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MIXING ZONE ANALYSIS FOR STORM WATER DISCHARGE INTERIM REPORT CNC CHARLESTON SC

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ENVIRONMENTAL CONSULTING AND TECHNOLOGY, INC.

MIXING ZONE ANALYSIS FOR STORM WATER DISCHARGE AT CHARLESTON NAVAL COMPLEX INTERIM REPORT

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1.0 INTRODUCTION

The Charleston Naval Complex (CNC) is a 1,575 acre area located in North Charleston along the west shore of the Cooper River. It is bordered to the east by the Cooper River, to the south by the Shipyard Creek, to the west by Spruill Avenue, and to the north by Hess Oil. Storm water runoff from CNC drains into the Cooper River, Shipyard Creek, and Noisette Creek, carrying potential pollutants with it.

The purpose of this study is to determine the zone of potential impacts on the receiving water quality caused by storm water discharges. Mixing zone modeling analyses are conducted in order to quantify the mixing zone.

1.1 SITE DESCRIPTION

The general topography of the CNC area is relatively flat and low lying. Most of the land surface slope is less than 2 percent. The land elevation in the area ranges from 2 to 11 meters below mean low water, and most of the CNC land surface lies below 3.7 meters below mean low water. The land use in the area is predominantly impervious heavy industrial land. Other land uses include marshlands, grassy fields, residential, light industrial, and commercial use. A southern portion of the CNC consists almost entirely of dredge spoil material, which is generally a mixture of sands, silts, and clays.

1.2 SITE DRAINAGE

Thomas & Hutton Engineering Company conducted a storm water assessment as part of the *Naval Infrastructure Study* in 1996. Subsequently, Davis & Floyd, Inc., conducted further engineering evaluations and produced a report *Evaluation of Drainage System Serving Charleston Naval Complex* (1998). According to these previous studies, the storm water drainage system is divided into 98 sub-basins. Some basins do not have any drainage facilities, and the storm water runoff drains directly to the receiving waters in the form of sheet flow, or overland flow. Other basins may have complex drainage systems that consist of catchments, inlets, storm sewer pipes, manholes, detention ponds, flow control structures, and outfall structures.

There are 54 known storm water outfalls at CNC. Only two outfalls drain into Shipyard Creek, eight outfalls drain into Noisette Creek, and the remaining outfalls drain into the Cooper River. The outfall structures are mostly reinforced concrete pipes (RCP) and corrugated metal pipes (CMP). The size of the outfall structure ranges from 20 centimeters (cm) (8 inches) to 137 cm (54 inches) in diameter. The most common outfall pipe sizes are 46 cm (18 inches) and 76 cm (30 inches) in diameter. The invert elevations of the outfalls are mostly between mean high water and mean low water.

1.3 BATHYMETRY

The width of the Cooper River fronting CNC ranges from 490 meters (1,600 feet [ft]) at the narrowest section to 1010 meters (3,300 ft) at the widest section, and the median width is about 915 meters (3000 ft). The depth of the main navigation channel in Cooper River ranges from 12.8 meters (42 ft) to 14 meters (46 ft) below mean low water. The length of the CNC waterfront along the Cooper River is about 6.04 kilometer (km) (3.75 miles).

Shipyard Creek consists mostly of dredged channel and turning basins that serve the industrial developments along the western and southern shore of the creek. The depths of the main channel and turning basins range from 8.5 meters (28 ft) to 13.7 meters (45 ft). The length of the deepened portion of the creek is about 1.52 km (0.95 mile).

Noisette Creek is mostly a natural tidal creek with a length of 2.3 km (1.4 miles). The width of the creek ranges from 15 meters (50 ft) at the upstream segment to 36 meters (110 ft) at the downstream segment. The depth of the Noisette Creek ranges from 0.15 meters (0.5 ft) to 1.5 meters (5 ft) below mean low water.

1.4 TIDES AND CURRENTS

According to National Oceanic and Atmospheric Administration's (NOAA's) tidal and current tables, the average tide range near the entrance of the Shipyard Creek is about

1.62 meters (5.3 ft). The average tide range in Cooper River near the south entrance of the Clouter Creek is about 1.65 meters (5.4 ft).

The average maximum flood current speed in Cooper River at North Charleston is about 0.57 meters per second (m/sec) (1.1 knots) and the average maximum ebb current speed is about 0.87 m/sec (1.7 knots). The average maximum flood current speed in Cooper River at Daniel Island Bend is about 0.62 m/sec (1.2 knots) and the average maximum ebb current speed is about 1.08 m/sec (2.1 knots). The maximum tidal currents at the spring tide are higher than the average maximum values. For example, the peak ebb current during spring tide at Daniel Island Bend can be as high as 1.90 m/sec (3.7 knots).

1.5 SALINITY

In addition to bathymetry and tidal currents, the salinity of the Cooper is another important factor that determines the characteristics of the mixing zone because of buoyancy effects. When storm water, a freshwater discharge, enters the saline Cooper River, the lighter freshwater tends to stay on top of the heavier saline water and hinders vertical mixing. Therefore, it is more difficult to dilute the storm water discharge when the Cooper River salinity is high.

According to the data collected by South Carolina Department of Health and Environmental Control (SCDHEC) at the Cooper River near Noisette Creek, the surface salinity ranged from 10 parts per thousand (ppt) at low tide to 22 ppt at high tide. The bottom salinity ranged from 16 ppt at low tide to 26 ppt at high tide.

The salinity data at the Cooper River near Shipyard Creek indicated that the surface salinity ranged from 15 ppt at low tide to 23 ppt at high tide. The bottom salinity ranged from 18 ppt at low tide to 31 ppt at high tide.

2.0 MIXING ZONE ANALYSES

During the course of urbanization, greater and faster storm water runoff occurred due to the increased impervious surface area in the watershed. In addition, the urbanization could also degrade the runoff water quality due to the soil erosion, pesticides, fertilizers, oil and grease, and other pollutants washed off by runoff from the developed lands. To assess the potential water quality impacts of the storm water discharges from the CNC and to evaluate the dilution effects of the Cooper River flow, mixing zone analyses were conducted.

2.1 METHODOLOGY

CORMIX, a mixing zone model recommended by the U.S. Environmental Protection Agency (EPA), was selected to evaluate the storm water discharge from CNC. An advanced Windows version of the model, CORMIX GT Version 4.1, was used for this study. The CORMIX model, also known as the Cornell University Mixing Zone Expert System, has been considered the most significant development in the field of pollutant plume prediction since the 1970s (Jirka et al., 1996). It was selected for this application over other potentially applicable models for several reasons:

- CORMIX is quite versatile, and it incorporates various algorithms to simulate the discharge plume along its entire length at different flow regimes.
- Most other available models are often limited to either the nearfield or the farfield region only, while CORMIX is capable of simulating both regions, as well as the transition zone between nearfield and farfield.
- CORMIX is widely used and accepted by permitting agencies.
- CORMIX code has been continuously improved and updated over the past years and is actively supported by the EPA Center for Environmental Exposure Assessment.
- CORMIX is recommended by EPA for mixing-zone analysis.

