mixing zone. Where discharge records are unavailable, as may be the case for headwater streams, field determinations can be made during fall or winter except under conditions of storm runoff or snowmelt.

The physical mixing zone often can be mapped by use of a passive tracer. A passive tracer is an inert substance that can be measured to a high degree of precision and is present in different amounts in the effluent and the receiving water. The most convenient passive tracer is specific conductance, which can be measured with high precision in the field (i.e., no laboratory analytical work is necessary), and often differs between effluent and receiving water. Other passive tracers include chloride and potassium, but these must be analyzed in a laboratory. In order to be useful in a mixing-zone analysis, the difference in concentration between an effluent plume and the receiving water must be detectable when the effluent plume has been 90% diluted by stream water. For example, if the conductance of an effluent is 200 μS/cm and conductance of the receiving water is 210 μS/cm, it would not be possible to use specific conductance as a passive tracer because a 90% dilution of the effluent by stream water could only be detected at a sensitivity of 1 μS/cm or less, which is beyond the capabilities of standard conductance meters.

When no suitable passive tracer can be identified, an active tracer can be used. An active tracer is one that is added to the effluent stream above the point of effluent discharge over an interval of time sufficient to allow its complete dispersion in the effluent plume. The most common active tracer is fluorescent dye (e.g. rhodamine), but inert salts such as sodium chloride or lithium bromide also can be used.

If conductance can be used as a passive tracer, mapping of the physical mixing zone is undertaken by use of a conductance meter in the field. First, one or more upstream measurements and one or more measurements from undiluted effluent should be taken; these can be used as references for determination of percent dilution, if necessary (see below). A conductance measurement then is taken at several locations (10 - 20 for streams of moderate to large size, 4 - 10 for small streams) over a cross-section of the stream. This process is repeated at intervals of at most one-half bankfull channel width in the downstream direction until the range between measurements in a given cross-section is less than 10% of the mean. When the range is less than 10%, it is assumed that complete mixing has occurred (Appendix II).

When the point has been found at which complete mixing has occurred, data should be taken on one to several cross-sections between the last two cross-sections in the study. The purpose of these additional measurements is to locate more exactly the downstream end of the physical mixing zone. If this is not done, the dimensions of the physical mixing zone may be overestimated, which could cause a permit to be more restrictive than needed.

If conductance cannot be used as a tracer, the same procedure can be applied, but each measurement of conductance can be replaced with collection of a sample for laboratory analysis of a suitable passive tracer, or an active tracer can be used in conjunction with the same sampling scheme. If dye is used as an active tracer, field measurements may be possible with a fluorometer. Measurements of conductance or sampling for analysis of tracers can be done in the middle of the water column at each sampling point. While there is a possibility of incomplete vertical mixing very close to the point of discharge, this possibility diminishes rapidly with distance because the vertical dimension of a channel typically is much smaller than the horizontal dimension. Consequently, the issue of vertical mixing need not be considered unless some site-specific information clearly indicates otherwise.

The data on conductance or other tracers should be transferred to a conveniently scaled map of the stream that shows the reach under study and the point of discharge, as well as the boundaries of the stream under low-flow conditions. This map can be prepared by informal surveying techniques, i.e., this work does not require a high degree of technical proficiency in mapping.

Measurements of conductance or other tracers should be used in calculating percent effluent for each point of sampling. The values for proportion of effluent then should be placed on the map at the appropriate points. Proportion of effluent (k) is estimated from the following equation: $k = (T_m - T_u)/(T_e - T_u)$ where T_e is concentration of tracer in effluent, T_u is concentration of tracer in upstream flow; T_m is concentration of tracer in the mixture at point of sampling ($0 \leq k \leq 1$). When the values for k have been placed on the map, a line should be drawn around the boundaries of the physical mixing zone. The physical mixing zone occupies the entire area where there is an effluent-related gradient in concentration of the tracer ($k > 0.1$).

When the boundary of the physical mixing zone has been determined, its area should be estimated from the map. This can be accomplished by digitized integration, or it can be done more informally by the use of polygons that provide close approximations of the shape of the mixing zone. Often the mixing zone has a roughly triangular shape, and a triangular estimation can be justified.

Comparison of Areas: Regulatory Mixing Zone and Physical Mixing Zone

If the regulatory mixing zone is larger than the physical mixing zone (RMZ > PMZ), complete mixing of the effluent within the regulatory limit is assured. In such a case, the permit can be prepared as if the effluent were fully mixed at the point of discharge. If a comparison of areas shows that the physical mixing zone is larger than the regulatory mixing zone, further analysis will be necessary. Further analysis may or may not show the need for restriction of a permit limit by the mixing zone regulations, as explained below.

If it is suspected prior to a field study that RMZ > PMZ, the field work may be simplified by agreement with CDPHE staff. For example, a field study designed only to find the lower boundary of the PMZ might show that the entire stream area between the discharge point and the lower boundary is smaller than the RMZ. In this case, it is clear that RMZ > PMZ without further study.

Determination of Size for an Exceedance Zone

Up to this point in the application of the mixing zone regulation, it has not been necessary to distinguish among different regulated substances. If the physical mixing zone is larger than the regulatory mixing zone, however, exceedance zones must be identified and their areas must be estimated. The exceedance zone for a given substance is that portion of the physical mixing zone within which a standard (acute or chronic) is exceeded under critical low-flow conditions. Because standards differ by constituent, exceedance zones may differ in size from one constituent to another.

It is impractical to determine the size of exceedance zones for every regulated substance at a given point of discharge. As is usual practice for the preparation of permits, the permit writer will use a combination of site-specific data, effluent characteristics, and experience in identifying constituents of concern for regulatory purposes. For municipal dischargers, in the current regulatory environment, these substances often include ammonia and one or more metals. There are numerous other possibilities in specific situations or for industrial dischargers.

A dilution map, which consists of contours for the value of k as determined from the tracer study, is the starting point for determining the size of the exceedance zone. The simplest application of the map would be for a substance that carries a fixed numeric standard (i.e., standard not dependent on hardness, temperature, or pH). For such a substance, a hypothetical permit limit would be estimated by the usual procedures applied to fully mixed flows. The dilution map then would be used in preparing a concentration map for the effluent plume. For any given point on the map, the estimated concentration of a regulated substance would be as follows: $kR_e + (1 - k)R_u = R_m$ where k is proportion of effluent at the sampling point, R_e is the amount of the regulated substance in the effluent (permit limit with no mixing zone restriction), R_u is amount upstream, and R_m is the amount at the point of sampling.

When all of the concentrations are placed on the map of the physical mixing zone, a line can be drawn around the area that exceeds the chronic standard, and a second line can be drawn around a zone that exceeds the acute standard. The area enclosed by the first of these two lines is the chronic exceedance zone. The area inside the second line is the acute exceedance zone. These areas can be quantified from the map by methods such as those mentioned above for determination of area for the physical mixing zone.

