CHAPTER 3

Hydrologic Factors in Wetland Water Treatment

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INTRODUCTION

A wide variety of wastewaters have been treated with wetland systems. To at least some degree, most have been successful. Further advance of this technology must be based on a coordinated set of design principles. First among these is understanding wetland hydrodynamics and its influences on data acquisition and design. Three features of water movement in these systems distinguish them from conventional concrete-and-steel wastewater treatment facilities. First, because of large surface area together with outdoor location, wetland systems interact strongly with the atmosphere via rainfall and evapotranspiration. Second, because of high vegetation density, plants influence water movement, both overland flow and evapotranspiration. Finally, because contact times are long with respect to the time scales of rainfall and microbial dynamics but short with respect to seasonal processes, the operation of these systems may not be viewed as a steady-state process.

The purpose of this chapter is to set forth current information on key hydrologic processes, and to examine implications on process performance. Because wetland systems are usually isolated from surface runoff, that process requires little attention. The most important effects are increased catchment area created by dikes or berms forming the wetland, and perhaps some lateral wicking to berms during dry, unfrozen conditions. Water consumption for biomass production is a tiny fraction of total flow, and will not be mentioned further.

Snow and ice phenomena are basically unstudied. Existing results suggest that ice layers retard but do not stop water movement under the ice. Most snowfall is stored until spring thaw, when a significant portion of the melt water exits as over-ice flow. Treatment efficiency is reduced; hence, some degree of winter water storage is necessary in northern climates. Water irrigation can be conducted in winter without freeze-up, provided modest precautions are taken. The primary focus of this work is on the unfrozen seasons, or the entire year for southern locations.

The short-term dynamics of wetland treatment systems are poorly understood. Clearly, waves of concentration and water pass through these systems in response to unsteady pumping activities and atmospheric events. Descriptive tools are available for such behavior,[1,2] but the details are too lengthy to be included here.

FLOW RESISTANCE

Wetland system flow may be separated into overland and underground components, although the dividing line is arbitrary since ground level is difficult to define in wetlands. Hydraulic conductivity changes sharply between the vegetation and litter and the soils below. More important are changes in the fundamental rules that govern flow. All such rules relate flow rate to depth, travel distance, and slope of the water surface. Refer to Figure 1 for terminology.

For flow in fully saturated, fine grained soils, sands, and gravels, Darcy's law is expected to hold:

$$v = -k \frac{\partial P}{\partial x} \tag{1}$$

where v is linear velocity, x is travel distance, and P is pressure expressed in liquid head. The constant, k, is the hydraulic conductivity. This equation holds approximately for peat, but uniformity and directional preferences are questionable. This is the preferred calculation for infiltration.

For lateral free surface flow through coarse gravels and rocks, Ergun's equation is appropriate:

$$\rho g S = 150 \frac{\mu v (1-\epsilon)^2}{D_p^2 \epsilon^2} + 1.75 \frac{\rho v^2 (1-\epsilon)}{D_p \epsilon} \tag{2}$$

where
- S = the slope of the free surface
- ρ = density
- g = gravitational acceleration
- μ = viscosity
- ϵ = porosity
- D_p = particle diameter
- v = velocity = superficial velocity/ϵ

This equation adds a term to Darcy's law for turbulent flow, which can occur for the larger particle sizes. Further, it is "turned around" and is explicit in the slope of the water surface, not in the velocity. This equation calculates the extent of water mounding that may occur in wetland systems with underground lateral flow (the gravel bed systems). Figure 2 shows the expected mound height for an outlet depth of 50 cm and a porosity of 30%. As rock diameter and flow rate increase, turbulence may be present; the second term in the Ergun equation will contribute. Turbulence occurs when the particle Reynolds number, $D_p \rho v/\mu$, exceeds a value of 10. Significant water mounds can develop with certain choices for diameter and flow rate, and mound tilt can be

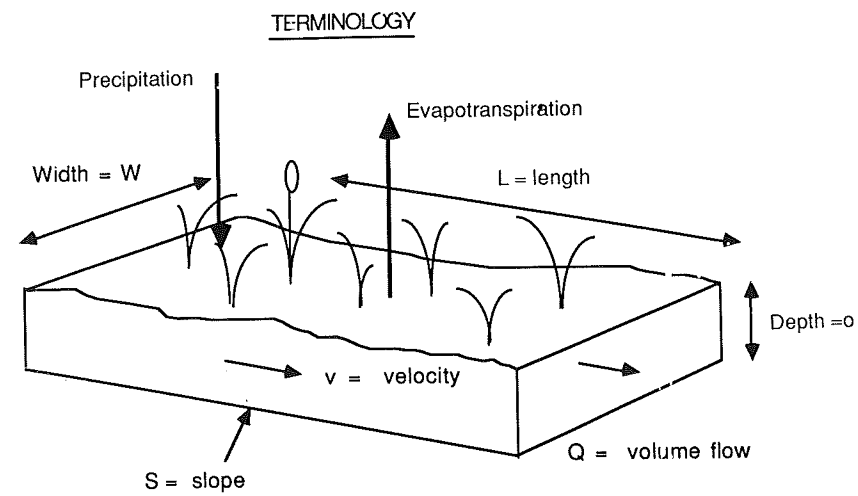

Figure 1. Terminology for wetland treatment systems.

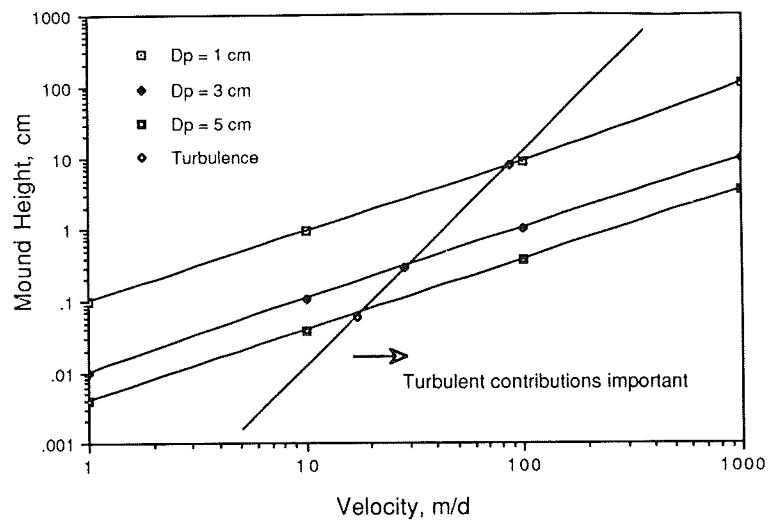

Figure 2. Water mounding potential for rock bed wetland treatment systems for different rock sizes and velocities. Based on exit depth of 50 cm and length of 100 m.

great enough to cause overland flow in the upstream sections of a rock bed wetland.

