SOUTH CAROLINA MIXING ZONE REQUIREMENTS, CORMIX MODELING AND NPDES PERMIT LIMITATIONS

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REFERENCE: *Proceedings of the 2012 South Carolina Water Resources Conference*, held October 10-11, 2012, at the Columbia Metropolitan Convention Center

ABSTRACT. South Carolina Department of Health and Environmental Control (SCDHEC) regulations allow mixing zones (i.e., surface water zones where water quality criteria can be exceeded) but restrict their size. The CORMIX model has been used by SCDHEC and the regulated community for many years, and it has become the SCDHEC-required standard for designing effluent discharge structures, estimating the size of discharge plumes/mixing zones, and maximizing instream mixing to achieve more favorable NPDES permit limitations. CORMIX may be used to optimize a new discharge structure (e.g., a multiport diffuser) or to model an existing outfall (e.g., a surface "channel" discharge) using steady-state or tidal simulations. Acute and chronic whole effluent toxicity are most commonly modeled, but CORMIX may also be used to determine maximum and "rise-above-background" thermal limitations and avoid costly instream studies. State mixing zone requirements and model predictions are used to determine appropriate permit limitations, but model results, along with previous discharge monitoring data (e.g., 25th percentile inhibition concentration, "IC_{25}," toxicity data) and a reasonable potential analysis, may also be used to reduce monitoring frequencies or remove limitations from a permit.

SC MIXING ZONE REQUIREMENTS

During NPDES permit development, SCDHEC must consider many factors when determining appropriate permit limitations for a wastewater discharge. The most restrictive of all factors considered is typically selected, and for many NPDES permits across South Carolina, water quality-based effluent limitations (WQBELs) are the most restrictive. WQBELs are based on maintaining the aquatic life and human health-based instream water quality standards provided in regulation. In the most basic terms, each downstream water quality standard (e.g., numeric criteria concentration) must be maintained after the upstream flow (at worst-case conditions, typically the annual minimum 7-day average with a 10-year recurrence interval, "7Q10") and background concentration is mixed with the discharge flow and concentration. South Carolina Regulation *R.61-68, Water Classifications and Standards* includes both specific numeric criteria for priority toxic pollutants to protect aquatic life and human health (refer to the Appendix of R.61-68) as well as narrative water quality standards. NPDES permit limitations ensure that these standards are maintained after the discharge mixes with the receiving water body.

WQBELs may also provide limited zones for dilution of the effluent plume where substances may exceed the instream standards. These "mixing zones" are established in to restrict the duration of exposure to organisms passing through the effluent plume and protect the waters' designated uses. Per R.61-68.B.39.a, "Mixing zone means, for surface waters, an area where a discharge undergoes initial dilution and is extended to cover the secondary mixing in the ambient waterbody. A mixing zone is an allocated impact zone where water quality criteria can be exceeded as long as acutely toxic conditions are prevented (except as defined within a zone of initial dilution) and public health and welfare are not endangered." The area of a mixing zone immediately surrounding an outfall is the zone of initial dilution (ZID).

While South Carolina's mixing zone requirements originated from EPA's 1991 *Technical Support Document for Water Quality-based Toxics Control* and later SCDHEC's 1998 *Toxics Control Strategy*, R.61-68 includes the current regulatory requirements, and the instructions associated with SCDHEC's May 2009 "Mixing Zone Request for Surface Water Discharges" form includes recommended boundary conditions/sizes for mixing zones. Permittees must use this NPDES supplement form to request a mixing zone for a new discharge outfall and must include it with updated model results during each permit renewal.

SCDHEC's recommended mixing zone boundaries are:

<u>Acute Mixing Zone/ZID Dimensions</u>
Width: 1/10 of the river width
Length: 1/3 of the river width

<u>Chronic Mixing Zone Dimensions</u>
Width: 1/2 of the river width
Length: Twice the river width

Though these boundaries are recommended by SCDHEC, R.61-68.C.10 states that, "The size of the mixing zone shall be minimized, as determined by the Department, and shall be based upon applicable critical flow conditions." Minimizing the mixing zone size to less than the recommended boundaries may be required based on site-specific biological, chemical, engineering, hydrological, and physical factors. R.61-68.C.10 also includes specific situations where mixing zones are not allowed such as for bacteria, where safe passage of aquatic organisms is obstructed, for potential adverse affects to a federally-listed endangered or threatened aquatic species, and for other specific situations.

