1994

Evaluation of Solids Generation in Lagoon Treatment Systems: Application to Bardstown, Kentucky

Paul M. McGinley
University of Kentucky

Evaluation of Solids Generation in Lagoon Treatment Systems
Application to Bardstown, Kentucky

by
Paul M. McGinley
Department of Civil Engineering
University of Kentucky
Lexington, KY 40506

for
The Kentucky Water Resources Research Institute
University of Kentucky
Lexington, Kentucky

presented to
Kentucky Natural Resources and Environmental Protection Cabinet
Frankfort, Kentucky
December 8, 1994

Evaluation of Solids Generation in Lagoon Treatment Systems
Application to Bardstown, Kentucky

Paul M. McGinley
Department of Civil Engineering
University of Kentucky
Lexington, KY 40506

I. Introduction

A municipal wastewater treatment plant in Bardstown, Kentucky has been operating for more than 10 years without removing any sludge from the plant. The facility uses lagoons followed by a biological packed tower to treat wastewater. Sludge generated during treatment accumulates and is returned to the lagoons, but does not appear to hamper the plant's ability to operate effectively. The facility is of interest because this solids management strategy delays consideration of solids disposal and there are preliminary indications are that the quantity of sludge which has accumulated in the lagoon system is less than that which would be anticipated in other forms of treatment (Mello and Sparks, 1993).

This report summarizes the results of a study which investigated the sludge accumulation in lagoon systems through both literature review and evaluation of the Bardstown wastewater treatment plant. Much of the information in this report has been presented in more detail in the Master's thesis of Jon Keeling (Keeling, 1994).

II. Process and Site Description

Lagoon treatment of wastewater has been practiced for many years in applications which range from primary treatment to effluent polishing. Wastewater lagoons encourage biological metabolism of organic matter in the waste and lagoon treatment systems can be differentiated based on the type of biological activity which occurs. In an aerobic lagoon, high turbulence levels and/or shallow depths lead to sufficient oxygen to promote biological activity. In a facultative lagoon, low oxygen (anoxic) bottom waters support biological degradation by organisms which can succeed under those conditions. In both cases, degradation of organic wastes continues in lagoons over long periods of time because the solids residence times in these systems can be quite long (e.g., years).

A 1994 survey of Kentucky municipal wastewater treatment plants showed that more than 40 plants currently use lagoons of some form in the treatment process (Oligee et al., 1994). In general, these facilities are relatively small with an average daily flow less than 0.5 mgd and only 3 lagoon systems had flows above 1 mgd. A limitation in lagoon treatment is the land area which is required. For example, at a typical loading rate range of 25-150 pounds of BOD/acre/day, an acre of lagoon would be required for every 125 to 750 people.

The municipal wastewater treatment plant in Bardstown, Kentucky is a 3 MGD design facility treating, on average, approximately one-half to two-thirds of that flow. The wastewater includes domestic wastewater from a population of 11,000 and industrial wastewater coming from 16 industries. 60% of the 0.65 MGD of industrial waste flow comes from two distilleries. Information from a recent report suggests that distillery waste is likely a substantial component of the organic (BOD) loading to the plant, at times providing more than half of the total (Hall and Associates, 1993).

The Bardstown wastewater treatment plant has two lagoons with surface aerators followed by a two-stage packed biological reactor and secondary clarifiers. Sludge from the secondary clarifiers is returned to the lagoons. The first lagoon has a normal operating depth of 16 feet and a surface area of 3.4 acres, the second lagoon operates at 12 feet deep and has a surface area of 2.6 acres. Total lagoon volume is 22 million gallons which results in a hydraulic retention time of approximately 14 days.

The size of the lagoons at Bardstown leads to a lagoon area of approximately 1800 persons/acre. The system operates at approximately 500 lb BOD/acre-day using mechanical aerators capable of 4-12 hp/million gallons. Mixing in the lagoons is not complete and solids are accumulating on the bottom of the lagoons.