Contact times for subsurface flow wetlands depend on depth and flow rate. In the absence of mounding, these parameters may be set independently, since velocity does not depend upon depth.

For lateral overland flow through wetland vegetation, an empirical flow law applies, similar in appearance to the Manning equation:

$$Q/W = a\,d^{b}\,S^{c} \tag{3}$$

where Q/W = volumetric flow per unit width
d = depth
S = slope of water sheet
a,b,c = constants

This equation is derived from the Ergun equation together with a depth-variable stem density and a depth-variable soil elevation distribution. A turbulence term is included because overland flow in a wetland is transitional between streamline and turbulent flow. However, it is then convenient to recorrelate the model to the empirical form shown above.[1]

This form of the equation recognizes that such flows are partly turbulent and partly laminar.[3] The exponent $b = 3.0$, and $c = 0.338$ for grassy slopes;[4] for the Houghton Lake wetland, $b = 2.5$–3.0 and $c = 0.7$–1.0.[1,5] The coefficient a is site-specific, but equal to 4×10^{6} in meters and days for Houghton Lake for $b = 3$ and $c = 1$. All wetland data sets show approximately the same depth dependence, but slope dependence is not as well defined. In any case, calculations are not sensitive to the slope term power.

Contact times (τ) are calculated by dividing the water volume in the wetland by the volumetric flow rate Q:

$$\tau = \frac{LWd\epsilon}{Q} \tag{4}$$

The wetland overland flow law may be used to eliminate the depth:

$$\tau = \frac{L\epsilon}{a^{1/b}\left(\frac{Q}{W}\right)^{1-1/b} S^{c/b}} \tag{5}$$

The power on flow is approximately 2/3, and on slope approximately 1/3. The recommended overland flow equations for terrestrial ecosystems[6] are similar in form but were calibrated for higher slopes and are seriously in error for wetland environments.

Attempts to set wetland operating depths may fail if vegetative resistance creates a significant slope to the wetland water sheet. Water will mound near the inlet to provide the necessary head to drive water through the vegetation.

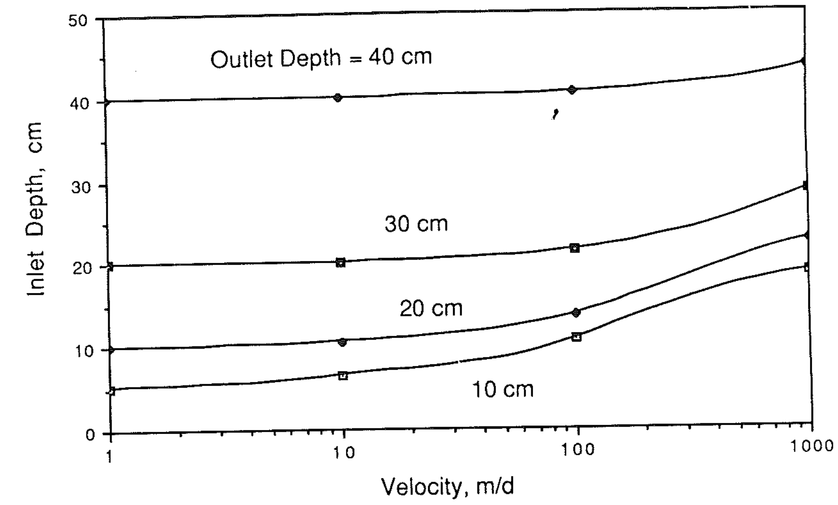

Figure 3. Size of the water mound for aboveground water flow through a vegetated wetland. Based on data from the Houghton Lake system and a length of 100 m.

Using results from the Houghton Lake, Figure 3 illustrates the size of this mound under different conditions of flow and outlet water depth.

EVAPORATION AND TRANSPIRATION

Atmospheric water losses from a wetland occur from the water and soil (evaporation), and from emergent portions of plants (transpiration). The combination is termed *evapotranspiration.* Many reports of wetland vaporization losses include the reviews of Linacre[7] and Ingram.[8] All have attempted to correlate data with ecosystem and meteorological variables and, in most cases, have compared data to open water evaporation. The results form a large and confusing literature, but a coherent set of principles may be drawn that is here restricted to "reedswamp" wetlands, i.e., those containing nonwoody emergent macrophytes, such as *Typha, Scirpus,* and *Phragmites.*

Vaporization energy comes principally from the sun, so the energy balance for the wetland is the logical framework to use for data interpretation. With reference to Figure 4:

$$Q_{rn} + Q_{ai} = Q_{e} + Q_{h} + Q_{s} + Q_{ao} \tag{6}$$

Net radiation (Q_{rn}) is the incoming solar energy less the back radiation and reflection. In turn, incoming radiation depends on cloud cover, time of the year, and latitude. Reflection depends on wetland albedo. Literature values are 0.1–0.4, with low values from low sparse vegetation and high values from

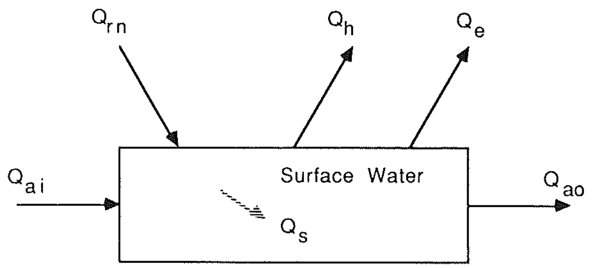

Figure 4. Energy flows which drive evapotranspiration. Net radiation and advective inputs result in vaporization, convection to the air, advective output and storage (rn = net radiation; ai = advective input; ao = advective output; s = storage; h = heat loss; e = evaporative loss).

dense, high vegetation. Transport of heat and water vapor from the surface is governed by local air swirls and is in a fixed proportion called the Bowen ratio. Wind speed influences both, as does vapor pressure and water temperature. Advection terms incorporate air current influences from adjacent environments.

