CORMIX Modeling of Sediment Plumes for the Oil and Gas Industry

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Abstract
This paper describes new CORMIX methodologies for environmental impact assessment of drilling muds and cuttings disposal from oil and gas well development in coastal waters. New features include model predictions of water column concentrations of the resulting suspended sediment plume and prediction of sediment deposit properties. The original CORMIX sediment source was originally developed for continuous dredging operations and contained the following five sediment size classes: chunks, sand, coarse silt, fine silt, and clay. To extend model capabilities, new sediment source specifications are now available. This includes 4 new sample sediment types specific to the oil and gas industry. The new sediment types with sample values are Water Based Mud (WBM) cuttings (9 particle size classes), Nonaqueous Drilling Fluid (NAF) and Cuttings (8 particle size classes), bentonite (6 particle size classes), and WBM solids (10 particle size classes). If the sample sediment types are not acceptable, the user may specify up to 10 sediment size classes. Particle density can be specified ranging from 1100 to 5000 kg/m^3. The number of solids classes, solids volume fraction, and the particle fall velocity must be entered. In addition, the new CorPlot post-processing tool plots water column concentrations as a function of plume trajectory as well as bottom sediment deposit footprint, thickness (accretion rate), and particle size distribution.

Keywords
Mixing Zones, Sediment Plumes, Drilling Muds and Cuttings, Plume Modeling, CORMIX, Sediment Deposits

INTRODUCTION

Wastewater disposal infrastructure design and management is increasingly important worldwide. The management of effluents such as municipal wastewater, desalination brines, thermal cooling waters, or industrial discharges requires better methods to mitigate negative impacts, protect human health, ensure regulatory compliance, and minimize costs.

Environmental regulations worldwide often include the concept of a mixing zone. Ambient water quality standards need not be met at end of pipe if a mixing zone is allowed by the regulatory authority [1]. A regulatory mixing zone (RMZ) is a limited region or area around the discharge where the initial dilution occurs. Figure 1 shows a plan view representation of a RMZ for a point source discharge. Dischargers must demonstrate sufficient dilution at the edge of the mixing zone to comply with water quality standards. Mixing zones are typically determined by mathematical modeling, however sometimes field dilution studies are required [2]. Mixing zones typically encompass the hydrodynamic near-field where outfall design and physical condition can have a strong influence on mixing.

CORMIX MODELLING TOOLS

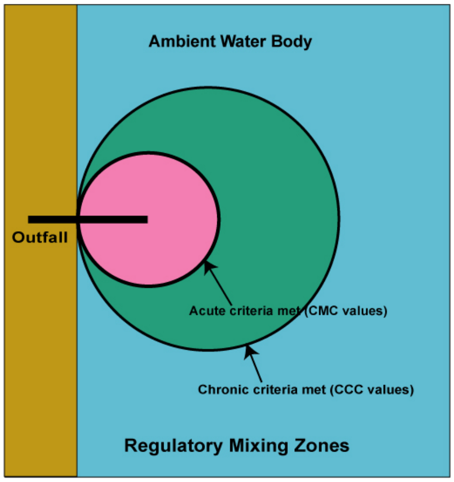

Figure 1 Regulatory Mixing Zones (RMZ).The discharge must meet minimum dilution at the edge of the RMZ.

The CORMIX modeling system has been in development since 1986 to simulate hydrodynamic mixing zones of point source discharges [3, 4]. The present system now incorporates several hydrodynamic simulation codes for single port, multiport diffuser and shoreline discharge sources [5-11]. Effluents modeled include conservative, non-conservative (1st order decay), thermal, brine, and sediment sources. It contains several pre- and post-processor system and computer-aided-design (CAD) tools including 3-D graphics for source specification and mixing zone visualization, sensitivity analysis tools, time-series simulations, performance benchmarking, and case validation [11-16]. CORMIX v7.0 GTH and GTD also integrate the CorHyd simulation tool for multiport diffuser internal hydraulics design [17]. CorHyd computes energy requirements, port flowrate, and diffuser head loss for multiport diffusers. CorHyd can be used to specify pipe dimensions, head requirements, port/riser configurations, and line source characteristics. This ensures an efficient line source discharge. CorHyd analysis, used in conjunction with CORMIX dilution predictions, can assist in the design of unidirectional, staged, and alternating diffuser configurations to optimize outfall design.