The CORMIX expert system offers the distinct advantage of incorporating field data, laboratory results, and computer models into a single analysis tool for a wide variety of discharge and receiving water conditions. The user specifies the properties of the ambient and discharge conditions, and the expert system chooses the appropriate algorithms to perform the simulation. The system considers three basic types of outfalls: surface discharge, submerged multiport diffusers, and submerged single-port discharges. The surface discharge model, CORMIX 3, is employed in this study.

Pollutant plumes are typically analyzed as having two major components: the nearfield and the farfield. The nearfield, also referred to as the initial dilution zone, is the receiving water in the immediate vicinity of the discharge. In this zone, the shape and extent of the plume are dominated by the momentum of the discharge jet as governed by the discharge structure configuration. The discharge itself is often called a jet to characterize its strong momentum. While pollutant concentrations are highest in the nearfield, it typically covers a much smaller area than the farfield. The farfield, on the other hand, is the area outside the active jet momentum region. Plume is transported and dispersed in the farfield by ambient flow. Dilution occurs much more rapidly in the nearfield than in the farfield.

Dunn *et. al.* (1975) summarize the following five physical processes as basic processes governing pollutant plume dispersion:

- Jet entrainment—Near the point of discharge, the momentum of the discharge jet causes turbulence that leads to the entrainment of ambient water into the jet flow. The turbulent entrainment results in an increase in the quantity of diluting flow associated with the jet, as well as a rapid decrease in concentration.
- Crossflow interaction—If the jet discharges into an ambient current, the current will cause the jet to deflect. In a tidal current, the reversing flow sometimes inhibits the dispersion of pollutants and leads to an overall larger plume.
- Turbulent diffusion—Natural mixing and dispersion processes will result in the dissipation of pollutants by mixing with ambient water.
- Buoyant spreading—The freshwater has buoyancy relative to the denser ambient saline water. Buoyancy may cause the plume to spread horizontally and may inhibit vertical mixing.

- Surface heat loss—If the outfall is a heated discharge, the thermal plume will lose heat to the atmosphere, limiting the size of the plume. This effect is more important in the farfield than in the nearfield.

Processes 1 and 2 dominate the mixing in the nearfield, and processes 3, 4, and 5 are important in the farfield.

2.2 MODEL SCENARIOS

For the purpose of evaluating the storm water mixing zone under a wide variety of discharge and ambient conditions, the following scenarios were selected for modeling analyses:

- Four outfall sizes were considered: 18, 24, 30, and 48-inch diameter.
- Two storm conditions were considered: moderate storm and severe storm. It was assumed that the effluent jet velocity was 3 feet per second (ft/sec) under a moderate storm, and 7 ft/sec under a severe storm.
- As many as seven ebb tide current speeds were considered (0.05, 0.1, 0.2, 0.3, 0.5, 0.8, and 1.19 m/sec). Similarly, as many as six flood tide current speeds were considered (0.05, 0.1, 0.2, 0.3, 0.5, and 0.67 m/sec).

Based on the scenario matrix, approximately a total of 70 model simulations were conducted for combinations of various outfall sizes, storm conditions, and ambient flow conditions.

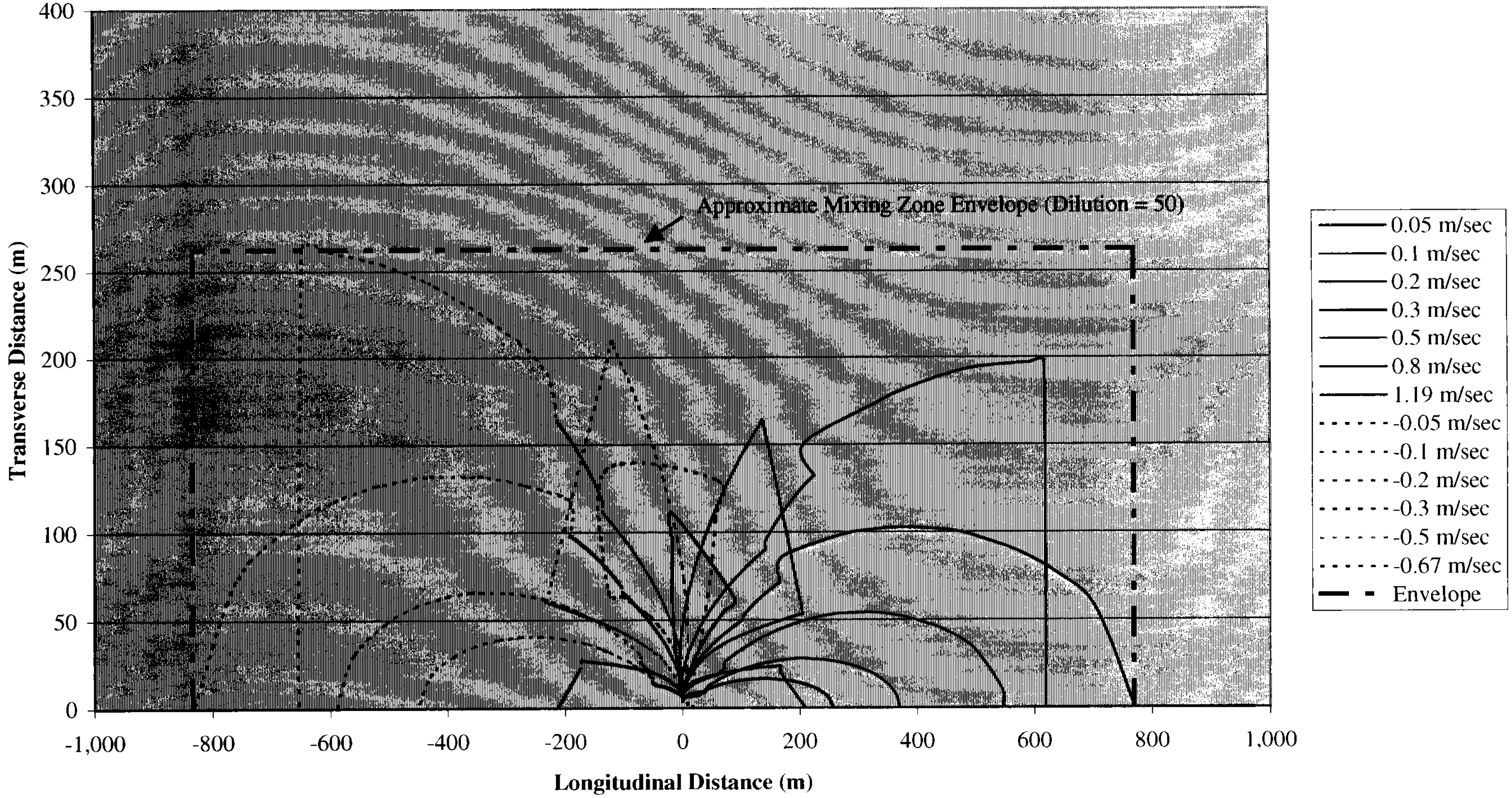
The following ambient and effluent characteristics were used as model input parameters:

- River width is 914 meters (3,000 ft).
- Average river depth is 7.6 meters (25 ft).
- Outfall is located at the water surface.
- The orientation of the discharge pipe is perpendicular to the shoreline.
- The direction of the discharge is horizontal.
- The surface salinity in the Cooper River is 10 ppt at low tides and 22 ppt at high tides. Salinity is linearly interpolated between high and low tides.

