# CHAPTER 36

# Monitoring of Constructed Wetlands for Wastewater

**Delbert B. Hicks and Q. J. Stober**

## INTRODUCTION

Use of constructed wetlands for the disposal and treatment of wastewater is emerging as an alternative to conventional approaches for small communities and industries. Operation and maintenance of any process control system are dependent on a monitoring plan that provides information for judging the attainment of treatment objectives, performance, efficiency and the long-term viability of the system. Operation and maintenance of conventional wastewater treatment systems are linked to a systematic and proven procedure of diagnoses and adjustments to system processes. Virtually all steps in the treatment process are subject to control. Responses in biological and chemical processes to adjustments are relatively rapid and easily monitored. This is generally not the case with wetland systems.

Wetlands represent a highly diversified yet ecologically integrated system of plants and animals. No visible boundaries of compartmentalization exist in terms of the flow of energy and matter. Our knowledge of the complexity of these ecological systems is not complete; hence, early diagnoses of failing wetland functions can be difficult to recognize. Adjustments to the physical, chemical, and biological process of the wetlands are not easily accomplished nor are the effects rapidly apparent. For these reasons, the long-term monitoring of wetland treatment systems is essential to develop an information base needed to operate and maintain a healthy biological system. In short, monitoring data are essential to measure the treatment levels and to indicate the functional status and biological integrity of the wetland system.

As seen in the topics of this conference, the use of engineered wetlands for wastewater treatment has a wide range of applications including the processing of domestic waste from single housing units, small municipalities, industrial sources, urban runoff, or a combination of all of the above. In some instances, the benefits of the constructed wetlands can go beyond objectives of treatment to include fish and wildlife enhancement and recreational returns. As the complexity of wastes treated by a wetland increases so do the monitoring requirements, because more variables are introduced which may result in system failure or lead to undesirable side effects. Cost and effort of monitoring increase with chemical complexity of the influent to be treated and ecological diversity of the wetlands to be maintained. This chapter presents monitoring strategies in a hierarchical order according to increasing complexity and implementation effort.

## MONITORING PLAN

Scope of a monitoring effort is linked directly to goals of the treatment project. For example, combining treatment with fish and wildlife enhancement for public benefit would require a monitoring strategy that not only provides data for judging pollution control but also public health and ecological assessments.

Basic elements of a monitoring plan include clearly and precisely stated goals of the treatment project and specific objectives of monitoring. Other elements include statements of organizational and technical responsibilities, tasks and methods, quality assurance procedures, schedules, reporting products, resource requirements, and budget. Written clarification of these elements is essential to assure that a continuum among the data sets exists through the life of the project, which could span many decades. With time, changes in project personnel, regulations, policies, results of data, and funding will foster rethinking of monitoring objectives and assessment strategies that could alter system operation. A well-conceived and clearly defined monitoring plan serves as a point of reference and source of perspective for maintaining a meaningful information base through the life of the project.

### Compliance Monitoring

Monitoring for compliance with a discharge permit probably represents the minimum sampling requirements and complexity. The exception may rest with a small wetland system that features domestic wastewater treatment with no surface discharge and subsurface flow.

Where the wetland treatment system discharges to public waters, performance objectives in terms of treatment goals are established through compliance requirements of a wastewater discharge permit, i.e., the National Pollutant Discharge Elimination System. Compliance monitoring involves an array of parameters that may be both biological and chemical in nature. Parameter selection and discharge limits are a function of the level of water quality protection assigned to the receiving water body by the appropriate regulatory agency. The purpose of attaining compliance is to assure that state water quality standards of the receiving stream are maintained.

Typical parameters of interest include $BOD_5$, total suspended solids, pH, and fecal coliform bacteria. The suite of parameters would no doubt be expanded as the chemical complexity of the wastewater influent increases and could include toxicity assessment, nutrients, and priority pollutants. Methods for analyses are found in numerous publications.[1-4] Assessing the bacterial quality of effluent poses special considerations because of potential contributions from animals using the wetland system, such as ducks and other warm-blooded animals. Should the compliance parameters be reported in terms of mass loading rates, the flow of the discharge also will require monitoring.