Given sufficient meteorological data, the energy balance can calculate evaporation or evapotranspiration.[9] The text of Eagleson[10] is one of several sources of extensive explanation. About a dozen pieces of information are needed to use this method, some of which are not available *a priori,* such as albedo. Although the calculation is intended only for evaporation, it is frequently used to estimate evapotranspiration.

Data requirements of the energy balance estimation procedure led to many simpler, more empirical procedures.

The following propositions are supported by available data.

1. *The presence of vegetation retards evaporation.* Vegetation increases shade and humidity and reduces wind near the surface. A litter layer can create a mulching effect. A sampling of percentages of open water evaporation is as follows: Bernatowicz et al.,[11] 47%; Koerselman and Beltman,[12] 41–48%; Kadlec et al.,[13] 30–86%. However, the wetland does not necessarily conserve water, because transpiration can equal or exceed the difference.
2. *Wetland evapotranspiration, over the growing season, is represented by 0.8 times Class A pan evaporation from an adjacent open site.* The Class A pan integrates effects of many meteorological variables, with the exception of advective effects. This result has been reported in several studies, including: western Nevada,[13] northern Utah,[14] and southern Manitoba.[15] Stipulation of a time period in excess of the growing season is important, because short-term effects of vegetation can invalidate this simple rule of thumb. The effect of climate is apparently small, since annual data for a wastewater treatment wetland at Clermont, Florida were 0.78 times the Class A pan data from the nearby Lisbon station.[16] This multiplier is the same as for the potential evapotranspiration from terrestrial systems.[17]

   Class A pan data are tabulated monthly and annually in *Climatological Data,* published by the U.S. National Oceanic and Atmospheric Administration, Asheville, North Carolina.

3. *Wetland evapotranspiration and lake evaporation are roughly equal.* This is a corollary to *2,* since Class A pan evaporation is 1.4 times lake evaporation. Roulet and Woo[18] report this equality for a low arctic site, and Linacre's[7] review concludes: "In short, rough equality with lakes is probably the most reasonable inference for bog evaporation." Vegetated potholes lost water 12% faster than open water potholes,[19] but Virta[20] (see also Koerselman and Beltman[12]) found 13% less water loss in peatlands. There is a seasonal effect which can invalidate this in the short term.
4. *About half the net incoming solar radiation is converted to water loss on an annual basis.* Reported values include 0.51,[13] 0.47,[14] 0.64,[18] and 0.49.[21] If the radiation data from the Clermont wetland is used to test the concept, the value is 0.49, based on Zoltek et al.[16]

   Incoming radiation at the top of the atmosphere is tabulated in several texts, including Thibodeaux,[22] who also gives ground level data for selected cities for 1971. Ground level radiation shows effects of cloud cover according to:

$$Q_{nr} = Q_{ar}\left[0.803 - 0.340n - 0.458n^2\right] \tag{7}$$

   where n = fractional cloud cover (available in *Climatological Data).*
5. *Seasonal variation in evapotranspiration shows effects of both radiation patterns and vegetation patterns.* The seasonal pattern of evapotranspiration resembles the seasonal pattern of incoming radiation (Figure 5). However, attempts to apply *4* (above) on a monthly basis do not produce a constant multiplier. During the course of the year, wetland reflectance changes, the ability to transpire is gained and lost, and a litter layer fluctuates in a mulching function. Christiansen and Low,[14] computed a crop coefficient to account for vegetative effects. In addition to effects due to radiation, wind, relative humidity, and temperature, this is the ratio of wetland evaporation to lake evaporation. The result is a growing season enhancement followed by winter reductions (Figure 6). A similar coefficient derived for the Clermont wetland shows different features. Seasonality is shifted, presumably due to climatic differences; enhanced growth due to nutrients may lead to greater stem densities and biomass, amplifying the vegetative effect and increasing the mulching effect.
6. *Very small wetlands will react strongly to the surrounding microclimate.* Linacre[7] calls this the "clothesline effect," citing several studies with enhanced evapotranspiration for what amounts to potted plants. Since treatment wetlands tend to be small, it is reasonable to enquire at what size this effect becomes important, but little information is available. A wetland of "less than one hectare" displayed minor differences from similar studies on larger wetlands.[12] At Listowel, Ontario,[23] lake evaporation reasonably estimated evapotranspiration for 0.1 and 0.4 hectare wetlands. However, as size decreases, the advective terms in the energy balance become important; Penman methods are no longer adequate; and ratios to pan and lake evaporation, and to radiation, would not hold.
7. *Type of vegetation is not a strong factor in water loss determination.* Bernato-

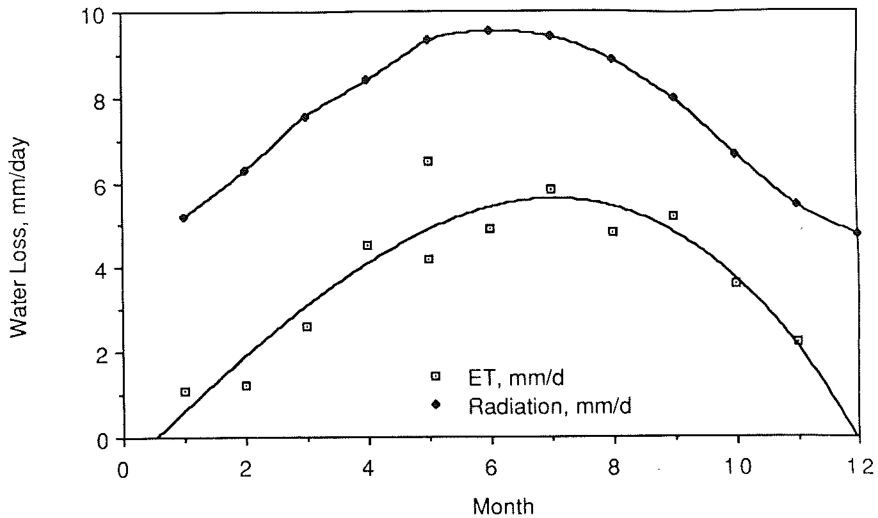

Figure 5. Radiation at ground level and measured evapotranspiration for the Clermont, Florida site. Net radiation is expressed in units of potential evaporation.