III. Sludge Accumulation in Lagoons

The solids which accumulate in a lagoon represent both the incoming suspended solids which settle and the microbial biomass from conversion of organic matter in the wastewater. These processes are no different from those which occur in other forms of wastewater treatment (e.g., activated sludge or fixed film) for which solids removal from the facility is much more regular owing to the limited storage capacity for sludge within those types of treatment units. Relating the quantity of solids to the quantity of sludge is very dependent on the percentage of the sludge which is water. Changes in sludge water content, while altering the volume dramatically, and consequently sludge volumes or weights cannot be used to characterize different treatment processes. The quantity of solids will reflect both the wastewater composition and aspects of the treatment process which act to degrade and/or create solids. To develop an approximate idea of the quantity of solids which are generated during the treatment of municipal wastewater, a recent survey showed that on average, about 0.5 tons of dry solids are removed for every million gallons of wastewater treated (Oligee et al., 1994).

To-date, the sludge generation within lagoon systems has not been similarly quantified. Sludge volume, particularly depth, is more frequently reported because sludge accumulation in lagoons may interfere with the lagoon's ability to effectively treat wastewater. For example, reported sludge accumulation in lagoons ranges from 0.04-0.35 inches/year (Gray, 1989), 0.8 inches/year (Vuillot, 1988) and 1.1 inches/year (Carre, 1990). Similarly Clark et al. report that sludge accumulates at a rate corresponding to 8.8 to 14 cubic feet per 1000 person/day. Although these accumulation rates seem small, it is difficult to compare them to sludge generation at other facilities. Several assumptions regarding the solids content of the sludge were made and used to convert sludge depths to dry tons of sludge solids per million gallons of wastewater flow. The results shown in Figure 1, demonstrate the sludge quantities reported in these lagoons could range from 0.01 to 0.22 dry tons of sludge solids per million gallons per wastewater treated. While it is apparent that less solids might be generated in lagoon treatment than in other treatment types, it is also apparent that what might appear to be a low levels of sludge accumulation (e.g., 1 inch/year) in lagoons does not necessarily indicate low solids accumulation in comparison to other treatment types.

What is an inch of sludge?

Assume 200 people/acre @ 150 gpcd:

$$\left(150\ \frac{gallon}{person\text{-}day}\right)\left(200\ \frac{person}{acre}\right)\left(365\ \frac{day}{yr}\right) = 11\ million\ \frac{gallon}{acre\text{-}yr}$$

Quantity of dry solids in 1 inch of sludge @ 1% solids:

$$(1\ inch\ sludge)\left(\frac{1\ ft}{12\ inches}\right)\left(\frac{43560\ ft^2}{acre}\right)\left(\frac{62.4\ lb\ sludge}{ft^3\ sludge}\right)\left(\frac{0.01\ lb\ dry\ solid}{lb\ sludge}\right)\left(\frac{1\ ton}{2000\ lb}\right) = \frac{1.1\ dry\ ton}{year}$$

Convert to dry tons per million gallons (DT/MG):

$$\frac{1.1\ dry\ ton\ /\ acre\text{-}year}{11\ million\ gallon\ /\ acre\text{-}year} = 0.10\ dry\ ton\ /\ million\ gallon$$

Adjust for other solids contents:

Percent Solids (%)	DT/MG
1	0.10
2	0.20
4	0.40
6	0.60

Figure 1. Example calculations to relate sludge depth to solids quantity.

Low solids accumulation in lagoons has been traced to effective degradation of organic material. Researchers have observed lagoon systems in which most of the organic load is degraded on an annual basis and the result is a sludge accumulation which is attributed to only those solids which are more recalcitrant to degradation. Eckenfelder (1989), for example, presents an equation for sludge yield in facultative lagoons suggesting sludge accumulation in a lagoon will be equivalent to the inert material entering the lagoon plus approximately 5% of the BOD. In contrast, for other treatment types, a considerably higher percentage of the BOD mass is assumed to appear in the sludge (e.g., 30-50%, Viessman and Hammer, 1993).

Recently, several models have been developed to predict solids accumulation in lagoons (Narasiah et al., 1990; Middlebrooks et al., 1965). Application of these models is complicated by the number of parameters which must be estimated. In simple models of solids degradation, the rate of disappearance is often described using a first-order formulation, where the rate at which solids are degraded is proportional to the quantity of solids. In that case, the half-life of solids, the time required to decrease the concentration of solids by half, has been reported to range from 8 days to 7.5 months. For a half-life of 2 months, only 2% of the solids would remain after 1 year and it suggests that an annual degradation cycle is not unreasonable for lagoon systems. Consequently, the solids accumulation would be expected to be only that portion of the solids which have not been in the lagoon long enough to be effectively degraded, and those solids which are resistant to degradation.