2.3 MODELING APPROACH

Currently, there is no storm water quality data available at CNC outfalls. Therefore, the model results are presented in terms of dilution factors. Given the isopleths of various dilution factors under certain effluent conditions, the pollutant plume can easily be mapped if the discharge and ambient concentrations are known. The following describes the procedures to establish such isopleths, or mixing zone envelops, using a 30-inch outfall under moderate storms as an example.

The first step of the analysis is to conduct CORMIX modeling for various tidal current conditions under a discharge scenario (30-inch outfall, moderate storm). Based on the model results, the isopleths for a specific dilution factor, e.g., 50 to 1 dilution, can be established. Figure 2-1 shows the isopleths of 50 to 1 dilution during various phases of the tidal conditions. Each line encloses an area where the dilution factor is less than 50 and represents the instantaneous mixing zone at certain phase of the tide. The figure shows that the shape and orientation of the 50 dilution isopleths changes with the phase of the tide and the pollutant plume swings around the outfall when tide changes. For example, the 50 dilution plume is concentrated in a small area near the outfall during slack tides (0.05 m/sec and –0.05 m/sec). A negative current speed represents flood tide and a positive current speed represents ebb tide. In the initial phase of the flood tide (-0.1 meters per second [m/sec]), a wide plume (209 meters from shore) is developed because the ambient current is not strong enough to significantly deflect the jet moment. When the flood current increases to -0.2 m/sec, the length of the plume increases while the width of the plume reaches its maximum size (263 meters from shore). When the flood current increases to -0.3 m/sec, the width of the plume started to decrease because the stronger ambient current begins to effectively deflect the plume. In the meantime, the length of the plume reaches its maximum because the stronger current carries the plume further upstream. When the flood current continues to increase, both the width and the length of the plume start to decrease because the strong current enhances the turbulent mixing, reduces pollutant concentration, and thus reduces the mixing zone size. The ebb tide cycle also shows the similar pattern as the flood cycle.



Note: Negative current velocity represents flood tide.

FIGURE 2-1.
STORM WATER MIXING ZONES WITH VARIOUS CURRENT CONDITIONS (DILUTION FACTOR = 50) 30-INCH DIAMETER OUTFALL UNDER MODERATE STORMS

Source: ECT, 2001.

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The final step is to determine an envelop for the zone of 50-dilution during the entire tidal cycle. This envelope can be simplified by a rectangular box that encloses all instantaneous mixing zones, as shown in Figure 2-1. The limit of the mixing zone envelop for 50-dilution is 263 meters offshore, 833 meters upstream, and 770 meters downstream.

Similarly, the envelopes for various dilutions factors can be developed. Figure 2-2 shows the envelopes for dilution factor of 10, 20, 50, and 100 for a 30-inch outfall under moderate storm conditions. The concept of the mixing zone envelope is a conservative method to evaluate the impacts of a discharge. The actual mixing zone size at any instance is smaller than the overall envelope, as shown in Figure 2-1.

The following describes the procedure to compute the mixing zone using Figure 2-2 as an example. If the storm water iron concentration is 10 milligrams per liter (mg/L), the ambient iron concentration is 0.1 mg/L, and the surface water quality standard is 1.0 mg/L. The effluent will require a dilution factor of 11 in order to comply with the water quality standard. By interpolate between 10 and 20 dilution isopleths in Figure 2-2, the size of the mixing zone envelop is about 157 meters offshore, 374 meters downstream, and 461 meters upstream. Therefore, the dilution envelope is a convenient tool to quantify the mixing zones and to evaluate water quality impacts.

2.4 RESULTS

Using the technique described in Section 2.3, the dilution envelops, or mixing zones, are developed for various discharge conditions. Figures 2-3 through 2-6 show the mixing zone envelopes under a moderate storm with an outfall diameter of 18, 24, 30, and 36 inches, respectively. Figures 2-7 through 2-10 show the mixing zone envelopes under a severe storm with an outfall diameter of 18, 24, 30, and 36 inches, respectively. The dimensions of the dilution envelopes for each discharge scenario are tabulated in Table 2-1 through 2-4.

Unlike industrial discharges, the pollutant contents in storm water are typically not exceptionally high. Normally, a dilution factor of 10 is sufficient to meet the water quality standard. Therefore, the largest mixing zone envelope (48-inch pipe under severe storms) is 200 meters offshore, 505 meters downstream, and 629 meters upstream. A typical mixing zone envelope (30-inch pipe under moderate storms) is 154 meters offshore, 347 meters downstream, and 440 meters upstream.