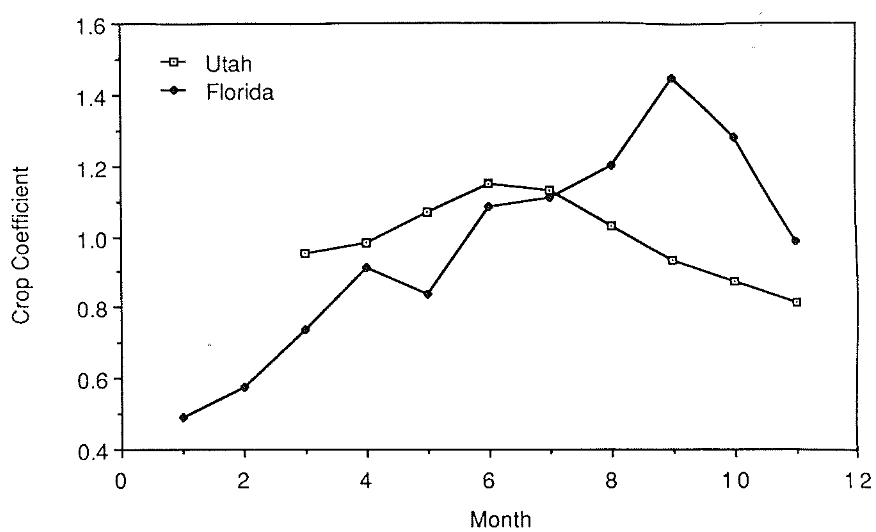

Figure 6. Effect of vegetation as a modifier of potential evaporation. This crop coefficient alters the distribution of water loss throughout the year but not the annual total.

wicz et al.[11] found small differences among several species, including *Typha*. Little difference was found among two *Carex* species and *Typha*,[12] and Linacre[7] concludes: "[I]t appears that differences between plant types are relatively unimportant."

8. *Energy associated with incoming wastewater is not likely to be a strong addition to solar energy in the summer, nor the source of large water losses in the winter.* Simply calculate the energy associated with the temperature reduction of incoming water and compare it to net incoming solar radiation. The rate of water loss due to dissipation of ΔT degrees of incoming water temperature is given by:

$$\text{loss} = (Q/LW)(c\Delta T/\lambda) \tag{8}$$

where loss = cm/day
(Q/LW) = loading rate, cm/day
$(c\Delta T/\lambda)$ = (sensible heat/latent heat) ratio
= $\Delta T/585$

Summer temperature drops were 10°C for the Listowel system (Figure 7), contributing only a 2% loss of applied water. This is, however, a 5–10% augmentation of the evapotranspiration rate of 5 mm/day for Listowel.

ATMOSPHERIC AUGMENTATION

Flow through a wetland system is augmented by precipitation and (negatively) evapotranspiration. Precipitation records are available for nearby sites, and the above outlines methods for estimating evapotranspiration. This section addresses what effect these gains or losses have on wetland hydrodynamics. It is important to note the range of additions or losses expected for typical operations. Figure 8 shows annual data for two northern wetland treatment systems, Bellaire and Houghton Lake Michigan. Even on a long-term basis, rain and vaporization have significant effects. Over one to two months, these wetlands have operated with total evaporation of added wastewater and, at other times, with ratios of rain to wastewater of greater than 1. An expected range of fractional augmentation is ±1.00.

Evapotranspiration slows water flow and increases contact times, whereas rainfall has the opposite effect. For a wetland operated at constant depth, the actual contact time is given by:

$$\tau_a = \tau \left[\frac{1}{\alpha}\ln\left(\frac{1}{1-\alpha}\right)\right] \tag{9}$$

where α is fractional augmentation and τ nominal contact time, based on nominal depth and wastewater addition rate. Evaporation has a strong influence on contact time (Figure 9). Rain, characterized by negative values of augmentation, has a lesser effect. Because normal climatic time sequences combine gains and losses over the span of typical contact times, it is informa-

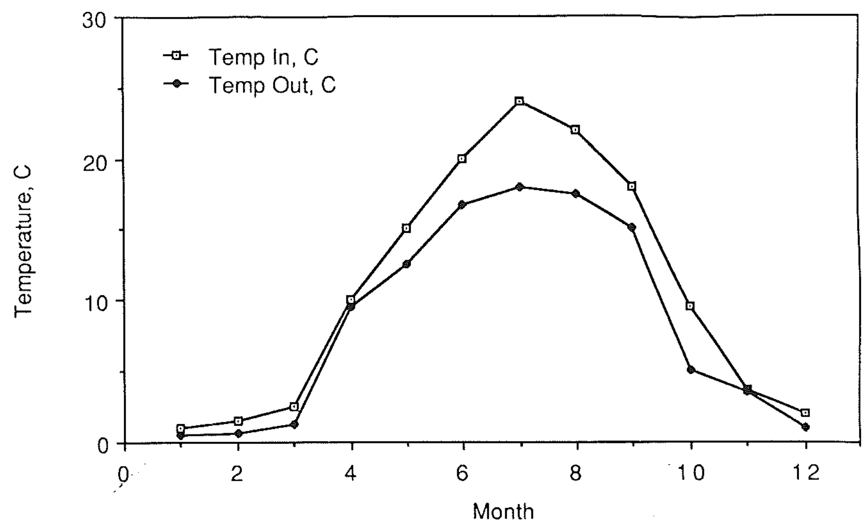

Figure 7. Temperatures of influent and effluent from the Listowel system.

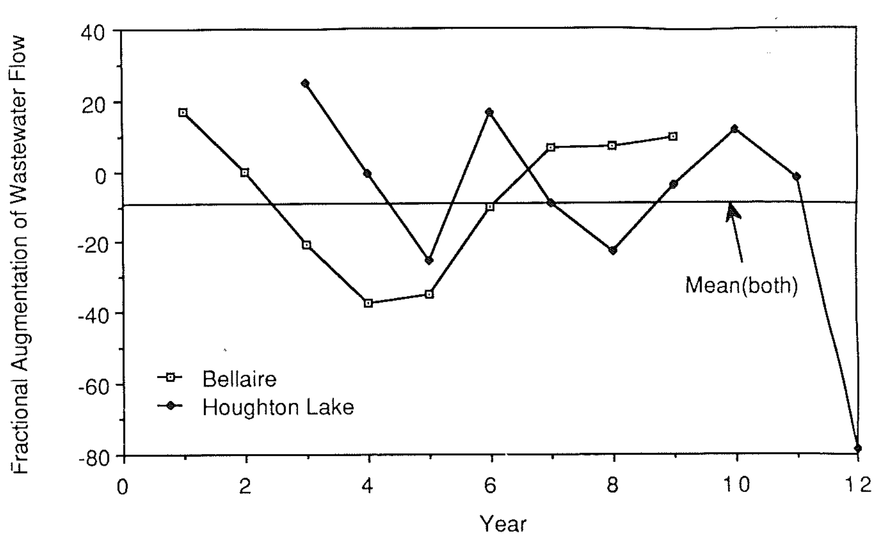

Figure 8. Additions and subtractions from annual wastewater flows to the Bellaire and Houghton Lake systems from rain and evapotranspiration.