PERMIT LIMITATIONS FOR MIXING ZONES

The instream concentration of effluent in a receiving water body is 100% at the immediate end of the discharge pipe or at each diffuser port, and as the discharge plume mixes with the ambient water, the concentration of effluent in the stream decreases. The instream effluent concentration along the plume's centerline at the point where either the SCDHEC-specified length or width boundary is reached first is used to determine the appropriate permit limitation. For example, as the plume moves downstream, expands, and becomes more dilute, the whole effluent toxicity (WET) 48-hour acute test concentration (ATC) and the 7-day chronic test concentration (CTC) may be 20% and 5% respectively at the more restrictive mixing zone boundary. Depending on the ratio between the acute and chronic test concentrations, both acute and chronic WET testing may be required in the permit, but without a mixing zone, chronic WET testing at 100% effluent would be required. For thermal mixing zones, a 100°F discharge into a freshwater stream (for example) must be cooled to below the 90°F maximum temperature standard within the ZID boundaries, and must meet the 5°F temperature change standard (above background based on local seasonal USGS/SCDHEC monitoring data) within the mixing zone boundaries. If both temperature standards are met, the permit would include, using the previous example, only a maximum 100°F temperature limitation. Note that generating thermal mixing zone models can be significantly cheaper than performing instream sampling and/or studies, such as a 316(a) thermal variance study.

CORMIX OVERVIEW

The CORMIX modeling system (licensed and distributed solely by MixZon Inc.) is a USEPA-supported, Windows-based software system (currently Version 8.0) for the analysis, prediction, and design of continuous (steady-state) point source discharges into various water bodies. Effluents considered may be conservative, non-conservative, heated, brine discharges or contain suspended sediments. The model focuses on the geometry and dilution characteristics of the initial (near-field) mixing zone as well as predicting the behavior of the discharge plume at larger distances (far-field). The three primary subsystems used for establishing water quality mixing zones are CORMIX1 for single port discharges, CORMIX2 for multiport diffuser discharges, and CORMIX3 for buoyant surface discharges.

As indicated, the hydrodynamics of an effluent continuously discharging into a receiving water body is modeled as a mixing process that occurs in two separate regions. In the first region (near-field), the initial jet characteristics of momentum flux, buoyancy flux, and outfall geometry influence the jet trajectory and mixing. In this near-field region, outfall designers can affect the initial mixing characteristics through appropriate manipulation of design variables (e.g., port diameter/exit velocity and port/plume jet orientation/depth). As the turbulent jet/plume travels further away from the source, the source characteristics become less important. Conditions existing in the ambient environment (far-field) will control trajectory and dilution of the plume through buoyant spreading motions and passive diffusion. These near and far-field hydrodynamic model regions are not related to the previously discussed acute and chronic regulatory mixing zones.

CORMIX MODEL SETUP AND EXECUTION

Note: The actual CORMIX program and an example model were utilized for the presentation associated with this abstract – select modeling notes are provided within this abstract.

In the early 1990's, CORMIX was originally a DOS-based program that required reentering all inputs for each model run, but fortunately all inputs are now entered into separate worksheets/tabs under the Windows-based system. These tabs are listed below with notes regarding select input variables. SCDHEC requires that the permittee provide a model input checklist with the mixing zone request form, model predictions, and plume graphics. SCDHEC may also request additional information regarding individual model inputs based on their review; therefore, providing a brief summary of the justification for the model inputs may expedite their review.

Project

Include detailed project notes in the space provided, because these notes, along with the model input justification previously mentioned, will provide the basis for future models (e.g., permit renewals).