Comparison of Sizes: Regulatory Mixing Zones and Exceedance Zones

The area of the exceedance zone for chronic exposures is compared with the area of the regulatory mixing zone for chronic exposures. If the regulatory mixing zone is the larger of the two, no further analysis is necessary for the chronic mixing zone. In such a case, the permit limit is set just as it would be for a fully mixed condition. A similar comparison of exceedance zone with regulatory mixing zone is made for the acute standard. The acute regulatory mixing zone is 10% as large as the chronic regulatory mixing zone for reviewable waters, and 25% as large for use-protected waters, unless there are site-specific reasons for acute mixing zones of other sizes (see the foregoing explanation of the regulation for more detail on this).*Adjustment of Permit*

Limits to Make Regulatory Mixing Zone Equal Exceedance Zone

If the exceedance zone is larger than the regulatory mixing zone for chronic exposures, the chronic effluent limit will be restricted by the mixing zone regulation, i.e., the permit limit for the substance in question will be lower than it would have been for a fully mixed condition. The appropriate permit limit is determined by downward adjustment of the limit until the zone of exceedance just matches the zone within which the chronic standard is exceeded. A similar approach is taken to the acute limit.

Constituents of concern for protection of aquatic life in Colorado often have limits that depend on pH, temperature, or hardness. Determination of permit limits in such a situation requires an extra step, but is fundamentally the same as described above for a constituent that is defined on the basis of concentration alone.

For permit limits on total ammonia, the pH and temperature for each location over each cross-section in the tracer study or a separate study of similar design should be used in calculating the percent unionized ammonia at that location in the cross-section. The total ammonia allowance in the discharge under the fully mixed condition (as determined by use of the Colorado Ammonia Model) can be used as a starting point for the next step. Mixed temperature is calculated from percent effluent plus data on effluent and stream temperature; mixed pH is calculated from percent effluent and hydrogen ion concentrations of effluent and stream. The total ammonia concentrations are mapped within the physical mixing zone based on percent dilution. For each location, the percent unionized ammonia is multiplied by the expected total ammonia. The result is a map of unionized ammonia. At this point, completion of the analysis is the same as for a substance whose limit is not dependent on pH or temperature.

For the acute standard on unionized ammonia, the procedure requires yet another step because the standard varies on the basis of temperature and pH. The acute standard should be entered at each point on the map along with the estimated concentration of unionized ammonia, and a line can be drawn around the locations that exceed the standard.

Mapping of exceedance zones for metals whose standards depend on hardness can be accomplished in a manner very similar to the one described above for acute standards on unionized ammonia. Hardness within the plume can be estimated from the percent dilution based on the hardness of the effluent and the receiving water prior to mixing. The procedure is then the same as described above for determinations involving acute limits for unionized ammonia.

Permits often differ from one season to another or one month to another because of variation in the annual cycle caused by seasonal changes in flow or chemical conditions in the receiving water. A full and independent mixing zone analysis for each season or month is seldom justified and would be called for only if the CDPHE staff perceives a defensible reason for requiring it, or a discharger requests it. Instead, the analysis should be conducted for the month or season of lowest flow according to the procedures outlined above. If these procedures lead to a restriction of the effluent limit for the month or season of lowest flow, the restriction can be carried over on a percentage basis to limits for other months. For example, if the mixing zone regulation caused a decrease in the permit limit for total ammonia from 10.0 to 8.0 mg/L in the month of lowest flow, limits for the fully mixed condition would be reduced by 20% for all other months or seasons, unless the discharger or the State wished to complete a separate analysis for other months or seasons.

Application of the Mixing Zone Regulations to Lakes

The efficiency with which an effluent mixes with the waters of a lake into which it is discharged will depend greatly on site-specific characteristics. Factors likely to be important include the following: (1) amount and velocity of effluent at the point of discharge, (2) exposure of the site to wind-driven currents in the lake, (3) depth gradient beyond the point of discharge, (4) physical confinement of the effluent beyond the point of discharge by topographic features, (5) presence of ice cover or water column density gradients (seasonal stratification). Some of these factors vary not only from site to site, but also from month to month at a given site. The complexity with which these factors interact is so great that calculations or models based on general principles are likely to lead to serious errors. Some types of computer models could be calibrated for estimates of mixing characteristics for a specific site, and would thus become more reliable than generalized models. The calibration process, however, would consume essentially the same effort as a set of field studies leading directly to mapping of the effluent plume, and thus would offer little advantage.

The most practical approach to definition of mixing zones for lakes is through field studies, and this approach is a requirement of the regulation. Field studies can be waived only when a new discharge is proposed for permitting. Under such conditions, absence of the discharge makes relevant studies of mixing impossible. In this case, an initial permit can be prepared on the basis of mixing characteristics for another site that has as many similarities as possible.

For streams, some approximate comparisons of the physical mixing zone and regulatory mixing zone are possible by the use of generalized equations, and in some cases lead to the exclusion of a particular discharge from additional requirements imposed by mixing-zone regulations. It is impractical to apply a similar procedure for mixing zones in lakes. The physical mixing zone in lakes is strongly influenced by seasonal conditions (ice cover, density stratification, etc.). Therefore, multi-season field studies are unavoidable.

Design of Field Studies

Field studies of mixing zones are accomplished by the use of tracers. For present purposes, a tracer can be defined as any substance that meets the following requirements: (1) it is inert, and thus changes in concentration only as a result of dilution, (2) it is present at different concentrations in the effluent than in the receiving water, (3) it can be measured with a high degree of precision relative to its concentration.

Tracers can be used either actively or passively. Use of an active tracer involves addition of the tracer to the effluent above the point of discharge. The most common tracer that is used in this way is fluorescent (e.g. rhodamine) dye, although an ionic substance such as sodium chloride or lithium bromide also could be used. It is essential that an active tracer be added steadily over a long period of time (e.g., 12 hours), so that the plume can fully incorporate the tracer.

Use of passive tracers often is feasible, and involves fewer complications than the use of active tracers. Some ionic solutes typically are present in effluent at concentrations considerably greater than those of receiving waters. Conductance is a possibility, as are chloride and potassium.

Use of either active or passive tracers is accompanied by collection of samples from the receiving water. Samples are collected in a radial pattern outward from the point of discharge. The radial pattern is established with a set (6 - 10) of marker lines that are spaced evenly in an arc around the point of discharge. Samples are then taken along each marker line. The interval of sampling along the marker line increases with distance from the discharge because rate of change in concentration decreases with distance from the point of discharge; the spacing of the sampling points along a transect typically would be geometric. For example, if a discharge enters a lake where the arc of water surface surrounding the point of discharge is 120^{o}, sampling lines (transects) might be set up at 15, 30, 45, 60, 75, 90, and 105^{o} along the arc. On each transect, sampling points might be located at distances from the shore of 1, 2, 4, 8, 16, 32, 64, and 128 m.

