# Integrated Modeling and Remote Sensing Systems for Mixing Zone Water Quality Management

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## Abstract

We have developed novel integrated remote sensing and hydrodynamic simulation methods for cost effective design, evaluation, inspection, maintenance, and repair of wastewater disposal infrastructure. Wastewater diffusers are needed to meet minimum dilution requirements within a regulatory mixing zone, a limited region around the discharge structure where the initial dilution occurs. We have created new methods for the CORMIX software system to provide comprehensive analysis of point source mixing zones. The CorHyd internal diffuser hydraulics simulation tool is introduced for design and analysis of multiport discharges. We have developed new methods to assess diffuser infrastructure physical condition using various remote sensing technologies. Our patent-pending aerial remote sensing platform monitors mixing zone water quality and provides assessment of outfall physical condition through diffuser performance monitoring. Our approach integrates simulation and sensor networks to provide advanced information technology on wastewater disposal infrastructure to designers, consultants, regulators, facility managers, and maintenance crews.

## 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 (USEPA 1984). 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

(USEPA 1991). Mixing zones typically encompass the hydrodynamic near-field where outfall design and physical condition can have a strong influence on mixing behavior.

## CORMIX-CorHyd Multiport Diffuser Hydraulic Modeling

The CORMIX modeling system has been in development since 1986 to simulate mixing zones of point source discharges (Doneker and Jirka 1990; Doneker and Jirka 2007). The present system now incorporates several hydrodynamic simulation codes for single port, multiport diffuser and shoreline discharge sources (Akar and Jirka 1991; Akar and Jirka 1991; Doneker and Jirka 1991; Jones, Nash et al. 1996; Jirka 2004; Jirka 2006; Jirka 2007). 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 (Jirka and Akar 1991; Akar and Jirka 1994; Akar and Jirka 1995; Jones, Nash et al. 1996; Doneker and Jirka 2002; Doneker, Nash et al. 2004).

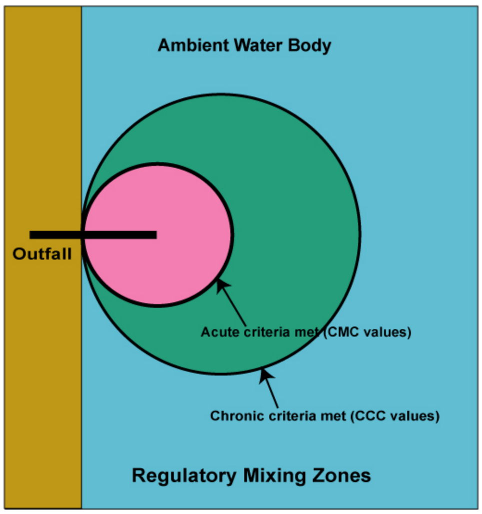


Figure 1. Regulatory Mixing Zones (RMZ). The discharge must meet minimum dilution at the edge of the regulatory mixing zone.

The newest CORMIX feature integrates the CorHyd simulation tool for multiport diffuser internal hydraulics design (Bleninger 2006). CorHyd computes energy requirements, port flowrate, and diffuser head loss for multiport diffusers. A definition diagram for CorHyd appears in Figure 2. CorHyd can be used to specify pipe dimensions, head requirements, port/riser configurations, and line source characteristics. It has features to assist in the design of port/riser groups to specify a uniform port discharge flow along the diffuser. 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 near-field mixing within the RMZ.

## Remote Sensing of Mixing Zones

With USEPA support, we have developed a remote sensing system for water quality monitoring in mixing zones (Doneker and Sanders 2007; Doneker, Sanders et al. 2008). This system includes an aerial platform and several in-stream sensors. Our patent-pending aerial system includes a tethered-balloon aerial platform with several sensors including infrared (IR) and visual cameras to collect site scale data.

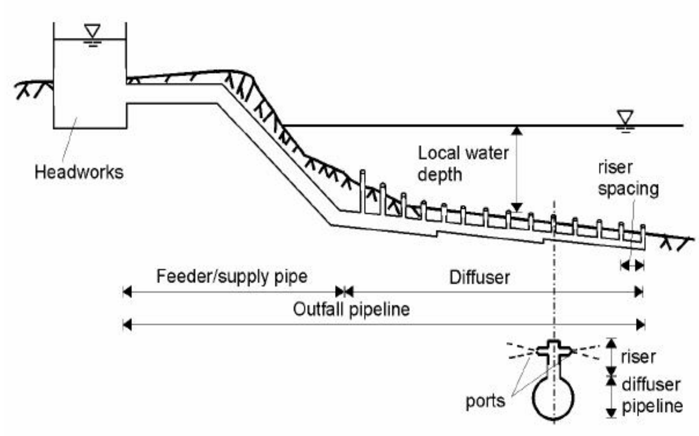


Figure 2. CorHyd definition sketch. CorHyd calculates energy loss and flow rate along the diffuser manifold. Line source behavior simulated by CorHyd is essential for diffuser infrastructure design, maintenance, and rehabilitation.