A more accurate assessment of the sludge accumulation in lagoons, particularly those in Kentucky, was the focus of this study. It was decided that this would require that the sludge quantity be quantity be quantified as dry sludge solids. For a given dry solids quantity, sludge volumes can be easily computed for different solids contents. This study examined the lagoon treatment system at Bardstown Kentucky in detail.

IV. Solids Quantities in the Bardstown Lagoons

Graduate students from the University of Kentucky accompanied wastewater treatment plant personnel while they measured sludge depths at the Bardstown wastewater treatment plant. Sludge from each sample point was obtained and brought back to the University of Kentucky water quality laboratory for analysis. The first 7 sampling points were in the first lagoon (#1 near the influent, #7 near the outlet) and 8 sampling points were used in the second lagoon (#8 near the inlet, #15 near the outlet) (Keeling, 1994). The sludge depth measurements and the solids content determined in the laboratory were used to compute a solids quantity in the lagoons. In Figure 2, a schematic of the sludge accumulation on the lagoon bottom is shown. It is apparent that the sludge depth observed is composed of a relatively compact solid region at the base of the water column and a layer of relatively uncompacted solids above. This configuration demonstrates the difficulty in attempting to quantify the sludge depth in a lagoon system and then use that information to quantify the solids quantity. The bottom layer in the sludge column had the highest total solids content. The average for five sample points in the first lagoon was 5.6% solids (by weight) in the bottom layer. A similar solids concentration was observed in the bottom layer of two sample points in the second lagoon. The fraction of those solids which were volatile did not dramatically trend with depth in the sludge column. Sludge from different points in the lagoon systems is shown in Figure 3 as total and volatile solids at different points in the sludge column and different sampling points.

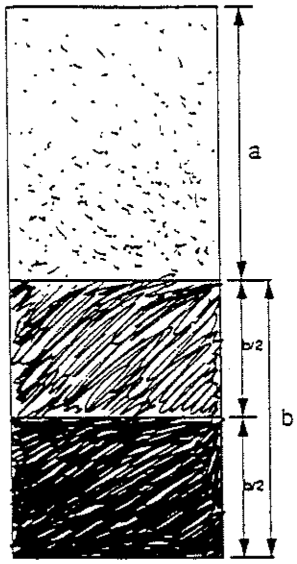

Figure 2. Typical sludge depth profile in lagoon.

The total quantity of sludge solids in the lagoon can be estimated by assuming that each sludge depth and solids content measurement is representative of the region which surrounds it. The distribution of the solids per square foot of lagoon is shown in Figure 4. It is apparent that a reduced solids quantity is observed at the first and last sample points in the lagoon. This likely reflects the flow regime in the lagoon with less settling occurring in regions of more rapid flow. In the middle of the lagoons, where flow is slower, the solids deposition should increase. If the sampling points at the beginning and end of each lagoon are neglected, the average solids deposition is 50.4 dry ton/acre in the first lagoon and 20.4 dry ton/acre in the second. Assuming that the solids quantities in these two lagoons are statistical variables within each lagoon, the 95% confidence intervals on that data would be 44-57 dry ton/acre and 15-25 dry ton/acre in the first and second lagoons, respectively. Using the average and ranges for solid deposition in the Bardstown lagoons, the total quantity of solids in the lagoon can be estimated using the normal operating surface area. The resulting quantity of solids is 223 dry tons of sludge solids (95% confidence interval of 188-258 dry tons) in both lagoons. A little over 75% of the sludge solids are in the first lagoon. Converting these sludge generation rates to rather simplistic units of dry tons of sludge solids per million gallons of wastewater treated provides a way to compare these results to other treatment systems. Assuming that the sludge has been accumulating for 13 years in the Bardstown lagoon systems and assuming an average flow of 1.4 mgd, results in a solids generation of 0.034 dry ton per million