At each sampling point on each transect, a sample is collected in the middle of the water column if the water column is shallow and unstratified. If the water column is deep, or if it is stratified, collection of samples at two or more depths may be necessary at each point. All of the samples are analyzed for the tracer. The percent dilution of effluent can be calculated from the concentrations of the tracer in the discharge and in the receiving water, as compared with the concentration of tracer in the sample.

The values for percent dilution can be used in preparing a map showing isolines (lines of equal concentration) within the discharge plume. Use of an isoline map for completion of the analysis may be cumbersome, however, because the isolines may not be stable through time. One alternative approach is to use a numerical analysis instead.

A numerical analysis of dilution must take into account two separate factors that influence the rate of dilution beyond the point of discharge. The first factor is the energy of the discharge itself, which carries forward from the discharge pipe or ditch under the force of gravity into the receiving water. Mixing by this process is highly efficient, and can cause 80% or more dilution of a small discharge within a distance as small as a few feet. Within a relatively short distance, however, the energy of the effluent stream is dissipated and a second factor becomes dominant. This second factor is water movement in the lake driven by wind or other forces, which involves not only displacement of local water with water coming downwind, but also dispersion through the process of eddy diffusion associated with turbulent flow in the upper mixed layer of the lake. Movement of lake water accounts for gradual dilution beyond the immediate area of the discharge.

The best way of dealing with the two processes that cause mixing is to separate them on the basis of an examination of the field data. A zone of rapid dilution typically can be identified from the field data, and the amount of dilution within this zone can be quantified empirically.

Dilution beyond this point usually can be treated as a logarithmic decay function, and quantified in this way by statistical analysis. The joint effect of the two processes can then be calculated for any given distance from the point of discharge.

Field studies of mixing for point-source discharges to lakes must be conducted more than once. An ideal study would involve monthly measurements, but studies of this type can be quite expensive. At a minimum, field studies must encompass all four seasons. Dispersion of effluent under ice may differ substantially from dispersion of effluent during summer, and dispersion during the two mixing seasons (fall and spring) may differ from dispersion at other times of year.

When the dispersion of effluent has been quantified for a specific date, either by mapping or by numerical analysis, the mixing-zone regulation can be applied. If the field measurements for a given sampling date are taken as a representative of a particular month or season, the area of the lake characteristic of that season must be determined from lake-level records. The area of the regulatory mixing zone for both acute and chronic exposures then can be calculated from percent area limits on mixing zones: 3% for chronic and either 0.30% (reviewable waters) or 0.75% (use protected waters) for acute mixing zones, unless site-specific information indicates a need for a smaller acute zone. The calculations are repeated for each month or season if there is significant seasonal or monthly variation in lake level.

The area of the regulatory mixing zone for either acute or chronic exposures corresponds to a specific concentration isoline.   The appropriate concentration isoline can be determined either from interpolation on a dilution map or from use of the equation representing dilution as described above. If an equation is used, the assumption will be that the plume has more or less regular geometric shape over a portion of a circle that corresponds to the dispersion area directly in front of the discharge (typically 90 - 180°).

When the appropriate dilution contour has been located in correspondence with the boundaries of the regulatory mixing zone, further calculations are possible. Dilution at the boundary of the regulatory mixing zone is the maximum amount of dilution that can be allowed for compliance with the water quality standards. Thus the standard plus the maximum amount of dilution can be used in calculating the maximum amount of a regulated substance that can be present in the effluent at the point of discharge.

Several additional factors must be taken into account when percent dilution is converted to a permit number for the effluent. These factors involve relationships between a numeric standard for a regulated substance and the quality of the water to which the standard is being applied. The two most common cases involve ammonia and certain heavy metals. For ammonia, pH and temperature affect the calculation of a permit limit. For some heavy metals, there is a relationship between the permit limit and the hardness of the water. Procedures for dealing with a mixing-zone determination for these regulated substances with water-quality dependent standards can be accomplished by methods essentially identical to those already described in the section on streams.

Permit limits for chronic exposures apply to 30-day averages for water quality conditions. Field measurements from studies such as those described above correspond to an instantaneous estimate of mixing. For this reason, it is appropriate to obtain 3-point moving averages of individual estimates for permit limits prior to assigning chronic permit limits for each month. This results in smoothing of the data, and reduces the possibility that errors or anomalies will have an excessive influence on development of the permit. Because they are spaced by an interval of several months, quarterly measurements cannot be smoothed in this way.

Use of Diffusers

The rate of mixing can be accelerated by the use of an effluent diffusion device. The use of such a device must be negotiated with the Permits Unit of CDPHE before its relevance to permitting can be established. No diffusion device can extend over the complete breadth of a stream because an acute mixing zone cannot occupy the entire width of a stream, due to requirements for a zone of passage.

Appendix I

Exclusion Tables for Application of the Colorado Mixing Zone Regulations for Streams

The distance required for complete mixing of an effluent discharge with a stream can be represented in general terms by equations that incorporate principles of turbulent mixing under site-specific conditions of slope, velocity, channel shape, and channel roughness. These equations are given on pages 29 and 30 of the EPA Region VIII guidance document for mixing zones (September 1995). The general equations for determination of mixing length do not, however, give very precise predictions for any particular site in the absence of site-specific studies that allow calibration of the equations. The equations are adequate for comparisons not requiring great precision, and are used here for the development of exclusion tables that can be used in identifying conditions under which the physical mixing zone below an effluent discharge to a stream will almost certainly be smaller than the regulatory mixing zone.

The first step in preparation of the tables was identification of three general classes of streams: low gradient (plains streams; slope < 0.0018), moderate gradient (transitional streams; slope 0.0018 to 0.005), and high gradient (montane streams; slope > 0.005). Characteristic values for variables to be used in the mixing equations were attached to each one of these categories of streams (Table I-1). Care was taken to choose values that are relatively conservative, i.e., that would be unlikely to under-predict the size of the physical mixing zone.

A second step in the preparation of the exclusion tables was to choose a range of widths and depths that could be applied to each category of stream. In Tables I-2 to I-4, these widths and depths, which are shown as rows and columns, allow the approximate combination of width and depth for any given stream at low flow to be located on a table.