Infrared remote sensing of mixing zones can be considered wherever a temperature difference ($\Delta T$) between effluent and ambient temperature is present. However, aerial IR sensors detect surface temperatures only. Thus, the variation in subsurface temperatures which may occur in deeper stratified flows cannot be detected. Therefore, our system concentrates on remote sensing of shallow layer flows. However, our platform may still be used in other situations with surfacing plumes. CORMIX modeling of surface plume characteristics is part of mission planning / feasibility analysis for IR remote sensing.

Aerial remote sensing has the potential to collect data over large regions in real time without disturbing or influencing the properties measured. However, currently available aerial remote sensing platforms are very expensive or not well suited for many mixing zone management issues (Wu 2002). Direct measurement of biophysical information such as temperature is dependent on the scale of the phenomena. To properly resolve mixing zone spatial scales with the Nyquist frequency limits requires resolution not readily available through space-based platforms and is limited to low-altitude helicopter or fixed-wing aircraft operations (Jensen 1996). Both the helicopter and fixed-wing aircraft platform have enjoyed widespread successful application in remote sensing of the spatial distribution of surface water temperature values in mixing zones (Torgersen, Price et al. 1999; Torgersen, Faux et al. 2001). However availability is limited, extensive operator training is required, and their costs are relatively high. Because of these limitations, conventional aircraft are not well-suited for rapid or routine deployment at a fixed location where hourly sampling may be required over an extended time.

There are several advantages to using balloons or blimps as platforms for aerial remote sensing. Balloons can be deployed quickly. Extensive operator training is not required. Tethered balloons can be moved and relocated easily, providing a more flexible method to collect data. Tethered balloons can be deployed on small boats in rivers to conduct water quality surveys over several stream miles.

Figure 3 illustrates the application of our remote sensing system. Platform sensors (Figure 3B) include visual and IR cameras, digital compass (platform x-y-z position and bearing to true and magnetic north), temperature/humidity sensor, and laser rangefinder (distance to target). Our ground station laptop computer uses our custom application ZoneView to communicate with the aerial platform via a wireless network. ZoneView monitors and positions the pan/tilt camera mount and captures sensor data. The aerial platform transmits visual and infrared images to the ground station in “near” real time, about once every second. All captured image data is stored locally on the laptop database which is tagged with GPS position information and other sensor readings.

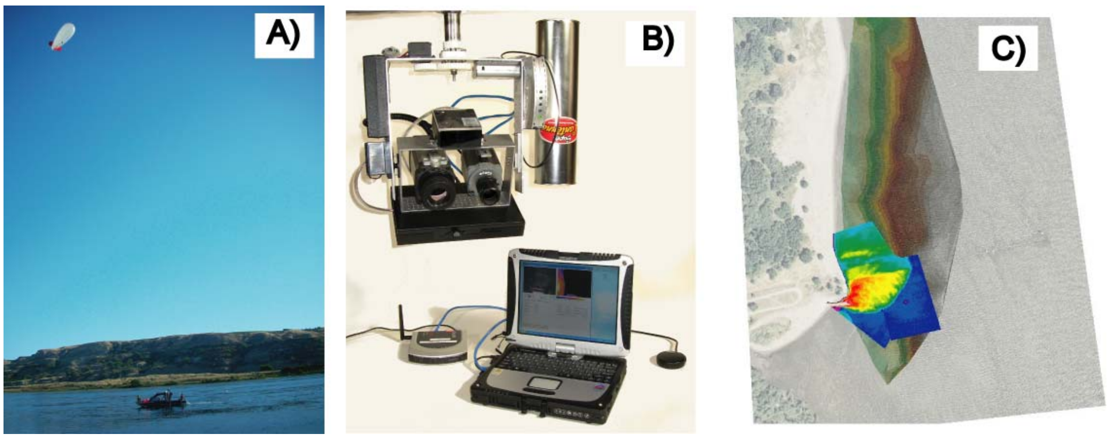


Figure 3. Integrated remote sensing of mixing zones. A) Balloon remote sensing platform deployment from a survey boat. B) Details of the remote sensing platform and ground station laptop ZoneView application using a wireless network. C) Geo-rectified aerial IR images with boat survey ADCP bathymetry data is used for CORMIX data input schematization.