Assessment of flow can be accomplished with weekly readings of a staff gauge on a simple "box" or V-notched weir.[5] The flow rate and the effluent concentration of the constituent of interest provide the basis for calculating mass loading to the receiving water body.

### Wetland System Performance and Treatment Efficiency

Long-term management of a wetland treatment system requires a thorough understanding of its efficiency to remove waste constituents and hydrographic factors that affect these processes. Seasonal and possibly daily variations in hydraulic loading of the wetlands affect inundation frequency and duration, detention time, and outflow rates. Hydrographic regime of the wetland affects distribution patterns of plant and animal communities of the wetlands, their vigor, and effectiveness of the wastewater treatment system.

Determining the hydraulic loading rate is the principal means of monitoring application rate of wastewater to the wetlands. This is best accomplished by establishing a continuous flow record or a minimum record based on a minimum of weekly measurements of the wastewater stream or streams discharging to the wetland. This record, coupled with the known surface area of the wetlands, provides data to calculate daily hydraulic loading rates. For example, a total daily wastewater inflow of 3785 $m^3$ to a wetland of 101 ha has an application rate of 2.54 cm per week. This rate assumes the wastewater inflow is uniformly distributed across the wetland and perpendicular to the flow axis.

To monitor the efficiency of constructed wetlands to treat and remove selected chemical and biochemical constituents of the waste stream, inflow and outflow measurements of the wetland treatment system are required. Flow information, along with inflow and outflow constituent concentrations, is the basis for calculating mass loading rates and reduction efficiency across the treatment system.

Inundation frequency and duration is a matter of relating the accumulated frequency and time that the water surface elevation exceeds the land surface of the wetland. To determine this relationship, a topographic survey of the constructed wetland is required. The topographic survey best follows the final grading of the wetland site. Surface water elevations can be determined from a staff gauge or recording water level instrument in the area of the wetland with the greatest depth. The topographic survey and water surface elevations can then be used to determine the volume of the water in the wetland, the inundation frequency, and the duration of flooding. Coupling the volume determinations with the hydraulic loading rates provides estimates of detention time of wastewater in the constructed wetlands.

Circulation of wastewater through the wetland is assumed to be uniform. However, should the wetland have patchy emergence of aquatic macrophyte communities or, possibly, irregular bottom contours, uniformity of flow through the wetlands should be examined with a dye tracer study to assess possible short-circuiting flow patterns.

## Monitoring Wetland Viability and Health

To optimize and sustain the long-term treatment capacity of a constructed wetland requires maintenance of a healthy and functional community of aquatic plants and animals. Monitoring these communities is the only means of judging their condition and their responses to changing hydrographic conditions, temporal effects, diseases, and varying chemical characteristics of the wastewater influent. Benthic aquatic macroinvertebrates, macrophytes, and fish are common focal points in biological monitoring.

Ideally, a biological monitoring strategy is formulated around a compare-and-contrast approach to assessing the biological condition. This approach must assume that applicable baseline or background data bases exist as a point of reference for comparison with data derived from the treatment wetland. In some cases, values from wetland literature serve this need. Another approach is to locate and monitor a nearby existing wetland of similar hydrology and wetland characteristics. An alternative is parallel construction and operation of a second wetland system to serve as a reference site until a baseline condition can be established. Following this goal, the second site can be managed in a rotational manner with the other system.

Wetland macrophytes (vegetation), a component of primary production, assimilate nutrients and produce organic matter via the photosynthetic process. The other functions include storage of chemicals in above- and below-ground tissues, transport of oxygen into the water sheet, and serving as substrate for microbial communities that treat the water. Therefore, it is necessary to monitor for changes to the vegetational community. The wetland can be viewed as an aquafarm and, as such, requires a normal amount of agricultural attention.