For each cell in each of the three tables, a computation was made of mixing length on the basis of equations for mixing length given in EPA guidance document. The shape of the mixing zone was assumed to be triangular with an apex at the point of discharge and a base located at the point of complete mixing. For each cell in each table, the mixing length, the width of the stream, and the assumption of its triangular shape were used in calculating the area of the physical mixing zone at low flow. For each calculation, it was assumed that the hydraulic radius of the stream was equal to wh/(2h + w) where w = width and h = mean depth, and that velocity could be calculated from Manning=s equation by use of the hydraulic radius and the value for Manning=s n shown in Table I-1.

The size of the chronic regulatory mixing zone was computed for each row in each of the three tables. In each case, the size of the chronic regulatory mixing zone is 6 x the square of the channel width, as specified by the mixing zone regulation. For this calculation, 2 x the width of the stream at low flow was used as a conservative estimate of bankfull width. The actual bankfull width cannot be determined on a generalized basis from the width of the stream at low flow.

Comparisons were made of the size of the regulatory mixing zone and the size of the physical mixing zone for each cell in each of the tables. Where the estimates indicated that the regulatory mixing zone would be larger than the physical mixing zone, the cell was filled in with the letter Y, indicating that the site in question should be excluded from mixing zone analysis. Where the physical mixing zone was larger than the regulatory mixing zone, the cell was filled in with the letter N, indicating that further consideration of the mixing zone would be warranted. For sites that meet the exclusion criteria in Tables I-2 to I-4, no separate consideration of the acute mixing zone is required.

In application of the tables, the cell that is numerically closest to the site-specific measurements should be used. Because the tables were constructed in an intentionally conservative manner, sites that are not excluded through use of the tables may, through further site-specific analysis, be excluded at subsequent steps in the mixing-zone analysis.

	High Gradient (montane)	Intermediate Gradient (transition zone)	Low Gradient (plains)
c*	0.6	0.6	0.6
slope	>0.005	0.0018-0.005	<0.0018
Manning=s n	0.075	0.035	0.030

*Channel irregularity factor (see EPA Region VIII, Mixing Zones and Dilution Policy, September 1995, p. 30).

Table I-1. Conditions for the three categories of streams represented in the tables.

Equations used in converting values from Table I-1 to Tables I-2 through I-4 (fps units):

$$\text{Velocity, fps} = \frac{1.486}{n}\left[\frac{(\text{stream width} * \text{depth})}{(2 * \text{mean depth} + \text{stream width})}\right]^{2/3}(\text{slope})^{1/2}$$

$$\text{PMZ area, ft}^2 = \frac{\text{stream width}^2 * \text{velocity}}{2\pi * c * \text{mean depth} * (32.2 * \text{mean depth} * \text{slope})^{1/2}} * \text{stream width}/2$$

$$\text{RMZ area, ft}^2 = 6 * (2 * \text{stream width})^2$$

Width in all instances is for the stream itself at low flow (not the channel); the equation for area of the RMZ includes the assumption that bankfull width is two times stream width at low flow.

	Depth, ft										
Width, ft	0.5	0.75	1	1.25	1.5	1.75	2	2.5	3	3.5	4
4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
8	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
10	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
12	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
14	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
18	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
22	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
26	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
30	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
35	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
40	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
50	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
60	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
70	N	N	N	N	Y	Y	Y	Y	Y	Y	Y
80	N	N	N	N	N	Y	Y	Y	Y	Y	Y
90	N	N	N	N	N	N	Y	Y	Y	Y	Y
100	N	N	N	N	N	N	N	Y	Y	Y	Y
120	N	N	N	N	N	N	N	N	Y	Y	Y

Table I-2. Exclusion table for montane streams.

	Depth, ft										
Width, ft	0.5	0.75	1	1.25	1.5	1.75	2	2.5	3	3.5	4
4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
8	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
10	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
12	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
14	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
18	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
22	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
26	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
30	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
35	N	N	N	N	Y	Y	Y	Y	Y	Y	Y
40	N	N	N	N	N	Y	Y	Y	Y	Y	Y
50	N	N	N	N	N	N	N	Y	Y	Y	Y
60	N	N	N	N	N	N	N	N	Y	Y	Y
70	N	N	N	N	N	N	N	N	N	Y	Y
80	N	N	N	N	N	N	N	N	N	N	Y
90	N	N	N	N	N	N	N	N	N	N	N
100	N	N	N	N	N	N	N	N	N	N	N
120	N	N	N	N	N	N	N	N	N	N	N

Table I-3. Exclusion table for streams of transitional terrain.

	Depth, ft										
Width, ft	0.5	0.75	1	1.25	1.5	1.75	2	2.5	3	3.5	4
4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
8	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
10	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
12	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
14	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
18	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
22	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
26	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
30	N	N	N	N	Y	Y	Y	Y	Y	Y	Y
35	N	N	N	N	N	Y	Y	Y	Y	Y	Y
40	N	N	N	N	N	N	N	Y	Y	Y	Y
50	N	N	N	N	N	N	N	N	Y	Y	Y
60	N	N	N	N	N	N	N	N	N	Y	Y
70	N	N	N	N	N	N	N	N	N	N	Y
80	N	N	N	N	N	N	N	N	N	N	N
90	N	N	N	N	N	N	N	N	N	N	N
100	N	N	N	N	N	N	N	N	N	N	N
120	N	N	N	N	N	N	N	N	N	N	N

Table I-4. Exclusion table for streams of the plains.

Appendix II

Criteria for Identification of the Fully Mixed Condition below Effluent Outfalls and Tributaries in Colorado Streams

Introduction

Application of Colorado=s Mixing Zone regulations may require, in some cases, field measurements leading to an estimate of area of the physical mixing zone, i.e., the effluent plume. Because the effluent plume becomes increasingly diffuse downstream, identification of its downstream end from field data may be difficult in the absence of criteria. The purpose of this report is to show how field data on Colorado streams have been used to develop criteria for identification of the downstream end of a physical mixing zone for purposes of applying the Colorado mixing zone regulations.

Methods

As explained in the foregoing guidance document, mixing zones can be mapped by use of a tracer. A tracer can be either passive (i.e., a constituent of the effluent) or active (i.e., added to the effluent). A passive tracer that proves useful in some cases is specific conductance, which is related to the ionic solids content of the water.

Specific conductance was used in all the field studies described in this report. A YSI model 85 conductance meter was used in making conductance measurements. Except during a warm up period of about 15 minutes when conductance measurements tended to increase by a few percent over the initial value when the machine was first turned on, conductance measurements made at intervals of 5 minutes in a single sample of water showed virtually no detectable variance (range, ca.1 μS/cm).

Conductance measurements reported here are corrected to a temperature of 25°C. Most meters, including the one used in this study, make this correction automatically. For instances in which no automatic correction is made, a computational correction must be made for temperature of the sample at the time conductance is measured.