To augment our aerial platform for monitoring point source mixing, we have integrated several additional boat-mounted sonar sensors: i) a 1200kHz Acoustic Doppler Current Profiler (ADCP) to collect detailed ambient velocity profiles, ii) a 60kHz depth sounder for bathymetry readings, and iii) a Dual Frequency Identification Sonar (DIDSON) acoustic camera to assess physical outfall condition and mixing zone dilution modeling. All boat survey data is tagged with Differential GPS coordinates for sub-meter accuracy of latitude and longitude position. Figure 3C shows the integration of site bathymetry from ADCP survey and aerial IR plume data. Site bathymetry is crucial to ambient schematization for CORMIX data input specification (Doneker and Jirka 2002).

**Acoustic Camera Imaging for Assessment of Outfall Physical Condition**

Physical condition of the outfall structure can influence mixing zone behavior. Diffuser structures may be damaged due to boat anchors or flooding; ports may be blocked or buried due to sedimentation. Sometimes, the “as built” configuration of a diffuser may differ from the design plans. When simulating mixing zone behavior with models such as CORMIX, the physical condition of the outfall can influence flow classification and dilution prediction. For these reasons, outfall physical inspection is often required for detailed mixing modeling and analysis.

Outfall inspection is commonly conducted by a scuba diver with a hand-held video camera. Turbidity is often so high that divers must in essence perform hand inspection. Divers may have little knowledge of multiport diffuser design so reporting of physical condition can be less than optimal. High turbidity conditions often produce poor quality video. Video images are not typically geo-referenced so it is difficult to assess physical condition spatially along the diffuser line.

Because of limitations in conventional underwater video imaging, we have evaluated and determined that the DIDSON acoustic camera can produce high quality images of outfall condition. DIDSON is a high-definition imaging sonar and gives near video quality images for inspection and identification of objects underwater. It is a surrogate for optical systems in turbid water. We deploy the DIDSON from our survey boat on a pole-mount as shown in Figure 4A. The camera connects to an onboard laptop computer for real time acoustic video imaging tagged with GPS coordinates and camera position.

An example of a DIDSON image of a multiport diffuser in a highly turbid river appears in Figure 4B. In this case, the condition, operation, and orientation of individual diffuser nozzles were confirmed for a large multiport diffuser. Information from the DIDSON physical condition assessment can be used for data input for subsequent CorHyd simulations and CORMIX model validation, e.g. CorHyd simulations can provide details on diffuser line source performance helpful in CORMIX data specification for source characteristics such as port vertical angle $\theta_0$.

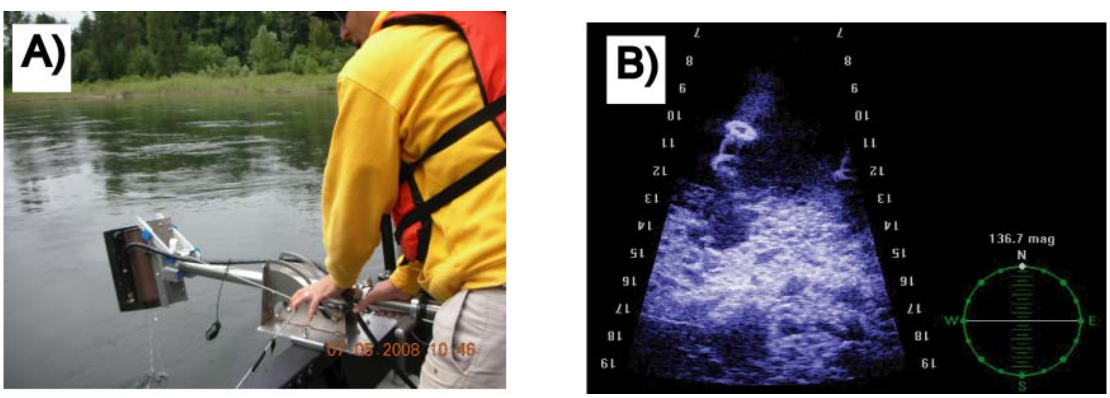


Figure 4. Deployment of the acoustic camera. The camera is submerged during operation. Port condition and geometry data from the acoustic camera is used for CorHyd diffuser hydraulic analysis and CORMIX mixing zone prediction.

