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# Methods for Collecting High-Frequency, Geographically Referenced in situ Water Quality Information

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**PROBLEM:** Water quality concerns at U.S. Army Corps of Engineers water resource development projects have increased in recent years commensurate with the growing use and popularity of these valuable resources. These concerns have prompted greater demands for environmental information upon which to base sound management decisions. However, increasing costs, limited operational funds, and reduced manpower are potential impediments to the Corps maintaining fully effective water quality monitoring activities. This problem is exacerbated by a growing requirement to obtain information that is both spatially and temporally complex. Continued success in managing these resources will, therefore, require the Corps to make innovative use of new and developing technology for the collection of environmental information.

**BACKGROUND:** Most reservoirs and natural lakes exhibit thermal stratification, which often leads to the establishment of pronounced vertical gradients in water quality (e.g., decreased dissolved oxygen concentration with increased depth). Because of this, monitoring efforts are frequently designed to describe vertical heterogeneity and involve depthwise data collection at a single station. Horizontal variations are addressed by establishing additional stations at sites assumed to be representative of relatively homogeneous regions of the lake or reservoir. However, spatial differences in water quality conditions are difficult to anticipate when developing sampling programs. In cases involving establishment of multiple stations, spatial differences in water quality may occur at spatial scales not addressed by a limited number of widely distributed sample stations.

Horizontal heterogeneity in water quality must be described to address many water resource management issues, such as the distribution of algae relative to sources of nutrients or the areal extent of dissolved oxygen declines downstream from point source discharges. Methods for acquiring the information to develop such descriptions must allow coincident collection of geographic location information and water quality data. Current geographic positioning systems (GPS) and increased public access to satellite-based navigational information have facilitated the development of new approaches to water quality data collection.

This technical note describes general considerations for designing and using systems for collecting geographically referenced water quality information, and suggested sample design considerations. Two case studies in which such systems have been successfully applied to acquire information for both riverine and lake environments are also described.

**MONITORING SYSTEM DESIGN:** A basic monitoring system consists of four primary components: a geographic positioning system (GPS); electronic field instruments for measuring selected water quality variables; a data logging device; and a device for acquiring sample water (Figure 1). Sample collection can be accomplished by either active or passive pumping.