Water must reach all parts of the wetland surface, or there will be immediate and long-term consequences. In the short term, there will be a loss of effectiveness in proportion to the area not exposed to wastewater. In the long term, lack of nutrients and water will cause the species of vegetation to change. The depth and duration of inundation can also affect the plants; with continued deep water, some species will eventually drown, even though they are adapted to standing water during a large portion of the year.

Accumulation of dead plant material is beneficial in two respects: (1) some of this biomass will be mineralized as sediment and retain chemicals in the ecosystem, and (2) this litter becomes substrate for microbes that clean the water. Of course, most dead plant material decomposes and returns the stored chemicals to the water.



Vegetation in a man-made wetland is subject to gradual year-to-year change, just as it is in natural wetlands. There may be a tendency for some species to die out and be replaced by others. Very temporary changes, such as the appearance of algae or duckweed, can occur in response to random or seasonal climatic changes.

Knowledge of these wetland functions must be used to maintain the desired water treatment capability for the wetland. Two things easily accomplished in vegetation monitoring are determination of the current species composition and standing crop size. Species composition is determined from inspection of quadrats[6] within the wetland at selected locations, perhaps complemented by aerial photography, both color and color infrared. Because of the slow rate of vegetative changes, which may not be obvious during the tenure of a single operator, good record keeping becomes essential.

Measurements of standing crop biomass will indicate if the vegetative storage is currently increasing or decreasing. End-of-season harvest and weighing of material from clip plots provide the necessary data. Storage can be estimated from published information on chemical composition of the plants in question. Sampling strategies for the assessment of macrophytes are further detailed elsewhere.[7]

Benthic macroinvertebrates occupy nearly all levels in the trophic structure of a wetland community. They may be omnivores, carnivores, or herbivores, and in a well-balanced system all types are likely to be found (detrital and deposit feeders, scavengers, grazers, and predators). The macroinvertebrate community is sensitive to environmental stress, i.e., pollution, and can serve as a useful means of detecting subtle and gross changes in the aquatic environment. This is possible because benthic macroinvertebrates generally feature a relatively long life span, thus integrating effects of conditions during the recent past. Taxa diversity and abundance respond to environmental stresses. With increasing stress upon the community, taxa are eliminated from the community according to their tolerance to the perturbation. The remaining taxa can grow in number due to reduced competition for space and food. Methods and sampling considerations for monitoring the benthic macroinvertebrate community have been thoroughly detailed.[8] These methods include both qualitative and quantitative assessments and can involve a variety of sampling techniques ranging from simple grab samples to artificial substrates for organism colonization.

Trace metal and organic contaminants enter wetlands with all influents and partition between the water, sediment, and biota. Many contaminants bind to organic particulates either in the effluent or in the wetland and are removed from the water. Contaminant monitoring in sediments is effective for identifying the treatment occurring in any wetland; however, the sediment may represent only a temporary sink. Contaminants in sediments can be biologically concentrated and magnified through each level of the aquatic and terrestrial food chain, resulting in special monitoring requirements.

Bioaccumulation of trace amounts of chemical contaminants in aquatic organisms also serves as a monitor of constructed wetlands. Contaminants of concern should be selected on the basis of the following characteristics: high persistence in the aquatic environment, high bioaccumulation potential, high toxicity to humans and/or wildlife, known or suspected sources of the contaminant(s) entering the system, and high concentrations in previous samples of fish and invertebrates from other similar systems.

General information on persistence, bioaccumulation potential, and toxicity may be obtained elsewhere.[9,10] EPA priority-pollutant organic chemicals and selected pesticides have been ranked in descending order of bioaccumulation potential according to their octanol-water partition coefficients. Organic compounds with a log octanol-water partition coefficient greater than or equal to 2.3 are usually recommended for inclusion in monitoring programs. EPA priority-pollutant metals have been ranked in descending order of bioaccumulation potential according to bioconcentration factors.[11,12] Screening of potential contaminants of concern should be done on a site-specific basis. Methodology for the chemical analysis of 45 xenobiotic compounds in fish tissue has recently been developed[13] to allow monitoring of multiple contaminants simultaneously.