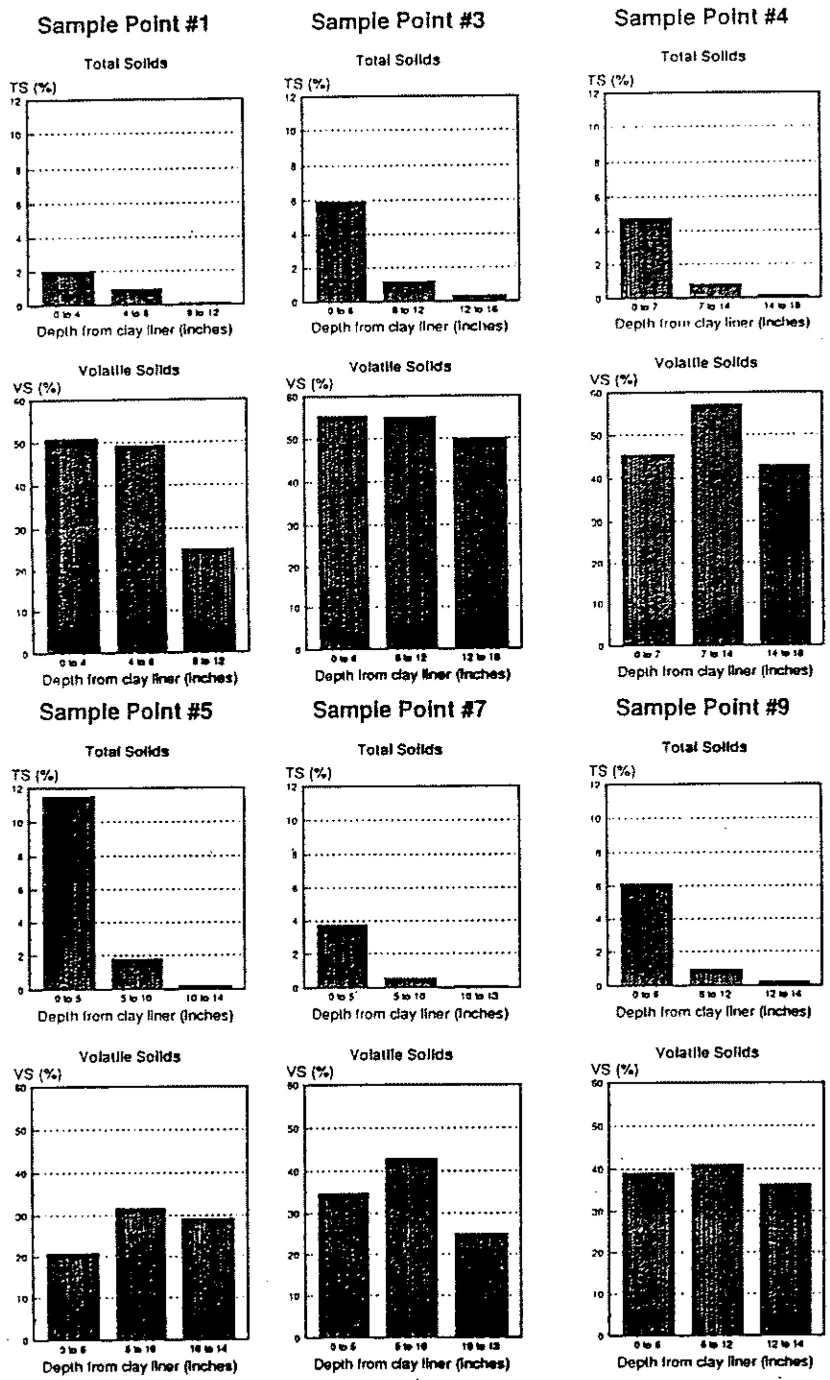

Figure 3. Solids content and volatile solids percentage in sludge at several points at Bardstown (Keeling, 1994).

gallons of wastewater (DT/MG).

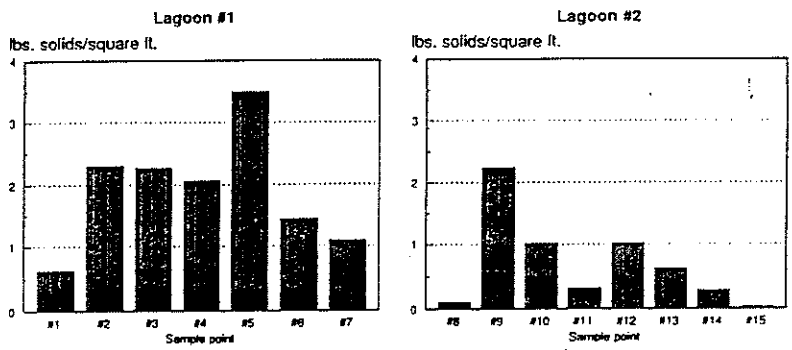

Figure 4. Sludge solid quantity at different points in Bardstown lagoon (Keeling, 1994).