NEW EFFLUENT TYPES FOR OIL AND GAS INDUSTRY DISCHARGES

Sediment effluent types previously developed for CORMIX were specific to effluents produced from dredging operations. Oil and gas well development effluents can include suspended sediment discharges during well development as well as produced (brine) water discharges during production. Drilling muds have special characteristics, depending on the specific formulation, including particle size distributions and particle densities [18]. During drilling operations, drilling muds and cuttings can be discharged into the water column. Because of the unique characteristics of some drilling muds, new sediment size classes and particle densities were added to the CORMIX dredge sediment effluent type.

CORMIX now allows for specification of up to 10 particle size classes with variable particle solids density from 1100 kg/m^3 to 5000 kg/m^3. Effluent types considered now include whole drilling muds solids discharged with water-based drilling mud (WBM), the cuttings and associated drilling mud generated while drilling with WBM, and the cuttings and associated drilling mud generated while drilling with nonaqeeous drilling fuild (NAF). Tables 1-4 shows the new sample effluent types for drilling operations as suggested by Nedwed (2004). The user can load these sample sediment data from CORMIX the using menus Pages ->Load Page Template ->Effluent Page ->Sample Files -> Drill-Cut-Muds. The user may also create a custom distribution if needed to describe effluent suspended solids characteristics. Table 5 shows the sample CORMIX sediment type developed for dredge discharges.

Table 1 Fall Velocity Distribution for WBM Cuttings

Solids Class	**Solids Density (g/cm^3)**	**Solids Volume Fraction**	**Fall Velocity (ft/sec)**	**Fall Velocity (m/s)**	**Distribution %**
1	2.650	0.042720	4.430E-06	1.35026E-06	8.00
2	2.650	0.032040	5.530E-05	1.68554E-05	6.00
3	2.650	0.037380	7.160E-04	2.18237E-04	7.00
4	2.650	0.016020	7.638E-03	2.32806E-03	3.00
5	2.650	0.010680	4.748E-02	1.44719E-02	2.00
6	2.650	0.096120	1.316E-01	4.01117E-02	18.00
7	2.650	0.085440	3.214E-01	9.79627E-02	16.00
8	2.650	0.080100	4.435E-01	1.35179E-01	15.00
9	2.650	0.133500	8.522E-01	2.59751E-01	25.00

Table 2 Fall Velocity Distribution for NAF Cuttings

Solids Class	**Solids Density (g/cm^3)**	**Solids Volume Fraction**	**Fall Velocity (ft/sec)**	**Fall Velocity (m/s)**	**Distribution %**
1	1.970	0.088200	1.083E+00	3.30098E-01	20.00
2	1.970	0.088200	1.017E+00	3.09982E-01	20.00
3	1.970	0.088200	9.510E-01	2.89865E-01	20.00
4	1.970	0.099200	8.860E-01	2.70053E-01	22.49
5	1.970	0.037500	7.550E-01	2.30124E-01	8.50
6	1.970	0.017600	5.910E-01	1.80137E-01	3.99
7	1.970	0.005500	3.940E-01	1.20091E-01	1.25
8	1.970	0.016600	1.970E-01	6.00456E-02	3.76

Table 3 Fall Velocity Distribution for Bentonite Particles

Solids Class	Solids Density (g/cm^3)	Solids Volume Fraction	Fall Velocity (ft/sec)	Fall Velocity (m/s)	Distribution %
1	2.300	0.000700	3.040E-01	9.26592E-02	0.70
2	2.300	0.030000	1.720E-01	5.24256E-02	30.00
3	2.300	0.030000	7.460E-02	2.27381E-02	30.00
4	2.300	0.025000	3.500E-03	1.06680E-03	25.00
5	2.300	0.005000	7.000E-04	2.13360E-04	5.00
6	2.300	0.009300	2.000E-04	6.09600E-05	9.30