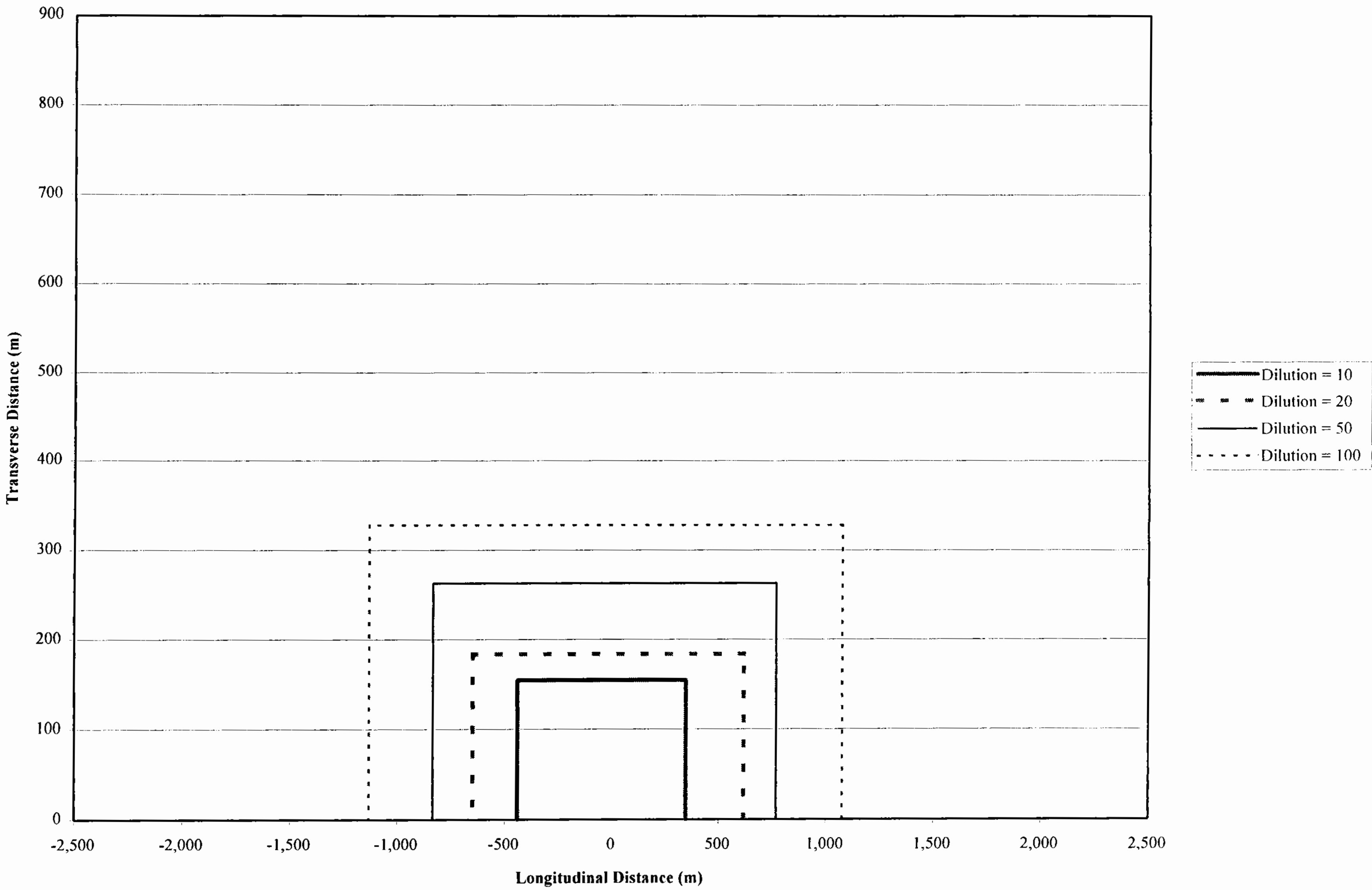

FIGURE 2-2.
STORM WATER MIXING ZONE ENVELOPE
MODERATE STORMS, PIPE DIAMETER = 30 INCHES

Source: ECT, 2001.

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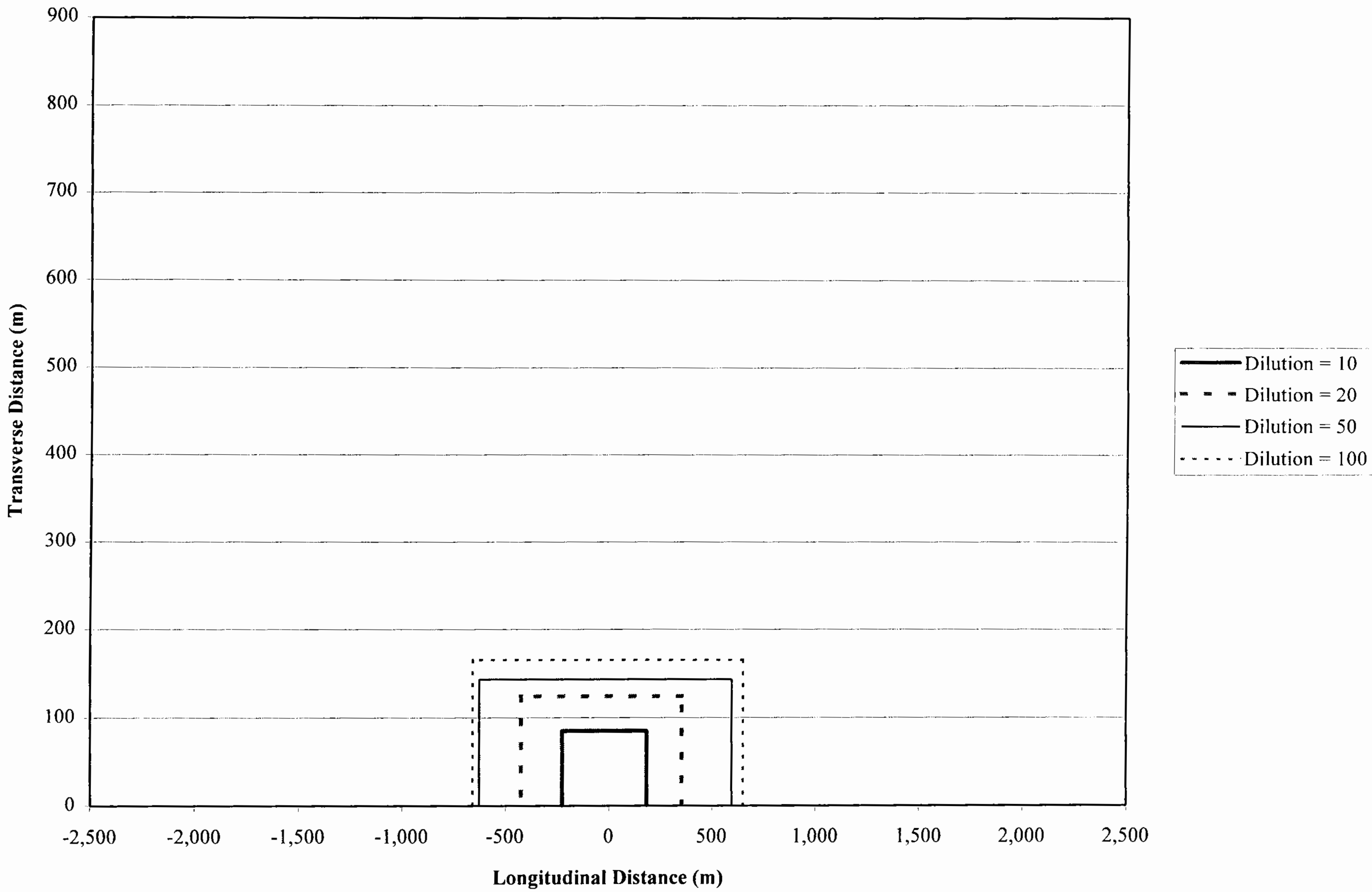

FIGURE 2-3.
STORM WATER MIXING ZONE ENVELOPE
MODERATE STORMS, PIPE DIAMETER = 18 INCHES

Source: ECT, 2001.