A number of field sites were identified for the study. These sites are listed and described below. At each field site, the cross-section of the stream was divided into > 10 equal distance intervals and a measurement of specific conductance was made in the middle of the water column with the meter at the junction of each one of these intervals. The data were then plotted, and the range, standard deviation, and coefficient of variation were computed.

At one of the stations (South Platte River, Meadow Island Ditch), cross-sectional measurements were repeated five times so that the repeatability of cross-sectional measurements could be quantified.

Selection of Sites

Each site was located a great distance (> 2 miles) from the nearest upstream tributary or effluent outfall. In other words, none of these sites incorporated a mixing zone for surface flows. Thus the field data for each site should be representative of the cross-sectional heterogeneity at or below the boundary of an effluent plume.

Table 1 gives a list of the field sites and stream widths on the date of the study. All the field data were collected during a period of low flow (March). Because mixing-zone regulations are based on the assumption that the critical mixing conditions will occur at low flow, measurements at higher flows would not be relevant.

The sites listed in Table II-1 encompass a range of stream types. Variations in size, likelihood of groundwater influence, and slope all may have a bearing on cross-sectional heterogeneity.

Figure II-1 shows the results for the repeated cross-sectional transects on the South Platte River. The conductance measurements showed a range of variation for any given cross-section of approximately 3 μS/cm. This variation was not random; it reflected a change in conductance from the west to the east bank of the river. Repetition of the measurement showed that the cross-sectional differences were quite stable. Repetition also showed a small but steady increase in conductance over the entire cross-section (probably caused by 24-hour pulsation of effluent release upstream). Although the cross-sectional information shown in Figure II-1 indicates clear differences across the channel and from one time of measurement to the next, it should be noted that the scale of measurement for Figure II-1 is greatly expanded. The overall range across time and distance is only 6 μS/cm, or less than 1% of the measured values.

Figures II-2 and II-3 show results for measurements at other sites. Measurements for most sites show extremely small amounts of variation over the cross-section (i.e., range equal 2 - 3 μS/cm). Other stations show more variation and it is associated in each case with a clear cross-sectional pattern: South Platte River at Hardin, Colorado River, South Platte River, Fountain

Creek. In each of these cases, the cross-sectional measurements suggest the influence of subsurface alluvial flow into the river, with consequent effects on the conductance over the cross-section. In all cases, however, the magnitude of these cross-sectional differences is small in an absolute sense.

Location	Date	Width m	Number of Measurements	Direction
South Platte River above Meadow Island Ditch	3/6/2000	34	17	W to E
South Platte River near Hardin	3/10/2000	62	30	N to S
Colorado River near Dotsero	3/8/2000	58	28	E to W
Blue River below Dillon Dam	3/8/2000	26	12	E to W
Arkansas River above Fountain Creek	3/7/2000	48	23	S to N
Fountain Creek near Mouth	3/7/2000	54	26	E to W
Clear Creek above Golden	3/8/2000	17	16	S to N
Poudre River at Mouth	3/10/2000	19	18	E to W
Boulder Creek at Eben Fine Park, Boulder	3/10/2000	6	11	S to N

Table II-1. Site characteristics.

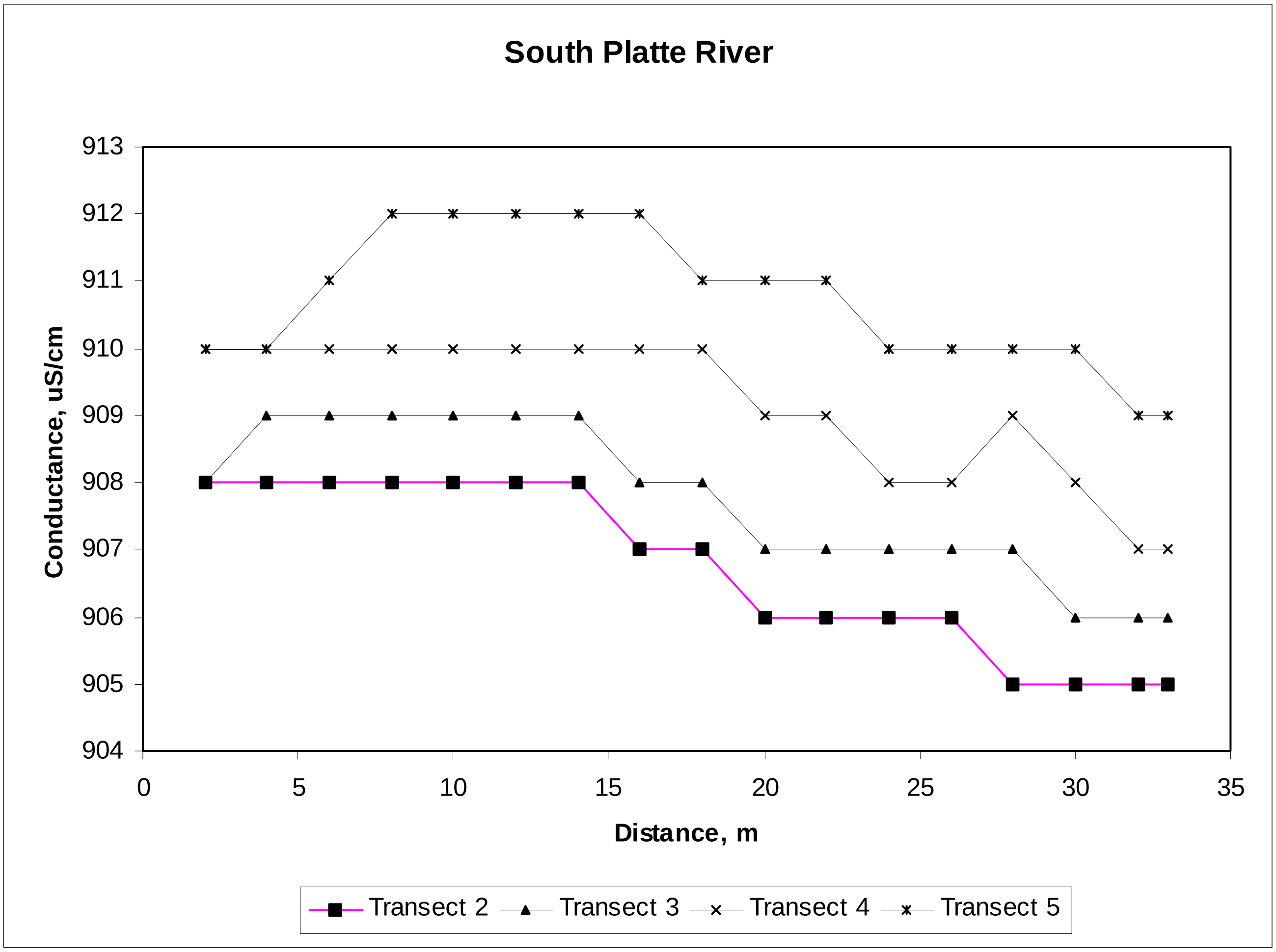


Figure II-1 Conductance measurements at intervals of 15 minutes on the South Platte River above Meadow Island ditch (6 March 2000, W to E).