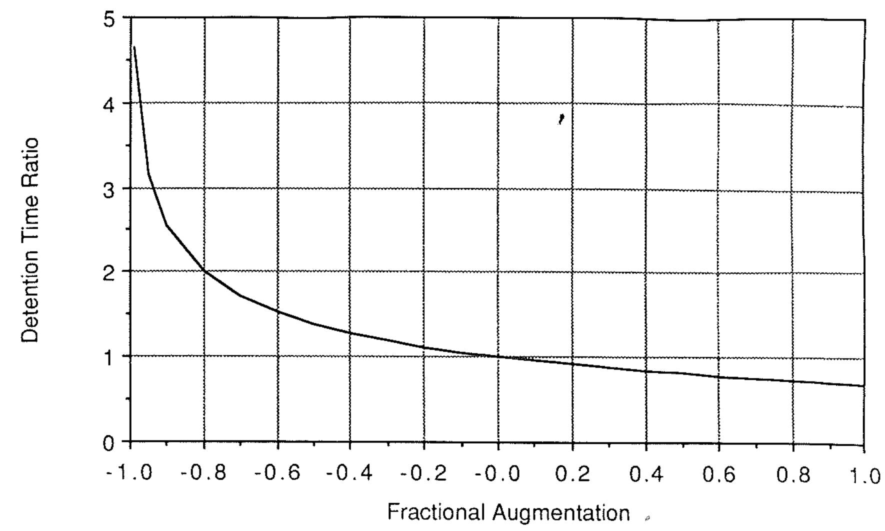

Figure 9. Effect of atmospheric augmentation on detention time. The nominal detention time is computed from the inflow.

tive to look at ratios of measured contact time to nominal contact time. Data for Houghton Lake, determined from water balance procedures, are shown in Figure 10; Figure 11 gives data from dye tracer experiments for Listowel. The range is 40–250% in both cases. The mean for Listowel, spanning all seasons over four years, is 126%. The Houghton Lake mean is the nominal 100%, since precipitation equalled evapotranspiration for the summer period.

The effect on depths and flow rates is more complicated because of wetland storage capacity and different operating modes. The general transient, depth-variable situation has been described and modelled by Hammer and Kadlec.[24] Results from three differently operated systems are given in Figures 12, 13, and 14. Figure 12 shows depth and average flow behavior for one summer season at Houghton Lake. This system is operated with intermittent irrigation, several days on followed by several days off. Flow is overland and controlled by topography of the natural wetland and the vegetation resistance. As a result, depth and flow vary strongly in response to addition patterns as well as atmospheric augmentation. Flow dependence on depth to the power of 2.0 produces greater flow fluctuations than depth fluctuations. In contrast, the Clermont, Florida system[16] applied wastewater one day in seven, and outflow was by infiltration to underlying peat and sand. Depth variations were much greater than outflow variations, as illustrated in Figure 13. The third mode of operation, for Listowel, Ontario, was constant depth (although there may have been some vegetation control for shallow depth experiments) and constant inflow. All atmospheric augmentation, therefore, showed up immediately at the wetland outflow (Figure 14). Thus, the time sequence in Figure 14

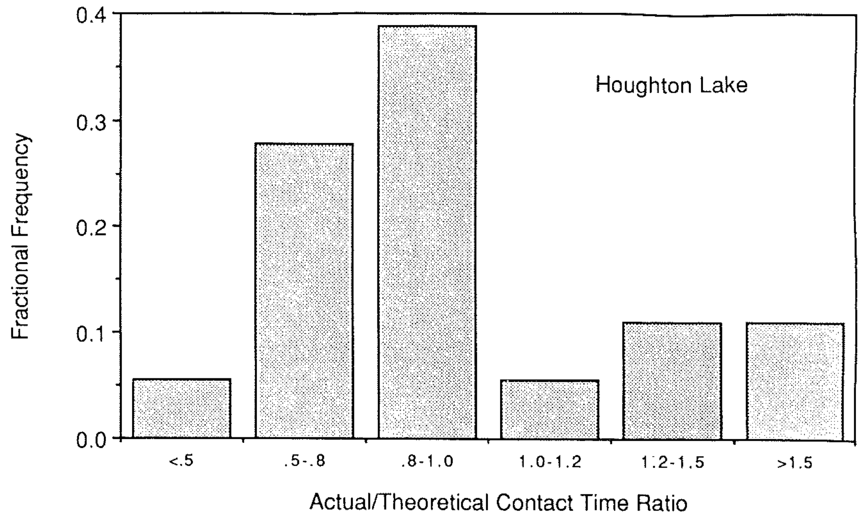

Figure 10. Distribution of contact times for the Houghton Lake system.

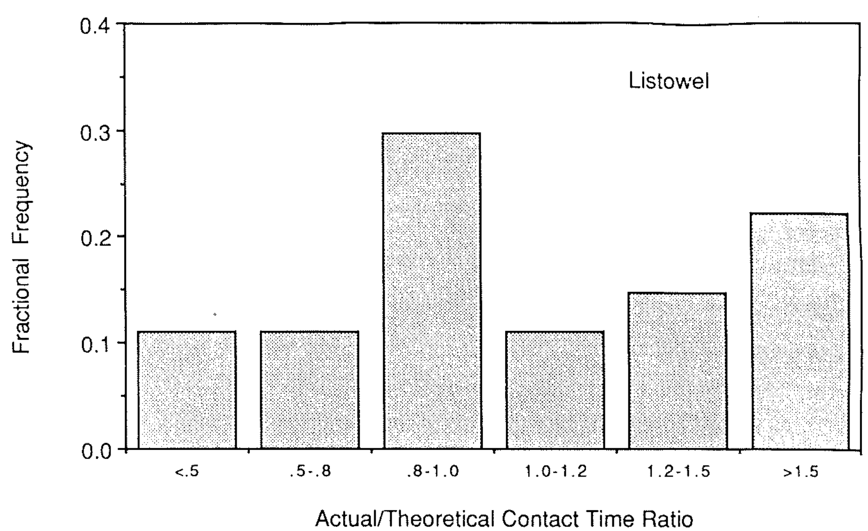

Figure 11. The distribution of contact times for the Listowel system.