Table 4 Fall Velocity Distribution for WBM Solids

Solids Class	Solids Density (g/cm^3)	Solids Volume Fraction	Fall Velocity (ft/sec)	Fall Velocity (m/s)	Distribution %
1	3.377	0.000530	3.680E-02	1.12166E-02	1.00
2	3.377	0.002110	1.400E-02	4.26720E-03	4.00
3	3.377	0.010160	2.700E-03	8.22960E-04	19.24
4	3.377	0.010160	2.100E-03	6.40080E-04	19.24
5	3.377	0.007000	1.680E-03	5.12064E-04	13.26
6	3.377	0.007000	1.430E-03	4.35864E-04	13.26
7	3.377	0.005280	9.840E-04	2.99923E-04	10.00
8	3.377	0.002640	4.860E-04	1.48133E-04	5.00
9	3.377	0.004220	2.000E-04	6.09600E-05	7.99
10	3.377	0.003700	8.990E-05	2.74015E-05	7.01

Table 5 Fall Velocity Distribution for Dredge Sediment CORMIX Solids Classes

Solids Class	Solids Density (g/cm^3)	Fall Velocity (ft/sec)	Fall Velocity (m/s)
Chunks	2.650	Instantaneous	Instantaneous
Sand	2.650	1.027E-01	3.13000E-02
Coarse Silt	2.650	1.373E-03	4.18500E-04
Fine Silt	2.650	8.530E-05	2.60000E-05
Clay	2.650	2.133E-06	6.50000E-07

CORPLOT GRAPHING TOOLS

The new CorPlot graphing tool will provide detailed deposition plots based on CORMIX simulation results of drill cuttings and muds discharge modeling study. CorPlot provides the following plots and outputs based on the CORMIX simulation for sediment discharges:

- Plots of sediment deposition contours on the sea bottom in plan view
- Sediment thickness on bottom along plume centerline
- Suspended sediments in the water column along plume centerline

In addition, CorPlot provides the following graphical outputs for dilution and concentration:

- Dilution isolines in plan view
- Concentration excess isolines in plan view
- Dilution vs. downstream distance
- Dilution vs. centerline trajectory distance
- Concentration excess vs. downstream distance
- Concentration excess vs. centerline trajectory distance

Figures 2 and 3 show examples of CorPlot results for suspended sediment deposition from drilling muds and cuttings. The bottom sediment accretion rates are given in mm/day. For some oil and gas well applications, the total discharge volume of suspended sediment can be small with respect to the transport and dilution capacity of the ocean. The deposit thickness may also be very small, typically less than 1 mm/day within the vicinity of the discharge due to the limited duration and small discharge volumes of suspended sediment.