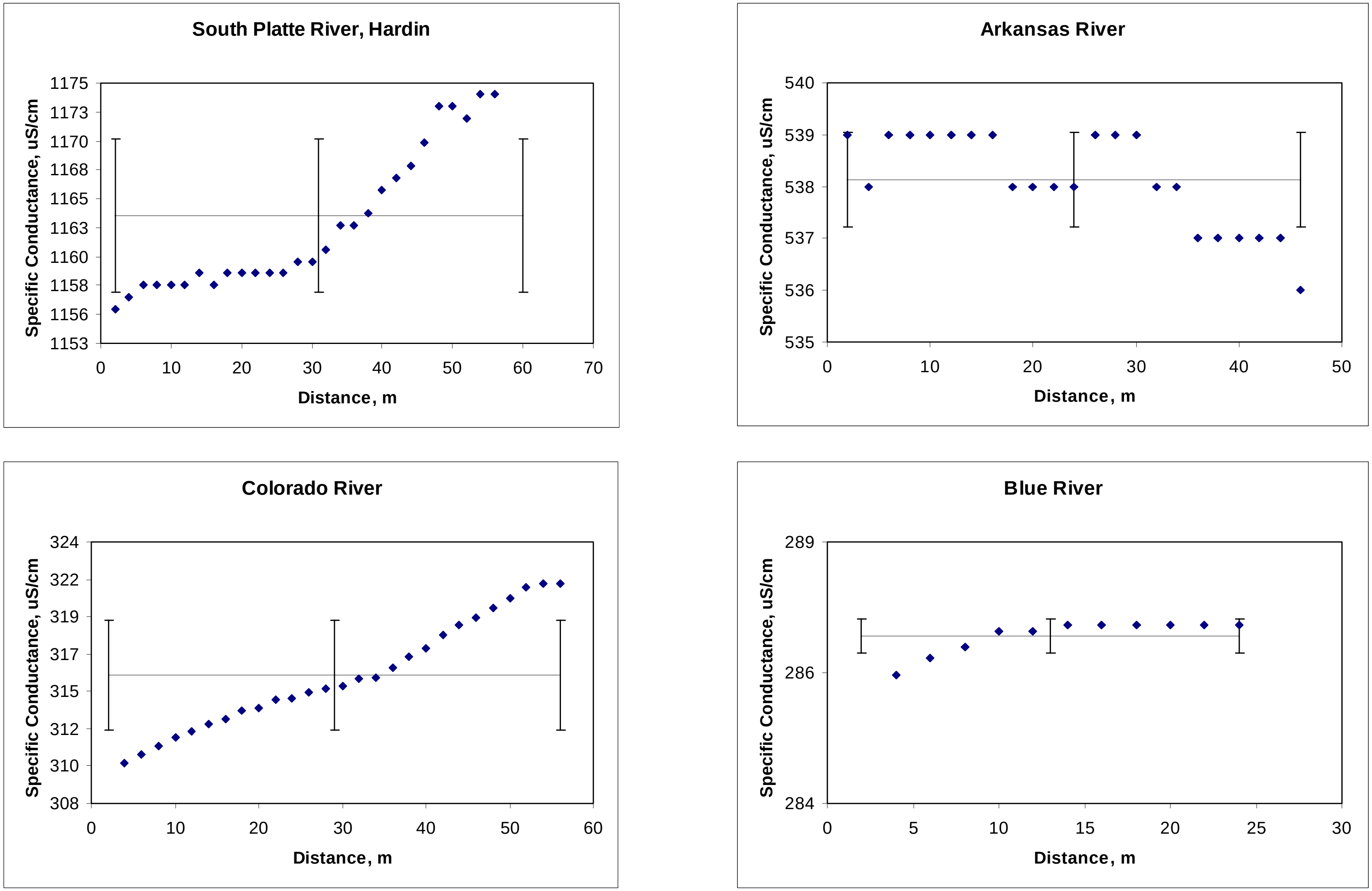


Figure II-2 Conductance plots

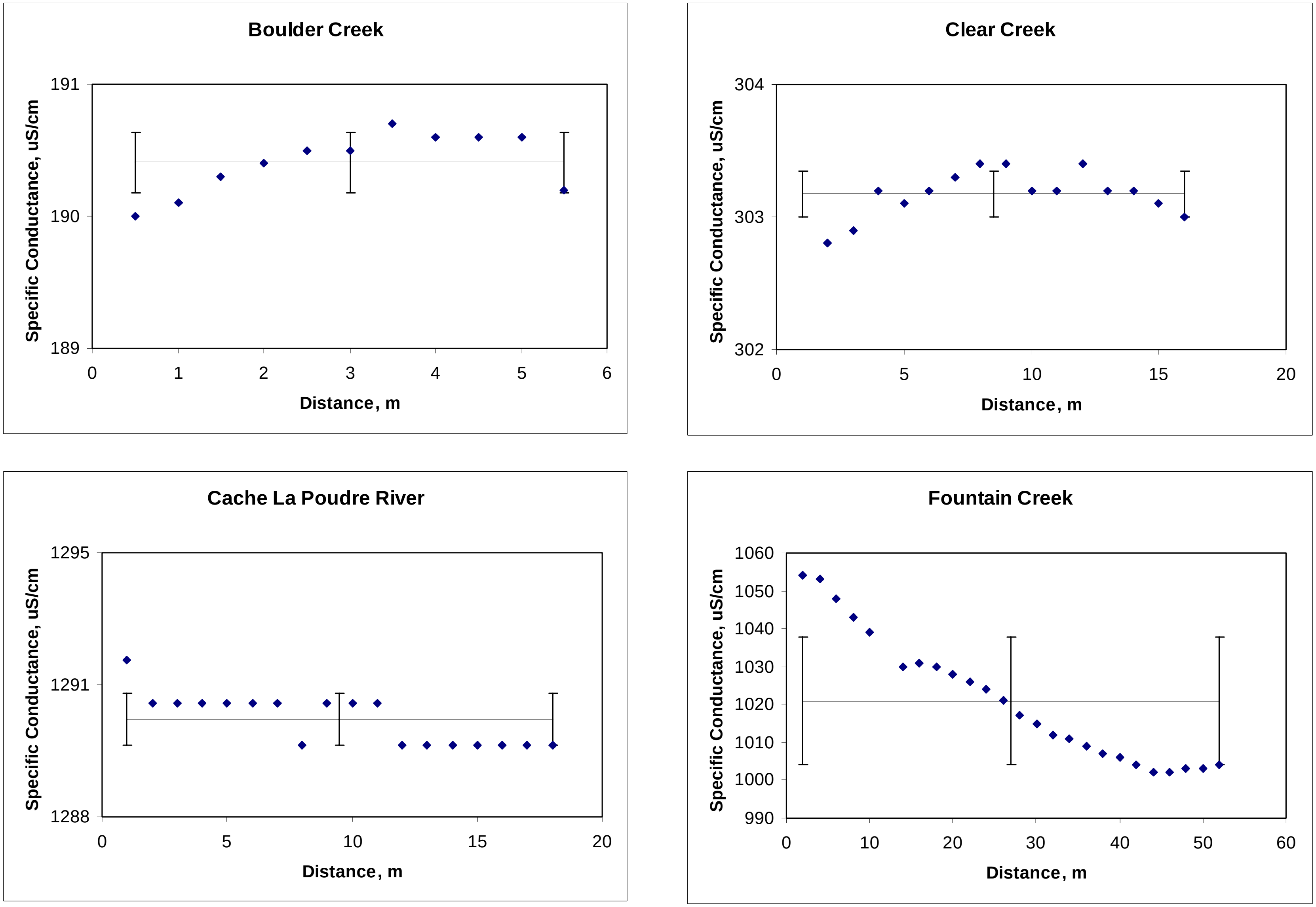


Figure II-3 Conductance plots

Table II-2 summarizes statistical information on variance over cross-sections. Because variance over cross-sections in some cases involves trends from one bank to another, the most appropriate index for variance is probably the range of measurements (normalized to the mean; expressed as % range) rather than standard deviation or coefficient of variation.

Discussion and Interpretation

The results of the field studies show that individual field sites where surface sources are fully mixed with the main stem can show cross-sectional variation in water chemistry. The largest source of cross-sectional variation is associated with unmixed flows from subsurface sources. While this source of variation is easily measurable, it is small in absolute magnitude.

Results of this study show that the range of measurements over a cross-section that is fully mixed with respect to surface flows often will be higher than 1% but is unlikely to be higher than 10%.

Criteria for Determination of Complete Mixing

Information on cross-sectional variability in water chemistry must take into account the possibility of some heterogeneity generated by processes other than effluent or tributary plumes. The field evidence presented in this report suggest that sources of cross-sectional variation other than tributaries or effluent plumes would not create cross-sectional variation exceeding 10% relative range. Thus for purposes of identifying the lower end of a physical mixing zone below a permitted discharge by use of a passive tracer, 10% relative range can be used as a threshold separating the unmixed from the fully mixed condition. For purposes of field studies related to mixing zones, effluent discharges will be considered fully mixed at the point downstream of the discharge where the relative range of cross-sectional measurements is 10% or less. It is assumed that relative range will be determined from a number of measurements sufficiently large to represent the true cross-sectional variation of the stream (12 or more points for wide streams; 6 - 12 points for streams of intermediate size, and 4 - 6 points for small streams). The relative range applies to measurements that are made with negligible relative measurement error. Where measurement error is significant, statistical adjustments can be made to extract measurement error from total error to give an estimate of degree of cross-sectional variation.