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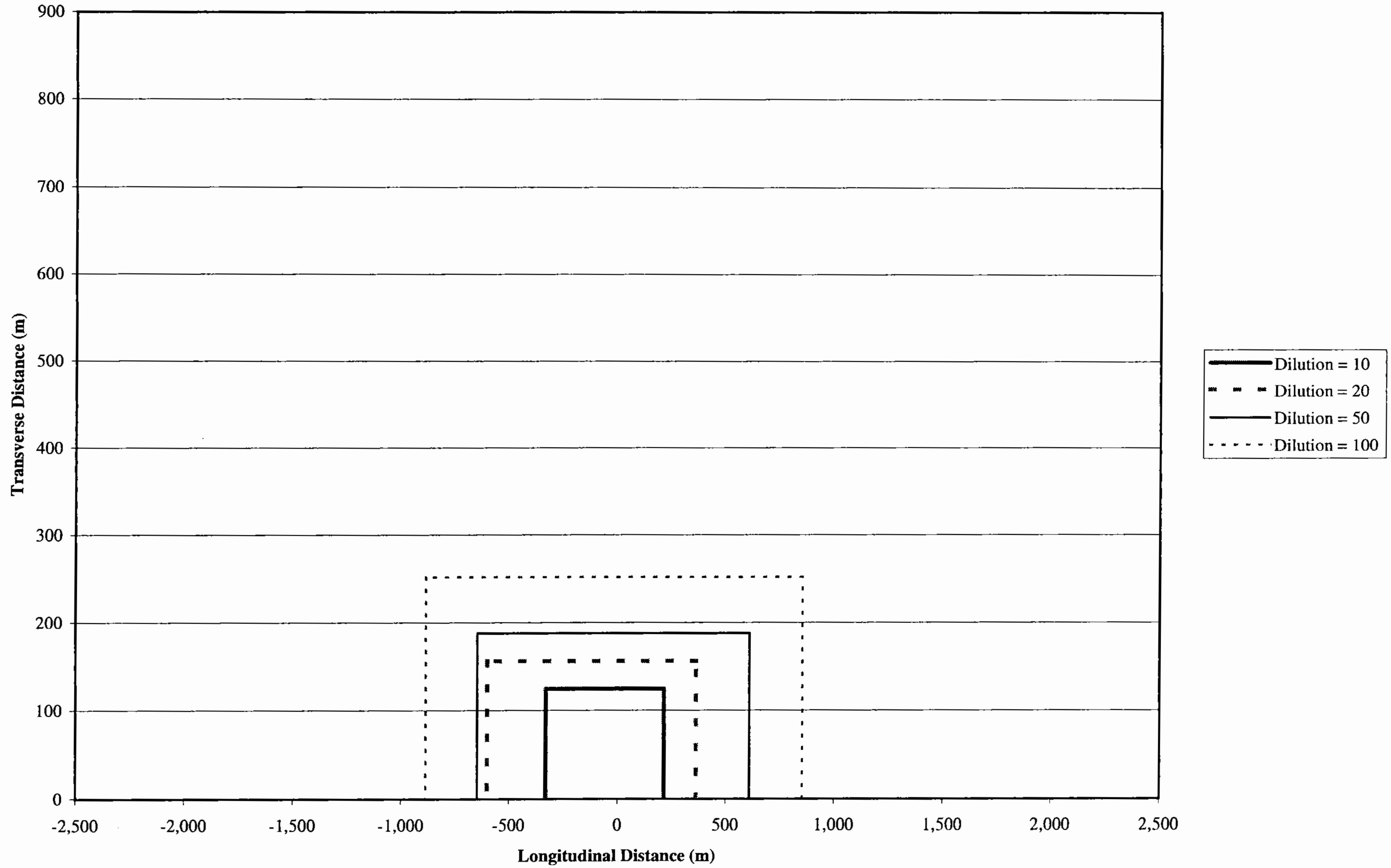

FIGURE 2-4.
STORM WATER MIXING ZONE ENVELOPE
MODERATE STORMS, PIPE DIAMETER = 24 INCHES

Source: ECT, 2001.

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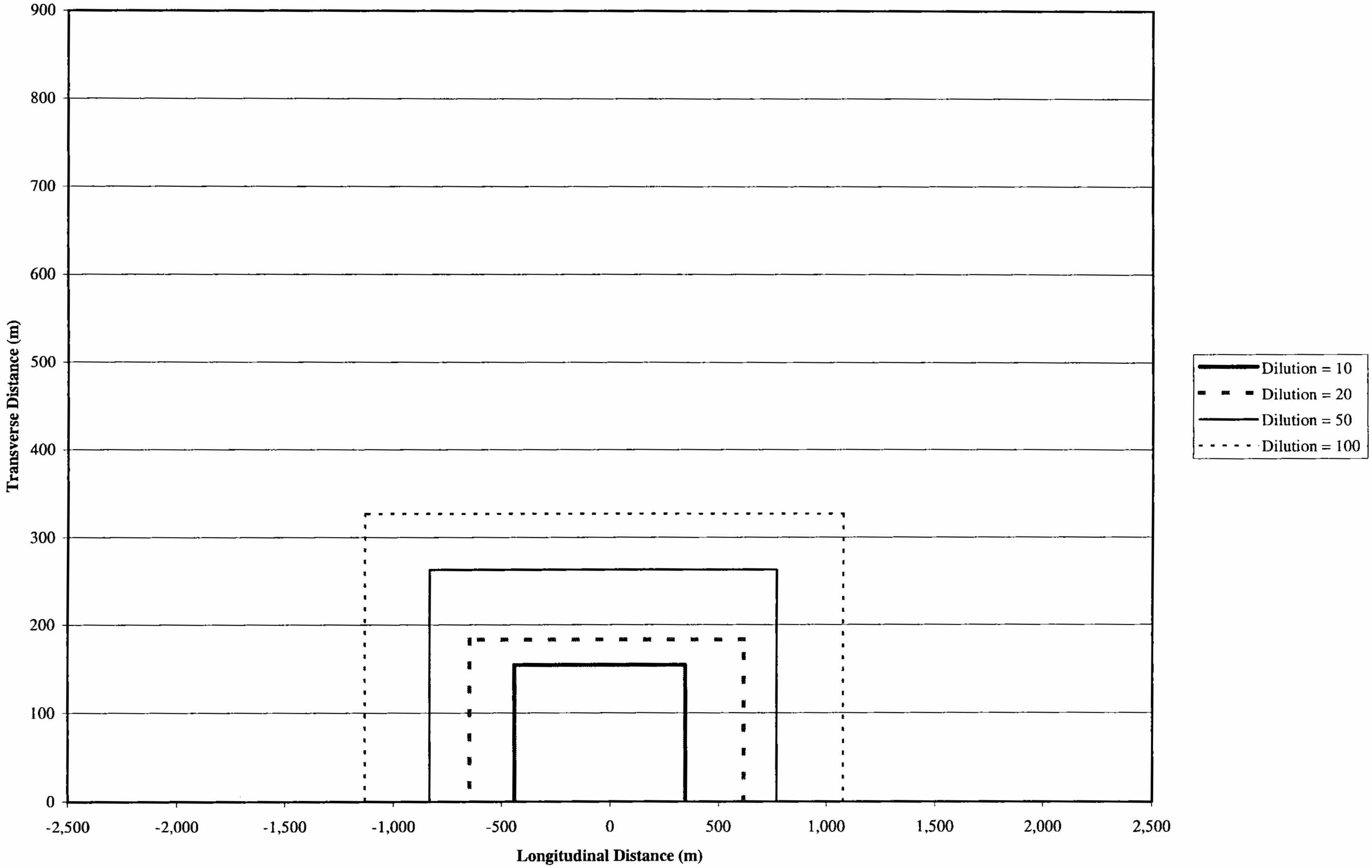

FIGURE 2-5.
STORM WATER MIXING ZONE ENVELOPE
MODERATE STORMS, PIPE DIAMETER = 30 INCHES

Source: ECT, 2001.