The monitoring design will vary with the type of constructed wetland to be evaluated and multiple uses that may be supported by a wetland. If the sole purpose of the wetland is wastewater treatment, the focus of sampling is to determine the health of the associated biota to ensure the proper long-term functioning of the wetland. The bioconcentration of trace contaminants in fish or invertebrate tissue may be used to indicate general health of the system, including the contaminant processing through the water and sediments to biological tissues. This monitoring provides an important feedback loop to assess the need for cleanup of the influent via source control and should be conducted over the life of the project. Whole body contaminant burdens of fish or invertebrates may have significance to the surrounding terrestrial environment, especially if top reptilian, avian, or mammalian predators become dependent on the wetland as a food source. However, if constructed wetlands are designed to support a diverse community of fish and invertebrates, the potential for human use of the aquatic resource may exist. We assume that public access can be controlled, eliminating the need to assess adverse human health effects from the wetland if significant organism contamination occurs. Depending on the wetland efficiency as a sink for trace contaminants or passage of these compounds or contaminated organisms out of the system into natural receiving waters, the potential risk to human health may require assessment.

An evaluation of the risks of consuming chemically contaminated fish generally focuses on estimation of the chance of incrementally increased risks of cancer and/or various noncarcinogenic and developmental adverse health effects in groups of people consuming various amounts of the contaminated fish over a 70-year lifetime. A draft methodology for conducting such assessments has been documented in a guidance manual[14] that provides a basis for evaluation along with guidelines for health risk assessment.[15] This methodology includes the conversion of measured values for contaminant residues in fish into daily doses to consumers based on the long-term average daily consumption.[16,17] The potential health effect resulting from estimated dose is calculated based on the USEPA carcinogenic potency factor established by toxicological testing results. The cancer risk is expressed in terms of a plausible 95% upper-bound estimate of increased lifetime incidence of cancer per unit of exposed population. The population usually at greatest risk is the local angler who may consume contaminated fish from a single source over a long period.



Sampling wetlands for contaminant accumulations in fish and invertebrate tissues should be designed to determine whether gradients exist downstream. Depending on the length of each system and water retention capacity, the monitoring design should focus on inflow and outflow areas as well as on areas where particulates tend to accumulate in the system. Many trace organics and metal contaminants are strongly adsorbed to particulates, and maximum tissue concentrations generally occur in organisms most closely associated with contaminated sediments. Benthic organisms, which inhabit and feed in contaminated sediments, and bottom-feeding fish species bioaccumulate the highest contaminant concentrations due to their close association.

If trace contaminants are carried through the wetland during flushing events or due to eventual system saturation, tissue contaminant monitoring in natural receiving waters may be necessary, including sampling of bottom fish and sport and commercial species above and below the outfall. Sampling proximity to the return flow and species selected should reflect those species spending most or all of their lives in the immediate vicinity. Both upstream and downstream samples are desirable, and more than one sampling station is usually required downstream to determine the extent of bioconcentration of specific chemical contaminants.

## CONCLUSION

An appropriately designed and implemented monitoring plan is essential to the successful management, operation, and maintenance of a constructed wetlands for treatment of wastewater. The monitoring plan comprises numerous components, including clearly stated objectives, technical and management responsibilities, quality assurance procedures, resources, and schedules. Scope of the monitoring activities is a function of the treatment goals, project benefits, and diversity of plant and animal communities involved in the wetland system. Results of monitoring serve to determine compliance of the wetland discharge with permit limits established by pollution control agencies. Monitoring of the plant and animal communities provides surveillance data necessary to determine health and viability of the wetlands and identify early signs of stress to the aquatic communities of plants and animals. Early detection of a failing wetland system is essential to the operation and maintenance of the treatment system.