Location	Range	% Range	S.D.	C.V. (%)
South Platte River above Meadow Island Ditch	906 - 909	0.3	1.2	0.1
South Platte River near Hardin	1156 - 1175	1.6	6.4	0.6
Colorado River near Dotsero	310 - 322	3.6	3.5	1.1
Blue River below Dillon Dam	286 - 287	0.3	0.3	0.1
Arkansas River above Fountain Creek	536 - 539	0.6	0.9	0.2
Fountain Creek near Mouth	1002 - 1054	5.1	16.8	1.6
Clear Creek above Golden	302.8 - 303.4	0.2	0.2	0.1
Poudre River at Mouth	1290 - 1292	0.2	0.6	0.05
Boulder Creek at Eben Fine Park, Boulder	190 - 190.7	0.4	0.2	0.1

Table II-2. Results of field studies.

Appendix III

Sample Calculations for the Application of Mixing Zone Regulations to Streams

The following calculations would apply for streams not shown exclusion by reason of extreme mixing ratios.

I. Obtain data for application of exclusion tables.

A. Locate 6 transects starting at the discharge point and spaced about

one bankfull channel width (A-F, Figure 1)

B. Measure stream width and obtain mean water depth at low flow for each transect; get means across transects.

Results: Mean width = 19 feet

Mean depth = 2.0 feet

C. Select proper exclusion table: plains, transition, or montane

Result: Plains

D. Apply exclusion table

Result: Excluded; no further analysis required.

II. If site is not excluded by use of table, map physical mixing zone.

A. For this step in the calculations, assume the following result from I above: Plains stream, stream width = 19 feet, mean depth = 0.75 feet; not excluded by table.

B. Estimate size of regulatory mixing zone: measure bankfull width at each of 6 transects (Figure 1, A-F), calculate mean width, square, multiply by

Result: RMZ = $(40)^2 \times 6 = 9600 \text{ ft}^2$

C. Map boundaries of physical mixing zone (at low flow). Try conductance first. Get upstream value and effluent value. Difference between the two multiplied by 0.1 must be greater than the sensitivity of the meter (usually 1 µS/cm). See guidance for other options if this does not work.