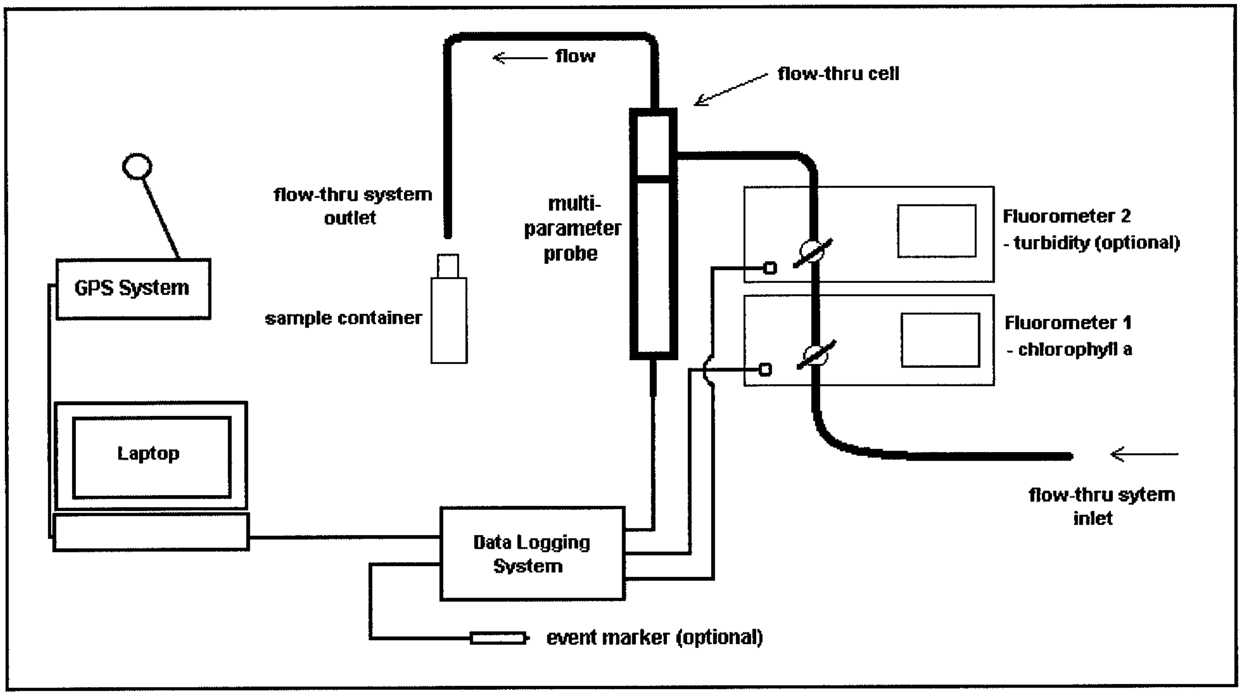

Figure 1. Generalized flow-through system for collecting high-frequency, geographically referenced in situ water quality data

Inactive pumping, of either a submersible or an onboard pump, collects sample water and provides the pressure to distribute it to each monitoring instrument. The advantage of this approach is that pumping or flow rate is independent of boat speed and can be regulated by the operator. Alternatively, sample water can be acquired passively using a pitot tube and a rapidly moving boat. (A pitot tube is easily constructed by bending a rigid collection tube or pipe horizontally so that the intake orifice is oriented upstream.) This approach requires sufficient boat speed to ensure an adequate water supply and sufficient pressure to distribute water to each instrument. In either case, water is collected from a desired depth, such as just below the surface, routed to each instrument through a series of pipes or hoses, and discharged overboard. Regardless of the approach used to collect water, the design of the monitoring system should ensure minimum water retention time between sample collection and measurement by an instrument.

Electronic field instruments commonly employed for in situ water quality studies can be easily incorporated into the design of a monitoring system. In general, water is either passed through a closed sample measurement chamber on the instrument or through a reservoir into which an instrument's probe is placed. For instance, each fluorometer incorporated in the example monitoring system configuration presented in Figure 1 is equipped with hose fittings at both the inflow and outflow of a flow-through cuvette supplied with the instrument. The multi-parameter water quality sonde (Figure 1), on the other hand, required construction of a reservoir fitted with inflow and outflow ports into which the sonde's probes were sealed. In all applications, care must be taken to ensure that sample water is well-mixed at the site of measurement and that air bubbles do not influence the measurement. Some applications may require incorporation of a bubble separation chamber to allow venting of unwanted air bubbles. In all cases, fittings must be airtight to prevent aspiration or leaks. A desirable feature in many applications is a tap at the discharge end of the system's plumbing to collect water samples for subsequent laboratory analysis.

Geographic position information can be obtained using commercially available GPS equipment. These systems generally include an antenna, which can be mounted in an unobscured location on the sampling boat, and a signal processor. Although the exact form of the output may be specific to the GPS model and manufacturer, each will provide current time and measures related to latitude and longitude. Systems capable of differential correction offer the added benefit of providing navigation information which, when viewed coincident with digital maps of the study area, allows the operator to visualize the boat's course across the study area.

Data logging is an essential aspect of system design. Water quality instruments can provide measurement information at relatively short intervals (1-5 sec). Similar reporting intervals are possible for geographic position information. Data logging provides a means to rapidly and accurately record large amounts of information for subsequent analysis. When the monitoring system incorporates multiple data sources, the data logging system must provide the means to merge data. The simplest method is to use a common data logger capable of acquiring and coincidentally storing data from each instrument in a single data file. For systems in which component instruments log data internally, care must be taken to ensure that data from multiple instruments can appropriately be merged prior to data assessment and analysis. In most cases, this will involve combining data files based on a common time variable.