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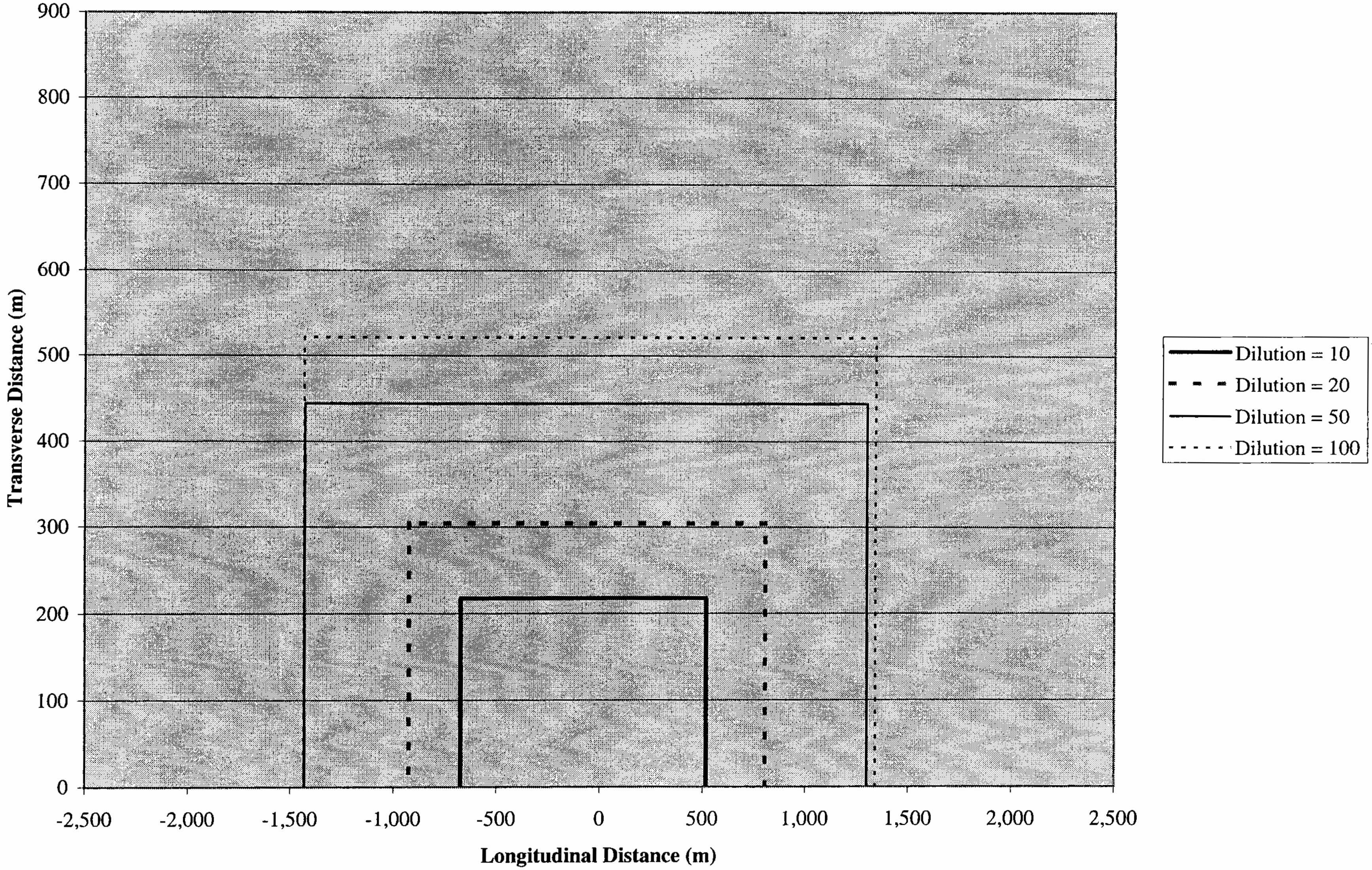

FIGURE 2-6.
STORM WATER MIXING ZONE ENVELOPE
MODERATE STORMS, PIPE DIAMETER = 48 INCHES

Source: ECT, 2001.

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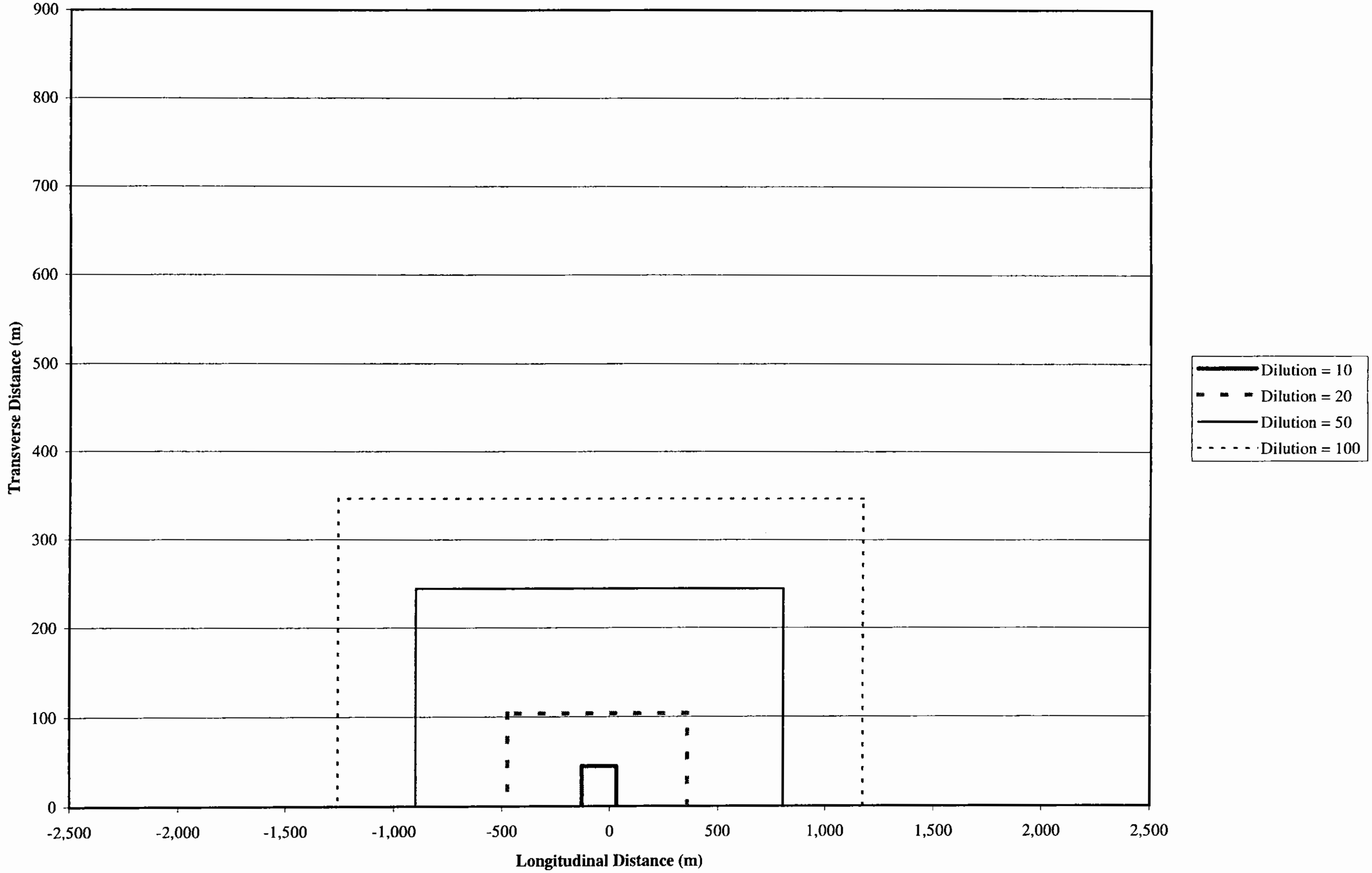

FIGURE 2-7.
STORM WATER MIXING ZONE ENVELOPE
SEVERE STORMS, PIPE DIAMETER = 18 INCHES

Source: ECT, 2001.