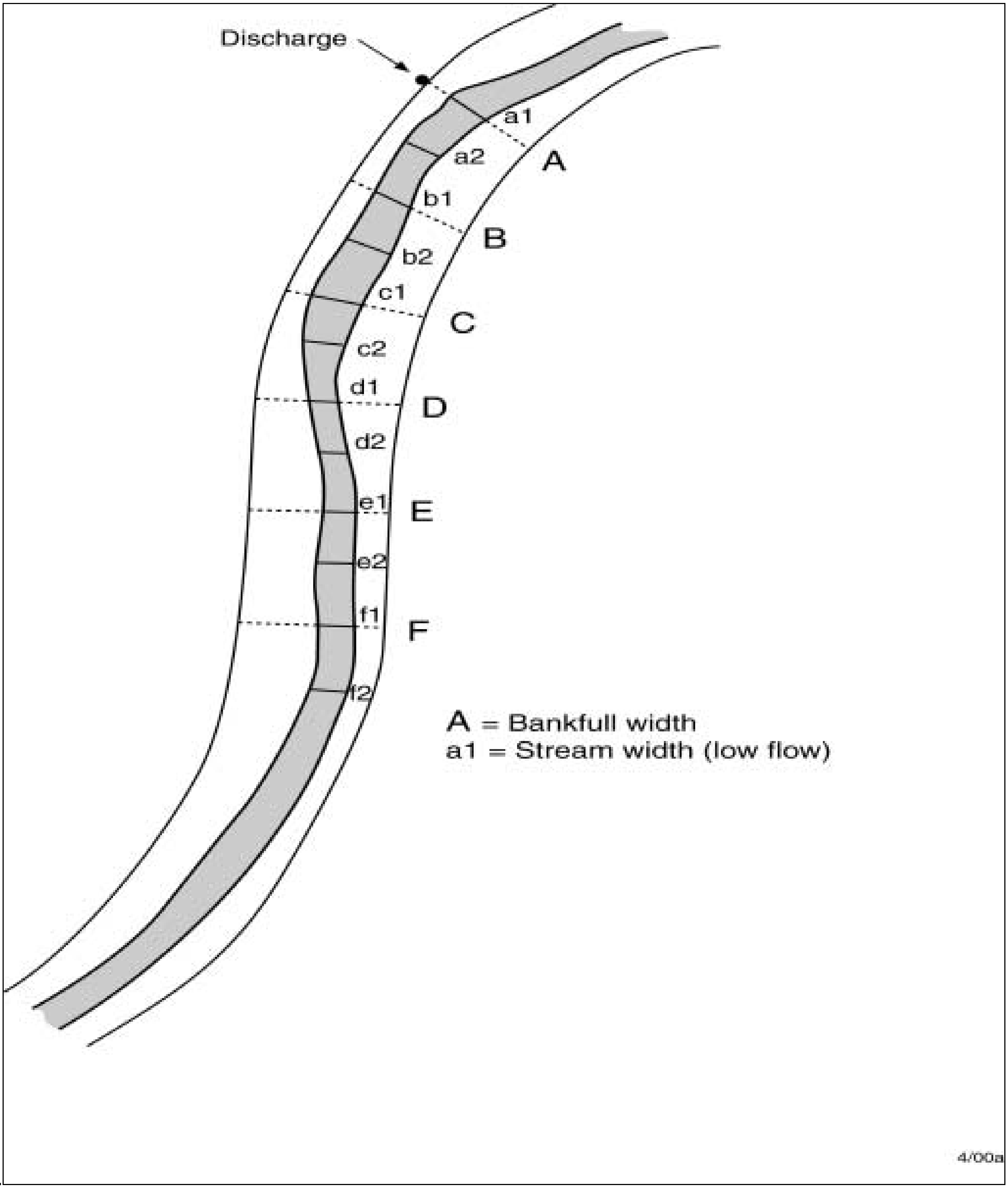


Figure III-1 Diagrammatic view of a study area below a discharge.

D. Obtain a number of cross-channel tracer (conductance) measurements at each of 12-15 transects (Figure 1, A1-F2). When measurements are within 10% over the cross section, add two transects just upstream to find the bottom of the PMZ.

E. Compute percent dilution for each measurement (see guidance for formula). On a map of the stream, place each one of the dilution estimates. Draw a line at the 90% dilution boundary (effluent 10% of mix) and estimate the area inside. This is the PMZ.

a) Result: PMZ = 8500 ft^2

F. Compare RMZ, PMZ

b) Result: RMZ>PMZ; no further analysis needed.

III. If RMZ<PMZ, map exceedance zones.

A. Identify pollutants of concern. If these include hardness-dependent metals, measure effluent hardness and upstream hardness. If ammonia is included, measure pH and temperature for effluent water and upstream (dilution) water.

B. From dilution map, estimate chronic standard (if it varies with chemistry) and estimate concentration of regulated substance, record for each point on the map.

C. Draw a line around chronic exceedances, estimate area. If EZ<RMZ, permit is not affected. Assume for this example EZ>RMZ and that ammonia is a pollutant of concern. Result: EZ = 10,500 ft^2 at a trial limit of 10 mg/L total ammonia in effluent.

D. Reduce trial limit 20% (based on visual estimate of EZ size reduction that is necessary), remap. Result: EZ very close to RMZ (within 5%); use this trial limit as permit limit.

E. Repeat for acute limit, using appropriate size for the acute RMZ (usually 10% or 25% of the size of the chronic RMZ, as explained in the guidance).

Appendix IV

Mixing Zone Guidance for Waters
with Threatened and Endangered Species

1. The Division will provide the United States Fish and Wildlife Service (Service) with information regarding proposed issuance of permits and their associated locations of discharge, as well as a list of stream segments that may be influenced by these discharges, twice each year in November and April . The Service will provide the Division with a list of streams or stream segments where threatened or endangered species occur[1]. Periodic meetings between the Division and the Service may be requested by either party for discussion of specific mixing or dilution issues prior to the time that permits are written. Permits drafted by the Division for waters with threatened or endangered species will be provided to the Service and the USEPA (EPA); the Service or the EPA may request that changes be made prior to release of the draft permit for public notice. The Division will provide copies of each public notice and of each noticed permit to the Service and to the EPA as soon as they are available. The Division will maintain a computerized, cumulative list of permits reviewed as described here as well as any actions that are taken in response to review. This list will be provided to the Service and the EPA along with each 6-month review cycle. It is expected that relatively few discharge permits will be identified for special attention because only a few discharges in Colorado are located where threatened or endangered species occur.

2. Permits for which the Service does not indicate concerns related to threatened or endangered species will require no modification to protect threatened or endangered species.

3. Permits for which the Service indicates concerns related to threatened or endangered species will

1 For purposes of this guidance, "threatened or endangered species" means aquatic species that are listed, candidate, or proposed for designation as threatened or endangered.

require site-specific adaptation of mixing zone regulations consistent with the following:

a. For aquatic life standards, the Division will presume that one of the following three options generally will be appropriate:

   (i) Limits may be based on mixing that will result from installation of a diffuser covering all or part of the low-flow channel. This option may be modified if the Service finds installation of a diffuser may adversely affect threatened or endangered species (e.g., by interference with fish migration). The use of a diffuser will be considered appropriate only if the acute and chronic low flows of the receiving water provide dilution of the effluent adequate for protection all of threatened and endangered species[1].

   (ii) Limits may be based on passive mixing. Passive mixing may involve use of all available dilution, if the permittee demonstrates that such mixing will be protective of all threatened and endangered species[1]. Such proposals will be evaluated by the Division on the basis of technical merit. Limits may be based on appropriate water quality standards to be met at end-of-pipe, unless some dilution can be justified. The Division will seek comments from the Service and the EPA in such cases.

   (iii) Limits may be based on relocation of a discharge to a less sensitive portion of the receiving water (e.g., away from nursery areas).

b. For standards related to protection of human health, the Division will presume that a mixing zone will adequately protect threatened or endangered species unless the Service or others provide evidence to the contrary, in which case the Division may deny or limit the size of a mixing zone on a site-specific basis for such standards.