Synchronizing sampling events with position acquisition and logging is critical to the success and usefulness of the resulting data sets. Such errors should be estimated and considered during data reduction and assessment.

**SAMPLING AND ANALYTICAL STRATEGIES:** Flow-through monitoring systems as described above can be utilized to collect high-frequency, geographically referenced water quality data along lateral or longitudinal transects in rivers, reservoirs, and coastal waters. Resulting data provide a more detailed information base upon which to quantify and assess spatial relationships in water quality than do data collected by traditional point sampling methods. Such relationships may be portrayed as simple linear plots based on single transects or as two-dimensional plots based on interpolation of data collected along multiple transects. The first approach is appropriate for describing trends over distance, such as those that might occur along a river reach impacted by point or nonpoint sources. The second is appropriate for collecting data for describing spatial gradients (lateral as well as longitudinal) commonly observed in reservoirs and coastal waters experiencing incomplete mixing. In both cases, high-frequency data, and the resulting graphical interpretations, provide valuable water quality management information.

**EXAMPLE APPLICATIONS:** The results of two case studies involving methods for the collection of high-frequency, geographically referenced in situ water quality data are presented below. The first provides an example of high-speed data collection along a 309-mile reach of the Ohio River. The second, based on studies of a shallow tropical lake, illustrates the collection of data and subsequent development of "maps" describing horizontal patterns in surface water quality conditions. Together, these examples indicate the range of monitoring opportunities offered by methods for collecting high-frequency, geographically referenced in situ water quality information.

**Ohio River (from River Mile 127 to 436).** A series of 13 locks and dams has been constructed along the Ohio River as a means to maintain a 9-ft (3-m) minimum channel depth for commercial navigation. A water quality concern for the river is reduced dissolved oxygen concentration conditions during periods of low flow, primarily in these navigation impoundments in the late summer months. These conditions are exacerbated by the influences of industrial outfalls and tributary confluences. A current management strategy is to augment flows in the Ohio River during low-flow periods by making releases from Corps tributary flood-storage projects.

The ameliorative effects of such releases can be optimized if the locations of dissolved oxygen sags are known. Therefore, a sampling plan was developed to collect water samples and in situ data along a 309-mile reach of the river. This was accomplished using a flow-through system that employed a pitot tube water collection device and a high-speed sampling boat. This allowed an extended reach of the river to be sampled intensively over a relatively short study period. Data were recorded on a logging system and viewed real-time on a laptop computer. River miles were recorded in the database with an event marker and served as geographic location indicators. Longitudinal changes in water quality conditions were described by plotting collected data versus river mile.

Marked patterns of change in water temperature and dissolved oxygen were observed across the 309-mile study reach (Figure 2). Temperature spikes observed at river miles 242, 260, and 405 correspond to the locations of coal-fired power-generating facilities. Coincident sags in dissolved oxygen were observed at river miles 260 and 405. Larger scale patterns of change in dissolved oxygen concentration may reflect diurnal changes and/or regional differences in water quality.

**San Jose Lagoon, San Juan, Puerto Rico.** San Jose Lagoon is a shallow (maximum depth ca. 3 m), poorly flushed, brackish-water lake located near San Juan, a large metropolitan area on the northeastern coast of Puerto Rico. The lake is part of the San Juan Bay and Estuary system and is connected through a series of lagoons and narrow channels to ocean outfalls. Water quality concerns include high concentrations of coliform bacteria, low dissolved oxygen concentrations, eutrophication, and the presence of toxic substances (Kennedy and others 1996).