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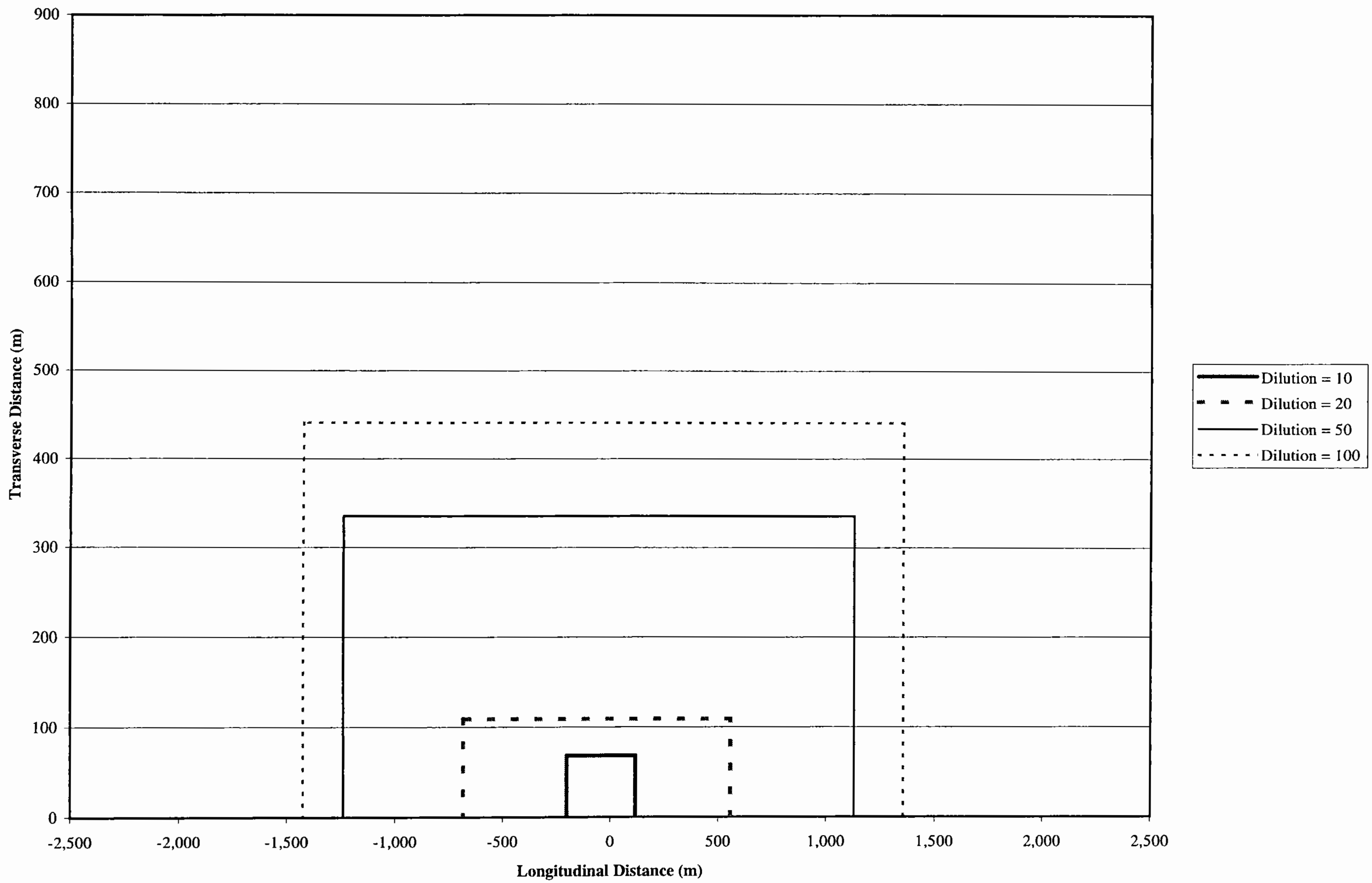

FIGURE 2-8.
STORM WATER MIXING ZONE ENVELOPE
SEVERE STORMS, PIPE DIAMETER = 24 INCHES

Source: ECT, 2001.

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Environmental Consulting & Technology, Inc.