## Conclusions

We have developed the technology and demonstrated the deployment of a lightweight aerial remote sensing platform to collect geo-referenced water quality monitoring data within mixing zones. Field survey data collected by our sensors is broadcast via a wireless network to coordinate and facilitate data collection among the survey crew. We have integrated boat mounted sensors to collect site velocimetry, bathymetry, temperature, and outfall physical condition to augment our aerial remote sensing data for mixing zone regulatory management. Temperature measurements from aerial IR images correlate strongly with boat mounted temperature sensors. The sensor data collected is used for CORMIX data specification and mixing zone model validation.

When the boat-mounted instruments are deployed in conjunction with our balloon aerial remote sensing platform, the ZoneView application gives the boat survey crew an aerial perspective to monitor boat sensor location in relation to the discharge plume to facilitate monitoring. This real time aerial view allows us to indentify critical monitoring locations for data collection within the mixing zone, as illustrated in Figure 5. Important mixing zone behavior such as the physical dilution, upstream density currents, plume boundaries, shoreline interaction, discharge canal leaks, and subsequent downstream mixing can be monitored in “real time”. This gives the boat crew detailed information on where to seek or obtain additional detailed data for subsequent modeling and analysis.

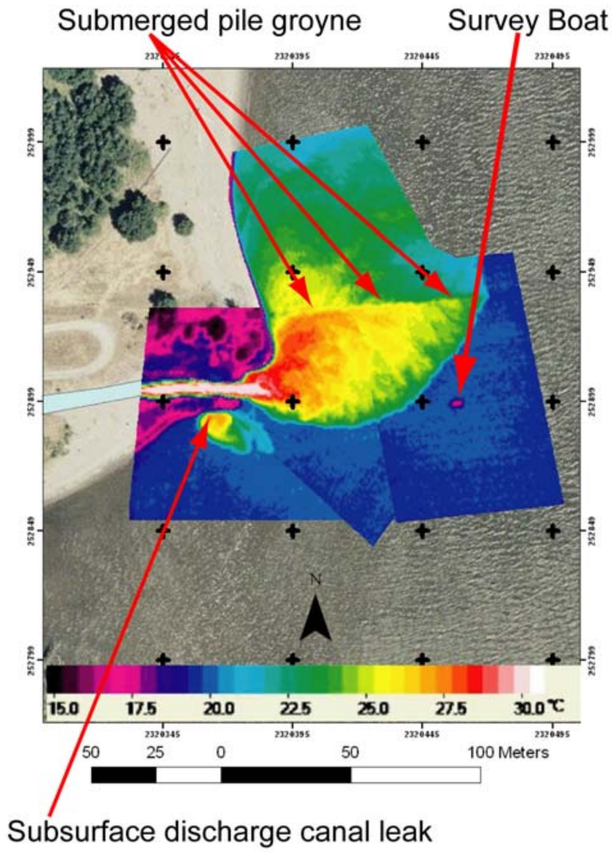


Figure 5. Details of the aerial IR image are available to the field survey boat crew in real time. This feedback allows boat crews to optimize collection location of field data collection for subsequent mixing zone analysis and CORMIX model validation.

The mixing zone dilution data provided by the aerial sensors provide high quality spatial relationships which would be difficult to discern with traditional mixing zone thermistor or dye studies. For example the subsurface discharge canal leak shown in Figure 5 was not apparent through visible inspection. This leak would be extremely difficult to identify with a synoptic dye measurement; however it is readily apparent with IR images. In addition, real time measurements provided by the aerial sensors can provide transitory spatial mixing zone data in unsteady environments, e.g. mixing zone properties during tidal reversal episodes which would be difficult (if not impossible) to capture with synoptic measurements.

We have found that the DIDSON acoustic camera resolves sufficient detail about diffuser condition to assist in assessment of diffuser condition and performance, e.g. port orientation, leaks, exit flow, and missing risers are clearly visible in the video images in shallow (< 10 m) riverine environments. We continue to develop methodologies to link physical assessment of diffuser condition with CORMIX simulation models.

We plan to evaluate additional sensors to integrate into our network for monitoring mixing zone water quality. These sensors include aerial hyperspectral sensors and boat mounted probes including Conductivity Temperature Depth (CTD) and dye sensors. We are currently working with USEPA to conduct an ETV certification of our remote sensing system for water quality monitoring in mixing zones.

In summary, this paper demonstrates integration of hydrodynamic modeling and remote sensing for mixing zone water quality management. We demonstrate how multiple sensors can be integrated with mathematical modeling to perform outfall mixing zone studies for regulatory compliance monitoring and mixing zone model validation.

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