Geographically referenced in situ water quality data were collected for the surface layer of San Jose Lagoon in August 1995 to better understand spatial heterogeneities in water quality. Variables included water temperature (degrees Celsius), dissolved oxygen concentration (milligrams per liter), specific conductance (microsiemens) and fluorescence (relative units) as an indirect measure of chlorophyll concentration. Because of shallow depths throughout the lagoon and safety considerations (small boat size and floating debris), boat speed was greatly reduced (6-8 km/hr) and a flow-through system was modified to include a pump. Sample water was pumped through the monitoring system continuously from a depth of approximately 0.1 m and discharged overboard as the sampling boat traversed the length of the main portion of the lake along a "zig-zag" course (Figure 3). Water quality variables were recorded at 1-sec intervals using a Campbell Datalogger (Campbell Scientific Inc., Logan, UT). GPS coordinates were logged using a Trimble Pathfinder® (Trimble Navigation Ltd., Sunnyvale, CA) and were corrected a posteriori based on fixed-position data recorded at the U.S. Coast Guard Station near San Juan.

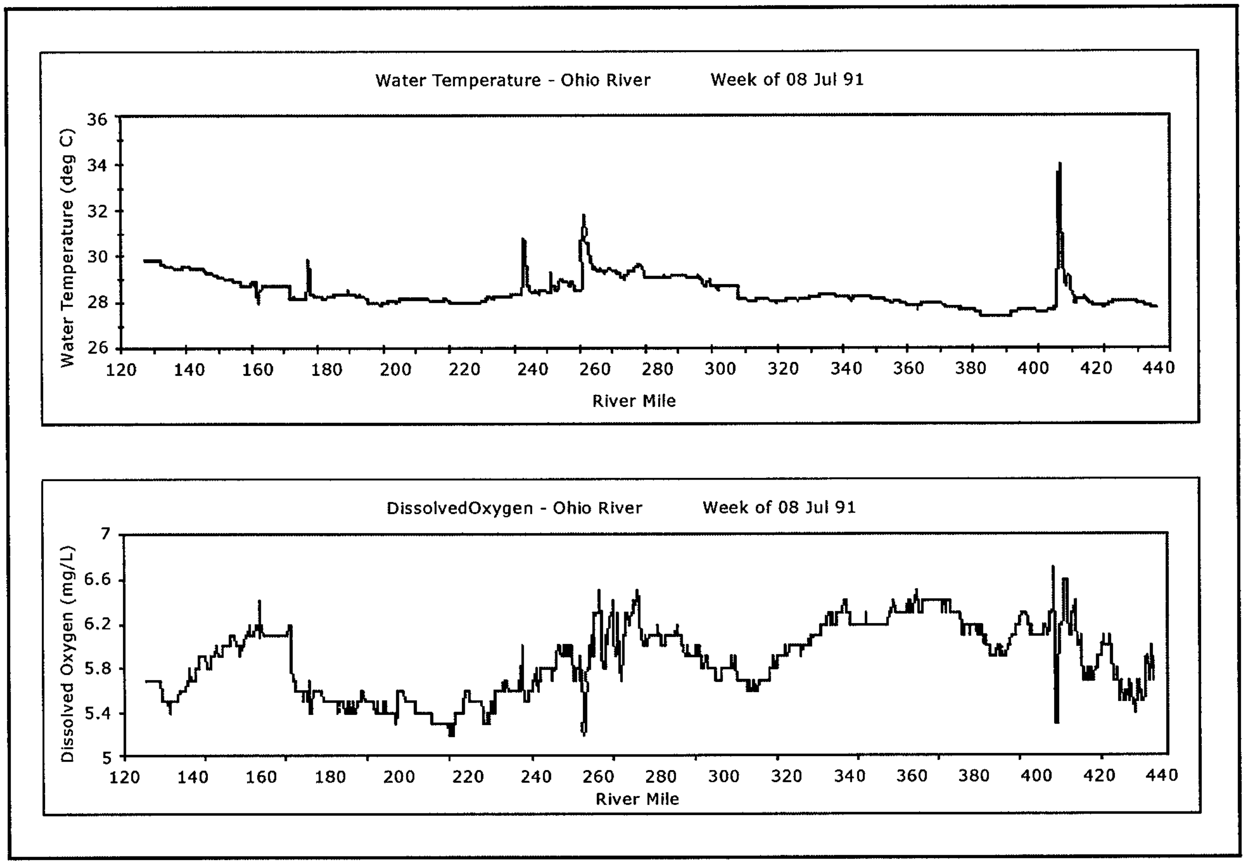

Figure 2. Changes in water temperature (upper) and dissolved oxygen concentration (lower) along a 309-mile reach of the Ohio River