Effluent

100% effluent with no decay is the starting point for WET models. The discharge flow rate may be the long-term average flow for an existing discharge, or it may be a pumped flow rate for an intermittent discharge. Note that for new, pumped discharges, the pump selection (i.e., flow rate, headloss, pump curve, etc.) should be coordinated with the diffuser/pipe design to maximize mixing while minimizing construction and operating costs. The difference between effluent and ambient temperature/density determines whether the plume floats or sinks, and this can have a significant impact on mixing.

Ambient

If not available from previous models, a stream survey (not necessarily by a registered surveyor) must be performed at the existing/proposed discharge location and at several downstream cross sections to the extent of the mixing zone (based on preliminary modeling). If an instream diffuser or pipe will be constructed, a geotechnical survey at the proposed location should also be performed. Stream flow velocities at regular width and depth intervals at each cross section may be taken, or alternatively, the actual stream flow (from a nearby USGS gaging station) may be used to convert (i.e., lower the water surface elevation) of the stream profile on the date surveyed to a profile during the worst-case (e.g., 7Q10) flow rate. The low flow-adjusted stream profile is used to determine the appropriate model “box” cross sectional width and depth that includes the majority of the stream flow at the discharge location. An approximation of the stream’s Manning’s-n or Darcy-Weisbach-f friction factor should also be determined during the stream survey.

While most discharges in South Carolina are into free-flowing streams, some are into lakes and tidal waters. CORMIX can address both situations, though the tidal simulation is simply a series of steady-state models that considers the buildup and flushing of a plume during a tidal cycle. SCDHEC has also approved worst-case non-tidal models (e.g., at slack low tide) for tidal discharges. Similar to temperature, ambient and discharge salinity/density are important inputs into tidal models as they affect plume buoyancy and mixing.

Discharge

The user selects the desired subsystem for either a single-port, multiport, or surface discharge, each with inputs that determine the location and orientation of the discharge in the receiving water. Because these inputs have the most effect on near-field mixing, for new/modified discharge structures (e.g., a diffuser), these inputs should be varied to maximize initial mixing while minimizing construction and operating costs. It may also be necessary to run several single-port models to represent a multiport diffuser based on the port spacing or varying/sloped stream geometry. The model includes size and location restrictions associated primarily with the ambient depth and width. Error messages regarding these restrictions will be flagged once the model is run, and the model predictions will not be generated until all restrictions have been met.

Mixing Zone

The inputs within this tab simply determine how many output steps to display, how far downstream to continue the prediction, and whether or not the model prediction and associated plume graphics should show where any designated water quality standards or mixing zone dimensions have been reached.

Output

The primary model outputs, and those required by SCDHEC, are the session and prediction files. The session file provides details regarding the model inputs and model run, while the prediction file provides a tabular representation of the plume width, depth and concentration as it moves downstream. CorVue, a post-processing program, may be used to generate color plan, profile, and isometric views of the plume.

RELATED TOPICS

Sensitivity analyses may be run on a model case with varying discharge flow rates, port cross-sectional areas (i.e., duckbill valves used to increase velocity at lower discharge flow rates), ambient depth and velocity, density, etc. This tool (CorSens) may also be used to model several discharge flow rates for a production-based tiered permit. A sensitivity analysis may also be used to extrapolate model predictions beyond a model restriction/error to meet a desired endpoint. If they exist, model restrictions/errors are noted in the model session and prediction files. For example, the model may predict concentrations beyond the point of limiting (available) dilution but provide an associated note.

A reasonable potential analysis may be used to compare previous acute or chronic (e.g., IC_{25}) serial dilution WET test data (provided by the laboratory and included on the SCDHEC “DMR Attachment for Chronic Multi-Concentration Whole Effluent Toxicity Test Results Using Linear Interpolation”) to the modeled ATC/CTC to determine whether or not continued WET testing is warranted. A reasonable potential analysis performed by the State includes the use a mass and variability-based spreadsheet tool to mathematically determine whether or not reasonable potential exists, but regulation allows the Department to consider other factors. Therefore, while WET limits, for example, may be removed from a permit, once-per-year monitoring and reporting may be required.

For new outfalls, SCDHEC may also require an instream verification study (typically using a tracer for WET) to validate the model results. If there are significant differences between the model prediction and the instream study, the permit limitations may be adjusted.