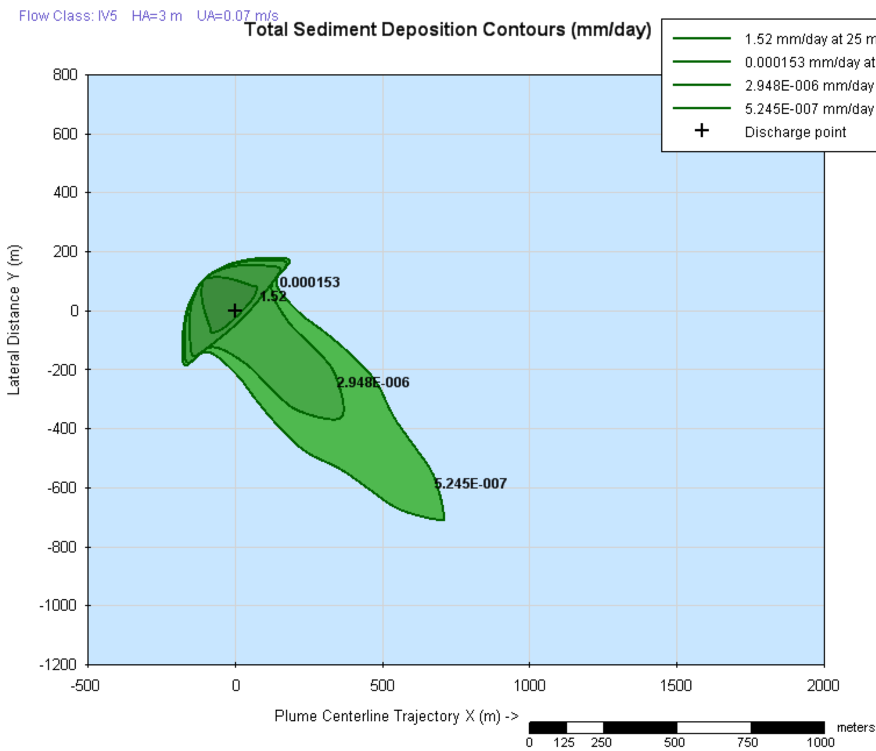

Figure 2 Sediment deposit depth contours.

It is often desirable to model varying ambient current directions with time series data for mixing zone predictions. This can be achieved using CorTime function within CORMIX v7.0 GTR. By combining the capabilities of the CorTime application and CorPlot, integrated deposition plots can be constructed. The plots are made over a user specified grid.

CONCULSIONS/RECOMMENDATIONS

New tools have been added to CORMIX to better handle sediment discharges from oil and gas operations. Effluents can have suspended sediment properties specific to oil and gas industry drilling muds and cuttings. Because of the different particle densities and settling velocities associated with different types of drilling muds, new sediment effluent input capability has been added to CORMIX. In addition, produced water discharges can be simulated as a brine effluent type. New CorPlot tools allow for plotting sediment deposition depth contours and water column concentrations of suspended sediment.

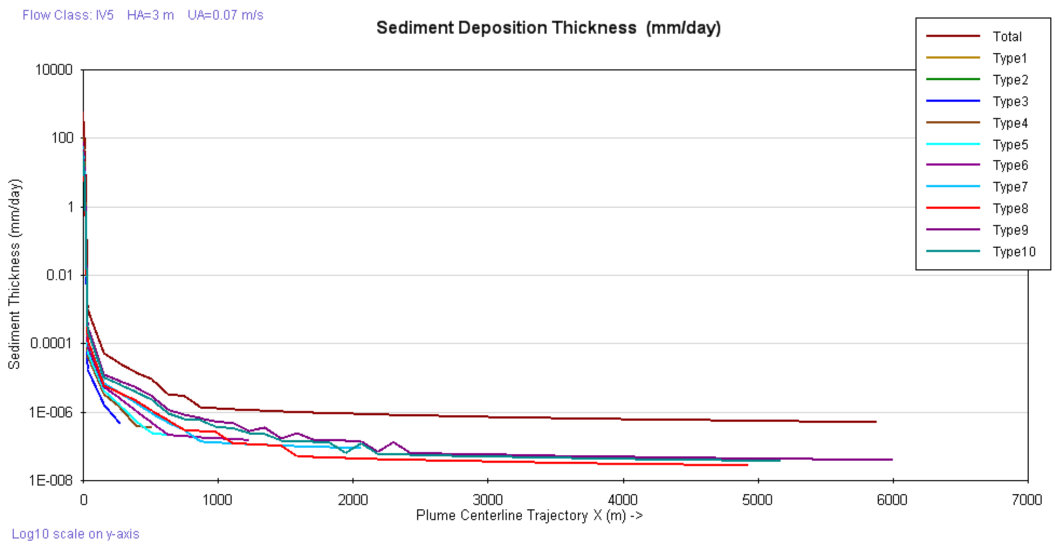

Figure 3 Sediment deposit thickness accretion rate and particle size distribution versus trajectory

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