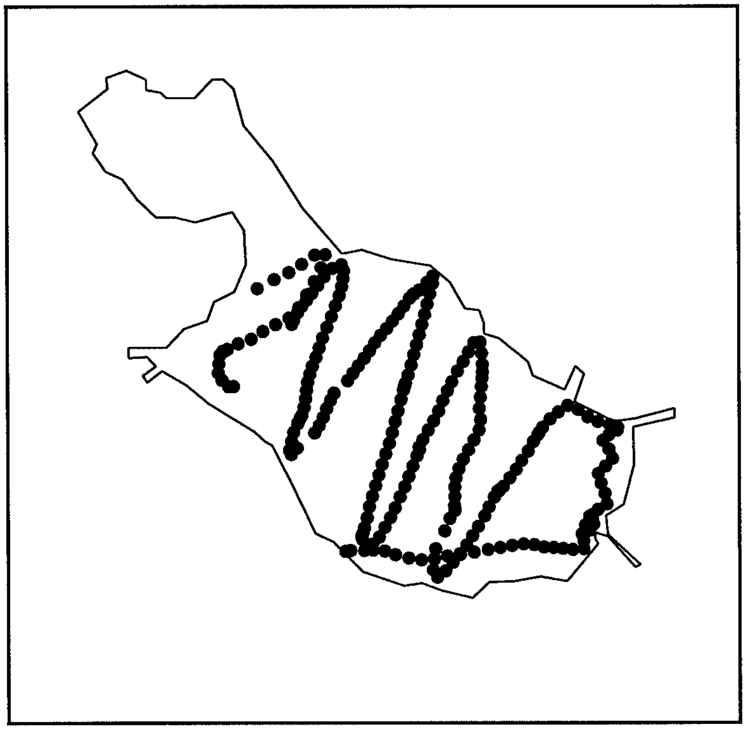

Figure 3. Map of San Jose Lagoon near San Juan, Puerto Rico. Solid circles trace course followed by sampling boat and indicate locations at which in situ water quality data were summarized

Files containing geographic location and water quality data were merged by time, a variable common to both data files. Because of the reduced boat speed and short logging interval, in situ measurements were averaged over consecutive 0.5-min periods as a means to reduce data density. This resulted in 234 observations for each water quality variable. Data contours were mapped using the grid-based plotting program Surfer( (Golden Software, Inc., Golden, CO). Surfer interpolates irregularly spaced XYZ data (e.g., latitude, longitude, and a selected water quality variable) within user-defined boundaries (Golden Software 1994).

High-frequency monitoring identified pronounced spatial heterogeneities for both dissolved oxygen and relative fluorescence (Figure 4). Such spatial patterns reflect the combined influences of internal processes and external inputs via tributary streams (Kennedy and others 1996), but would have been difficult to describe with traditional point sampling methods.

**CONCLUSIONS AND RECOMMENDATIONS:** Traditional sampling strategies involving sample collection at discrete locations offer a reasonable approach for acquiring water quality data in many instances, particularly when depth-wise profiles are required. However, horizontal patterns in the distribution of many water quality variables require new and innovative approaches to data collection. High-frequency, geographically referenced systems, which can be easily configured using currently available components, provide a means to collect spatially detailed information for surface and near-surface waters.