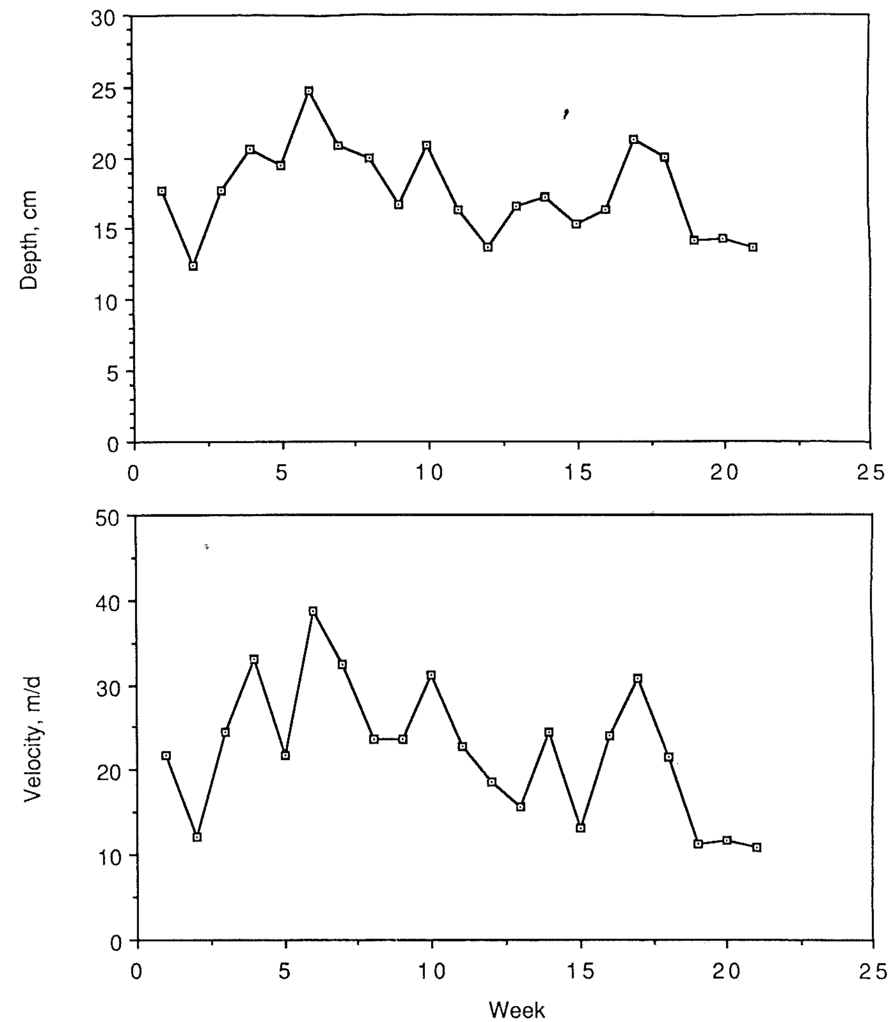

Figure 12. Weekly progression of depths and velocities for the Houghton Lake system, with overland flow through vegetation.

could be sampled to give a contact time distribution comparable to the composite of Figure 11. Clearly, the dye tracer studies missed some brief periods after rains, when average contact times were less than one-third the nominal contact time.

Given the complexity of hydrodynamics, it is very tempting to adopt averaging procedures for data analysis and for design. The next section estimates errors associated with averaging, in terms of the associated water quality parameters.

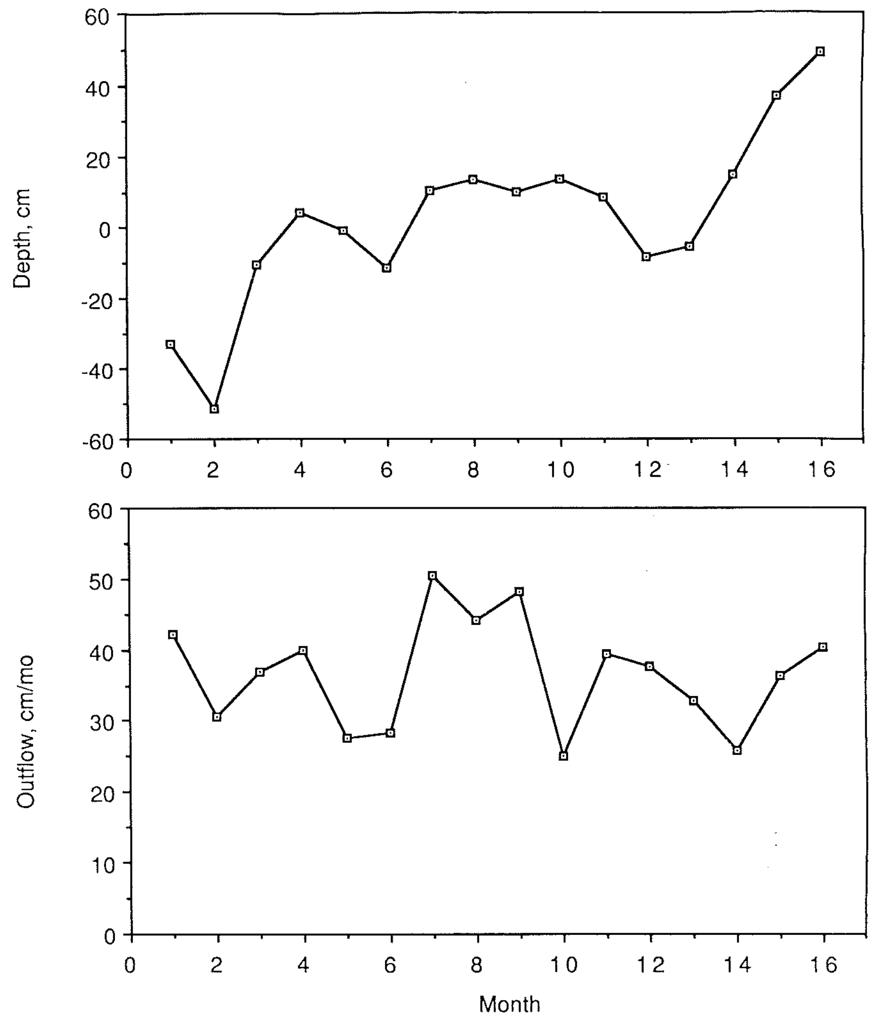

Figure 13. Monthly progression of depths and flow rates for the Clermont system, with vertical infiltration.