Engineered wetlands as treatment systems are appealing because of low costs of construction and simplicity of operation and maintenance needs. However, appropriate monitoring, though it adds costs, is a necessity and must be viewed as a priority over the life of the project.

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## REFERENCES

1. "Methods for Chemical Analysis of Water and Wastes," Environmental Monitoring and Support Laboratory, U.S. EPA Report-600/4-79-020 (Revised 1983).
2. *Standard Methods for the Examination of Water and Wastewater,* 16th ed. (Washington, DC: American Public Health Association, 1985).
3. Peltier, W., and C. I. Weber, Eds. "Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms," 3rd ed. Environmental Monitoring and Support Laboratory, U.S. EPA Report-600/4-85-013 (1985).
4. Weber, C. I. "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms," U.S. EPA Report-600/4-89-001 (1989).
5. "Water Measurement Manual," Water Resource Technical Publication No. 2403-00086, U.S. Government Printing Office (1974), p. 327.
6. Cox, G. W. *Laboratory Manual of General Ecology* (Dubuque, IA: W. C. Brown Publishers, Inc., 1970), p. 165.
7. Dennis, W. M., and B. G. Isom, Eds. "Ecological Assessments of Macrophyton Collection, Use, and Meaning of Data," ASTM Publication 8453, Philadelphia (1983).
8. "Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents," Office of Research and Development, U.S. EPA Report-670/4-73-001 (1973).
9. Lyman, W. J., W. F. Reehl, and D. H. Rosenblatt. *Handbook of Chemical Property Estimation Methods* (New York: McGraw-Hill Book Company, 1982).
10. Callahan, M. A., M. W. Slimak, N. W. Galde, I. P. May, C. F. Fowler, J. R. Freed, P. Jennings, R. L. Durfee, F. C. Whitemore, B. Amestri, W. R. Mabey, B. R. Holt, and C. Gould. "Water-Related Environmental Fate of 129 Priority Pollutants, Vol. I and II," U.S. EPA Report-440/4-79-029a/b. (NTIS No. PB80-204373 [Vol. I] and PB80-204381 [Vol. II])
11. U.S. EPA. "Water Quality Criteria Documents; Availability," 45 *Fed. Reg.* 231, Part V, pp. 79318-79379.
12. Tetra Tech, Inc. "Bioaccumulation Monitoring Guidance: 1. Estimating the Potential for Bioaccumulation of Priority Pollutants and 301(h) Pesticides Discharged into Marine and Estuarine Waters, Final Report," prepared for Office of Marine and Estuarine Protection, U.S. EPA, Washington, DC by Tetra Tech, Inc., Bellevue, WA.
13. "National Dioxin Study, Phase II, Draft Analytical Procedures and Quality Assurance Plan for the Determination of Xenobiotic Chemical Contaminants in Fish," EPA, ERL-Duluth, MN (1988).
14. PTI, Environmental Services Inc. "Guidance Manual for Assessing Human Health Risk from Chemically Contaminated Fish and Shellfish," draft report to Battelle New England Marine Research Laboratory for USEPA Office of Marine and Estuarine Protection, Washington, DC (1987).
15. "Guidelines for Health Risk Assessment," 51 *Fed. Reg.* 79318-79379 (1986).
16. Kreiger, R. A. "Derivation of a Virtually Safe Dose (VSD) Estimate for Sport Fish Containing 2,3,7,8-Tetrachlorodibenzo-p-dioxin," Minnesota Department of Health, Health Risk Assessment Section (1985).
17. "Assessment of Dioxin Contamination of Water, Sediment and Fish in the Pigeon River System (A Synoptic Study)," U.S. EPA Region IV Environmental Services Division for U.S. EPA Region IV Water Management Division, Report #001 (1988).