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> Kennedy, R. H., Meyer, R. M., and Cremeans, W. L. (1999). "Methods for collecting high-frequency, geographically referenced in situ water quality information," *Water Quality Technical Notes Collection* (WQTN AM-04), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/elpubs/wqtncont.html*

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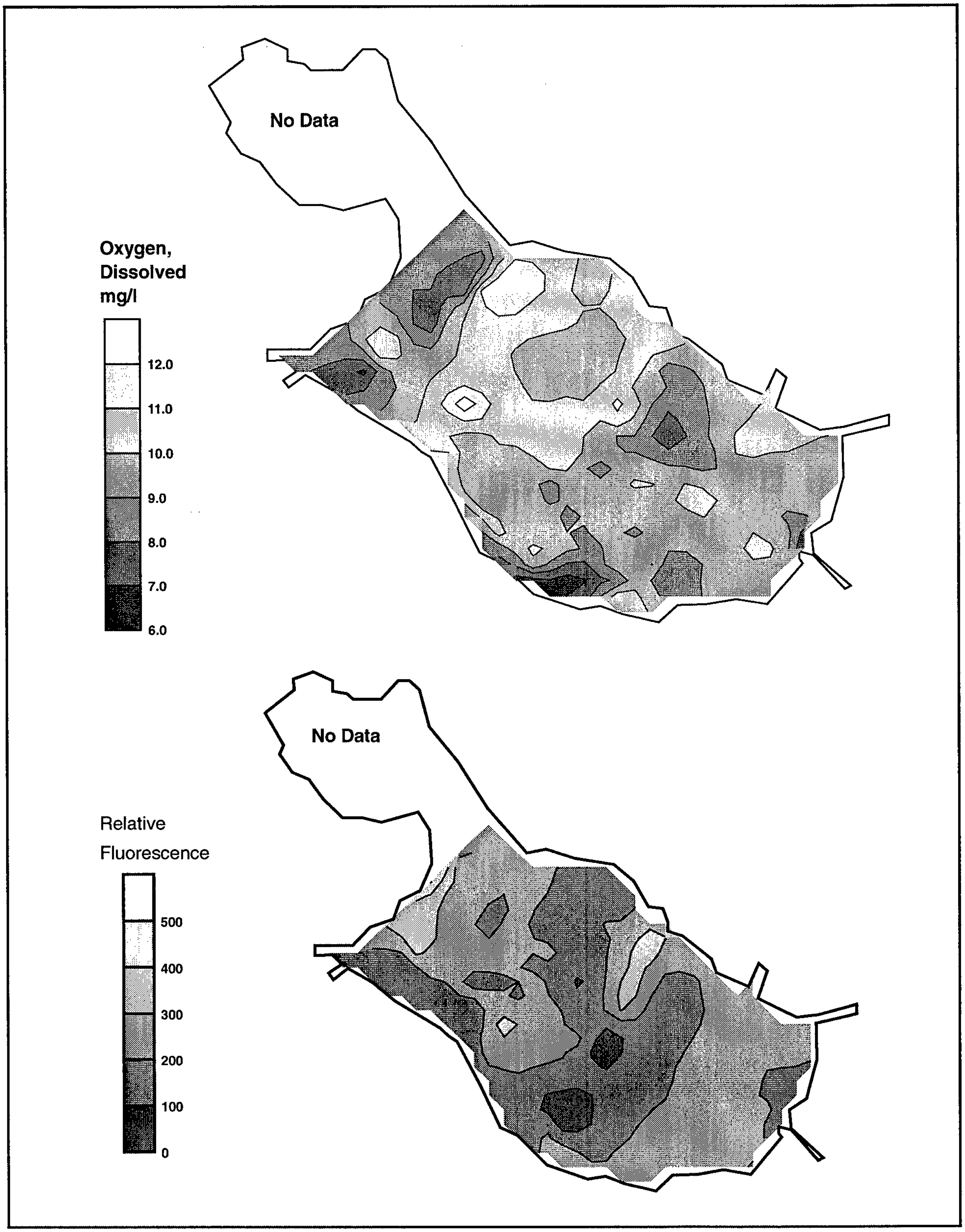

Figure 4. Spacial patterns in the distribution of surface dissolved oxygen concentration (upper) and relative fluorescence (lower) for San Jose Lagoon