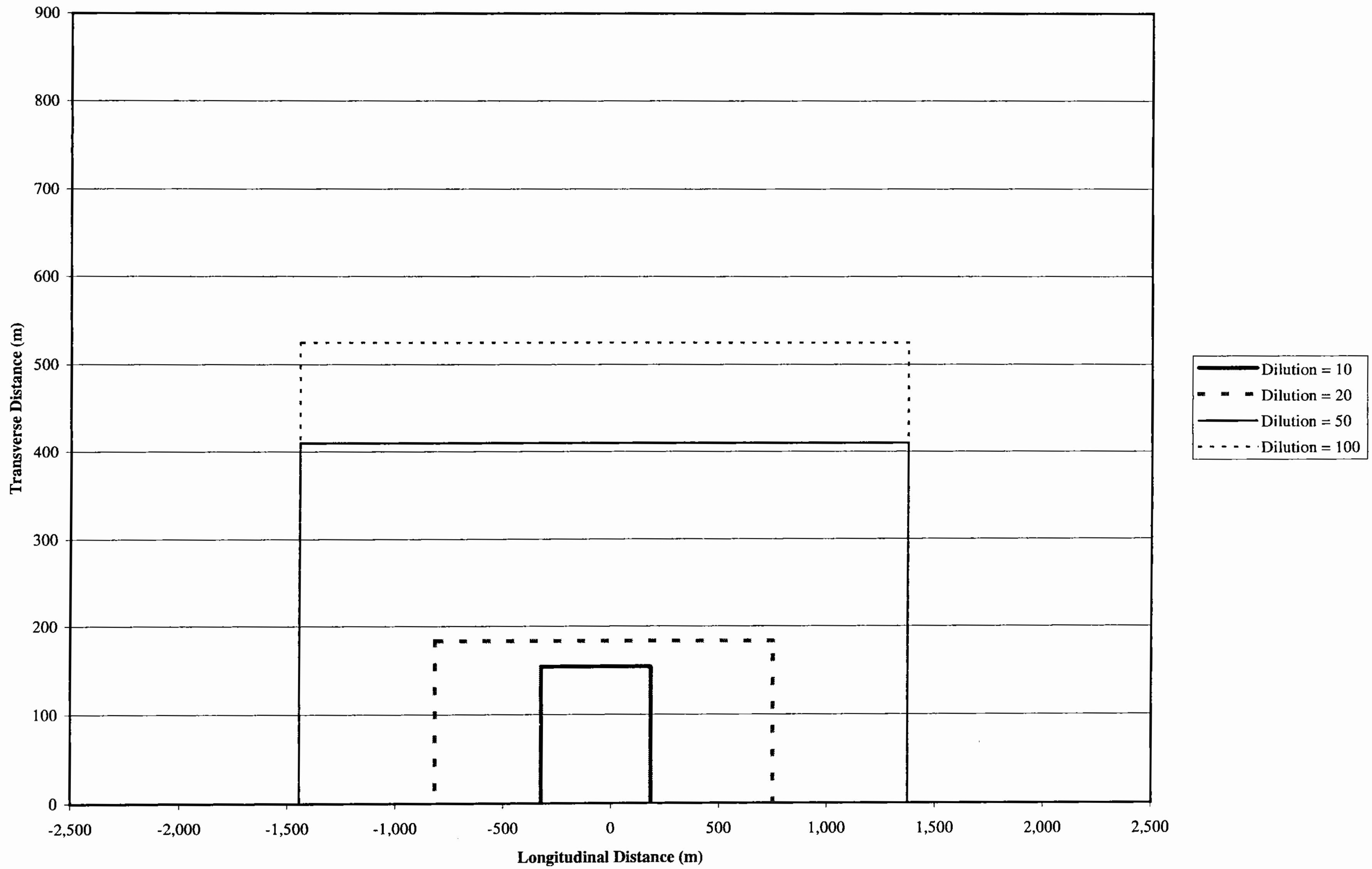

FIGURE 2-9.
STORM WATER MIXING ZONE ENVELOPE
SEVERE STORMS, PIPE DIAMETER = 30 INCHES

Source: ECT, 2001.

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Environmental Consulting & Technology, Inc.

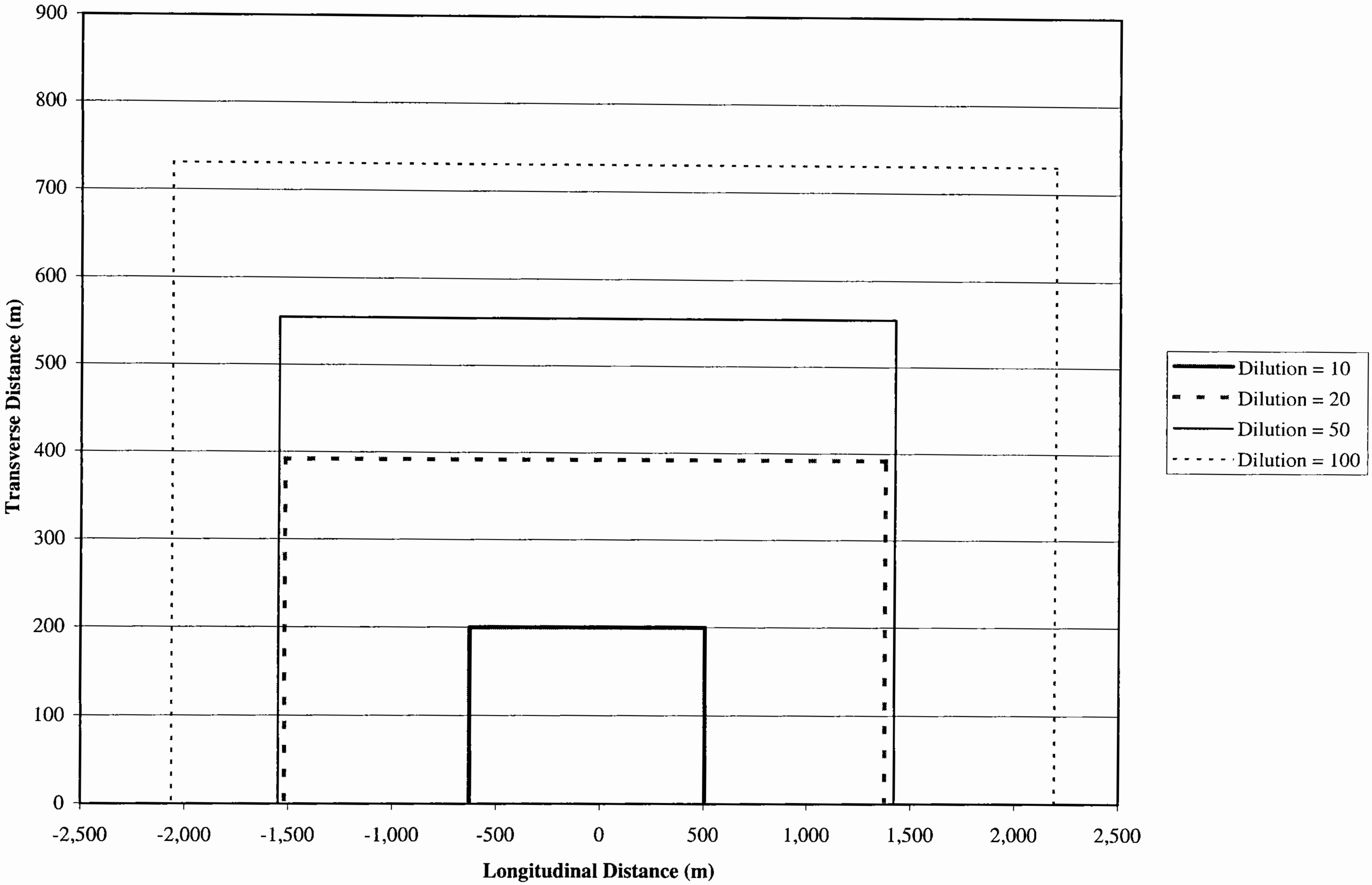

FIGURE 2-10.
STORM WATER MIXING ZONE ENVELOPE
SEVERE STORMS, PIPE DIAMETER = 48 INCHES

Source: ECT, 2001.

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Table 2-1. Mixing Zone Limits with Various Dilution Factors (Pipe Diameter = 18 inches)

Dilution Factor	Downstream Limit	Upstream Limit	Offshore Limit
Moderate Storm			
10	182	227	85
20	352	425	124
50	595	627	144
100	649	659	165
Severe Storm			
10	31	129	45
20	358	475	104
50	804	901	245
100	1,174	1,258	347

Source: ECT, 2001.

Table 2-2. Mixing Zone Limits with Various Dilution Factors (Pipe Diameter = 24 inches)

Dilution Factor	Downstream Limit	Upstream Limit	Offshore Limit
Moderate Storm			
10	215	330	125
20	363	601	156
50	610	647	188
100	855	886	253
Severe Storm			
10	116	202	68
20	556	685	109
50	1,130	1,240	336
100	1,356	1,425	441

Source: ECT, 2001.

Table 2-3. Mixing Zone Limits with Various Dilution Factors (Pipe Diameter = 30 inches)

Dilution Factor	Downstream Limit	Upstream Limit	Offshore Limit
Moderate Storm			
10	347	440	154
20	616	649	183
50	770	833	263
100	1,077	1,132	327
Severe Storm			
10	185	323	154
20	750	817	183
50	1,374	1,444	410
100	1,374	1,444	525

Source: ECT, 2001.

Table 2-4. Mixing Zone Limits with Various Dilution Factors (Pipe Diameter = 48 inches)

Dilution Factor	Downstream Limit	Upstream Limit	Offshore Limit
Moderate Storm			
10	516	675	218
20	805	926	305
50	1,301	1,433	445
100	1,343	1,436	522
Severe Storm			
10	505	629	200
20	1,376	1,517	392
50	1,422	1,548	555
100	2,193	2,064	731

Source: ECT, 2001.