WATER QUALITY CONSEQUENCES

Water quality improvement in wetlands may follow first order kinetics, and operating conditions may be predicted from the rate constant and contact time within the system:

$$\frac{C}{C_0} = \exp(-k\tau) \tag{10}$$

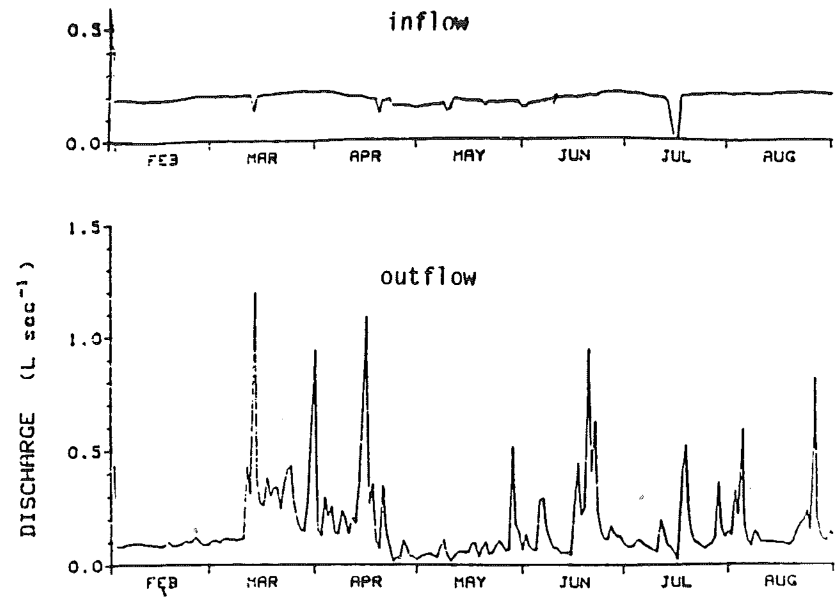

Figure 14. Progression of inflows and outflows for the constant depth Listowel system.

where C = concentration
k = rate constant
τ = contact time

Because of sizeable changes in contact time due to atmospheric conditions, errors may occur in rate constants or in designs, based on zero augmentation.

If data from the wetland system are processed to extract the rate constant, it would be logical to measure concentrations along transects down the wetland length to obtain the contact time effect. In the absence of rain or evapotranspiration, this is accurate. However, rain will cause dilution and speed flow, whereas evapotranspiration will cause concentration and slow the flow. Under either condition:

$$\frac{C}{C_0} = \left[1 - \alpha\frac{X}{L}\right]^{(k\tau/\alpha - 1)} \tag{11}$$

where x/L is fractional distance to outlet, α is augmentation ratio, and τ is nominal contact time. If the resultant data are plotted on semilog coordinates in an erroneous attempt to fit the process with the simple first-order formula, the results in Figure 15 are obtained. The curve fit is excellent for the simple model, but the slopes are not the correct rate constants. Evaporation gives too low a value, while rain gives too high a value. Table 1 gives values for resultant

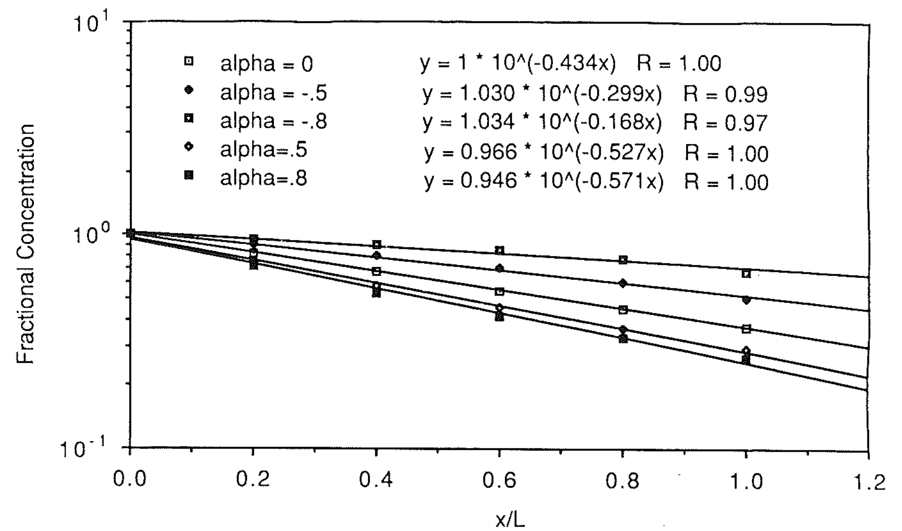

Figure 15. Regression of augmented flow concentration data for first-order kinetics.

errors in the rate constant for the case of nominal $k\tau = 1$ for various choices for the residence time (nominal, exit flow, and average flow contact times).

If the wetland infiltrates, similar types of errors can be made in determination of the rate constant. Water loss occurs as in evaporation, but the concentrating effect is not present. Figure 16 shows concentration transects may be fit by the first-order model, although the correct profiles are given by:

$$\frac{C}{C_0} = \left[1 - \alpha\frac{x}{L}\right]^{(k\tau/\alpha)} \qquad (12)$$

In this equation, α represents the fraction of incoming flow that infiltrates. Again, any of three contact times are candidates for data interpretation. Table 2 shows that significant errors in rate constant determination may result under conditions of infiltration for the case of the nominal $k\tau = 1$.

Errors are also possible in design. If accurate values of rate constants are used and no augmentation is assumed, calculated area may be less than required under some operating conditions, while under other conditions the system may have excess capacity. Evaporation can increase concentrations, which defeats the reactive consumption, or dilution can reduce concentrations and slow reaction rates. Table 3 presents these effects for various nominal design efficiencies. This is in some sense a "no-win" situation, because either too much land was used, or the system fails to perform up to design when subjected to atmospheric phenomena. These examples illustrate the possibility of errors due to the neglect of atmospheric phenomena.

Table 1. Errors (%) in the Rate Constant for a First-Order Reaction Occurring Under (Ignored) Conditions of Atmospheric Augmentation

Fractional Augmentation		Nominal τ	Exit τ	Average τ
(evap)	−0.8	+32	+137	+69
	−0.5	+21	+82	+46
	0.0	0	0	0
	+0.5	−31	−65	−54
(rain)	+0.8	−61	−92	−87

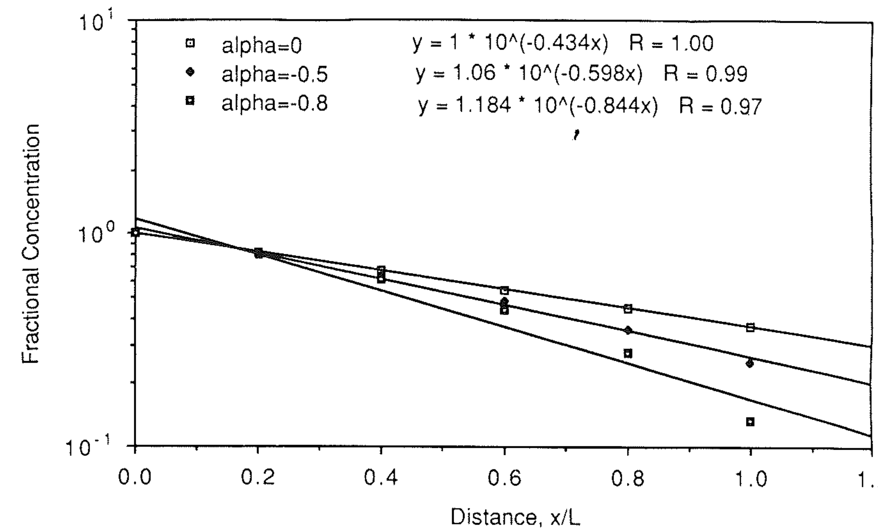

Figure 16. Regression of partially infiltrating flow data for first-order kinetics.

Table 2. Errors (%) in the Rate Constant for a First-Order Reaction Occurring Under (Ignored) Conditions of Infiltration

Infiltration	Nominal τ	Exit τ	Average τ
−0.8	+94	−61	−53
−0.5	+38	−24	−8
0.0	0	0	0

Table 3. Errors (%) in the Area Required for a First Order Reaction Occurring Under (Ignored) Conditions of Atmospheric Augmentation

		Design Percent Concentration Reduction		
Fractional Augmentation		63	87	95
(evap)	−0.8	77	112	131
	−0.5	82	103	113
	0.0	100	100	100
	+0.5	137	102	94
(rain)	+0.8	178	104	91

Note: Entries are the percent of the required area which is available.

CONCLUSIONS

Hydrological complexity makes design and data interpretation difficult for wetland treatment systems. It is not safe to ignore water exchanges with the atmosphere, because they can significantly contribute to total water flow. Rainfall causes two opposing effects: (1) dilution of wastewater, reducing concentrations; and (2) increased velocities, reducing retention times within the wetland. The result will be reduced exit concentrations, which can be interpreted as erroneously high rate constants for the process. The impact of a rain event on velocity is larger for a depth-controlled system than for a vegetation flow-controlled wetland, because the former lacks a surge damping mechanism.

Evapotranspiration can be approximated Weather Service Class A pans, multiplied by 0.8. Similarly, half the net solar radiation received also estimates the long-term average. On a short-term basis, the vegetation effects cannot be ignored, due to growing season enhancement and off-season mulching effects of litter. The impacts of evaporative processes on a wetland treatment system are not trivial. Even in northern climates, *all* applied wastewater can be evaporated during a dry summer season, as occurred twice in 10 years at Houghton Lake. Vapor losses affect water quality by increasing concentrations by evaporation and slowing the water and allowing more time for reaction. Apparent rate constants derived from evaporating systems can be significantly lower than true values. A wetland system designed without regard for atmospheric augmentation may be under- or overdesigned, depending on degree of treatment and local climatic conditions in terms of water gains or losses. An overland flow wetland leaking to groundwater (infiltrating) will apparently have better treatment when rated on the basis of the overland flow effluent, due to increased contact time. Whether the overall performance is better or worse depends on the treatment provided by underlying substrates.

Frictional effects associated with water flow through a gravel or rock substrate differ from flow through stems and litter aboveground. In the former case, system overloads can cause emergent overland flow near the entrance. In the latter, high vegetation densities can increase depths above planned weir settings. Both effects are forms of water mounding. The wetland will display both depth and flow variations in response to input dynamics in any case.

It seems likely that the above features of wetland systems, coupled with the fast dynamics not considered here, will manifest themselves as "site-specific performance" until the hydrological features are acknowledged in data interpretation.

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CHAPTER 4

Physical and Chemical Characteristics of Freshwater Wetland Soils

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OVERVIEW

Soils are complex assemblages of inorganic and organic material at the earth's surface that reflect long-term environmental changes. Specifically, any particular soil is a function of parent material acted on by organisms and climate and conditioned by relief over time.[1] The modern soil classification system used in the United States recognizes 10 soil orders distinguished by the presence or absence of diagnostic horizons and features that reflect differences in the soil-forming processes mentioned above. These soil orders range from recently formed Entisols with few diagnostic horizons to highly weathered Oxisols to organic Histosols.[2] Chemical and physical attributes among soils in different orders (and even within a given order) vary widely, and these differences must be considered in the construction and operation of wetlands for wastewater treatment.

Wetland soils are dominated by anaerobic conditions induced by soil saturation and flooding. Freshwater wetland soils can generally be distinguished from upland, nonwetland soils by two interrelated characteristics: (1) an abundance of water and (2) accumulation of organic matter. Excess water causes many physical and chemical changes in soils, and wetland hydrologic regimes can range from nearly continuous saturation (swamps) to infrequent, short-duration flooding (riparian systems). The most significant result of flooding is the isolation of the soil system from atmospheric oxygen, which activates several biological and chemical processes that change the system from aerobic and oxidizing to anaerobic and reducing.

This chapter reviews the chemical and physical parameters of soils, particularly freshwater wetland soils, that influence their ability to effectively treat wastewater. We will not cover all aspects of soil chemistry but will confine our discussion to the more important chemical processes and soil attributes, their role in the retention and transformation of specific wastewater constituents,