V. Discussion of Solids Generation

The solids quantity in the Bardstown lagoon system is compared to solids generation at other lagoon treatment systems in Table 1. In most cases, data from other lagoons was limited to one or two sludge depth measurements and a similar number of total solids determinations. Although it is apparent from the results shown in the Table that the Bardstown treatment system is one of the larger municipalities using such a lagoon in the State, its solids generation is consistent with the estimated quantities at several other facilities. Of course, correlations with wastewater flow neglect variation in wastewater strength which may also be important.

Table 1. Comparison of Estimated Solids Accumulation at Kentucky Wastewater Lagoons

Facility (mgd)	DT/MG
Calvert City (0.23)	0.016
Fordsville (0.05)	0.018
Bardstown (1.4)	0.034
Clay Lagoon (0.05)	0.043
Bedford (0.15)	0.054
Owenton (0.19)	0.157

Adapted from Keeling (1994)

Keeling (1994) summarizes the results of recent efforts to model solids accumulation in lagoon systems and presents a simple first order model for volatile solid degradation in lagoons. His review of the literature indicates that investigators have found rate constants which range from 0.003-0.083 day^{-1} for aerated and facultative lagoons. Keeling reports a degradation coefficient for solids based on a mass balance of the Bardstown lagoon which is

0.007 day^{-1}, within that range, although at the low end. Rate constants in this range correspond to a solids half life (the time required to reduce the mass of solids by 50%) of 100 days. Consequently, at the end of one year, only about 8% of the degradable solids would be left. Although the first-order model is probably a simplification, the results do indicate that the rate of solids disappearance in the Bardstown lagoon may lead to almost complete degradation within a year of deposition, consistent with systems which have been described in the literature.

In systems where degradable solids are relatively rapidly consumed, the key to assessing sludge accumulation may be the quantity of solids which are more resistant to degradation. The results of several literature and Kentucky lagoons were examined by Keeling (1994) and are summarized in Table 2. It is apparent that for Kentucky lagoons, the fraction of the solids which remain after 5 years or more may be close to 10% of that which was loaded in the system. Both Calvert City and Fordsville seem to have very low solids accumulation, at least according to the little information which was obtained, and may warrant further investigation. In all cases, the low solids accumulation may correspond to the fraction of nonvolatile suspended solids which are deposited in a lagoon. Three solids analysis performed from May, 1994 to November, 1994 at Bardstown indicated an average VSS/TSS of 0.88, suggesting that on average only a small portion of the TSS are nonvolatile. The result also suggests that most of the BOD which enters the lagoon system is completely degraded. Although such complete degradation is not anticipated during shorter solids retention times and operating conditions of more conventional treatment, in lagoon systems, the high solids residence times and biological processes in the system may permit more complete degradation. It is interesting to compare those results to a recent study of lagoons in Quebec, Canada. Using the results of Narasiah et al. (1990) Keeling (1994) showed cumulative solid accumulation which ranged from 12-33% with an average of 23%

Table 2. Sludge Solids Expressed as a Percentage of the Influent Total Suspended Solids (TSS)

Facility	Age	% of Influent TSS Remaining
Owenton	5	8.8
Bedford	10	9.7
Fordsville	10	1.8
Bardstown	11	8.2
Calvert City	17	2.8
Clay Lagoon	19	9.6

Adapted from Keeling, 1994

for four lagoons. Temperature may play a role in reduced solids decomposition and the study did not provide information on volatile/fixed composition of influent solids. Keeling (1994) began to examine the impact of lagoon depth on solids accumulation. In the literature, there are reports of lagoons which have much higher solids accumulation than those examined in this report. In several instances, those lagoons appear to be shallower (e.g., 5 feet) than Bardstown. Further research is necessary to evaluate the impact of lagoon depth on solids accumulation.

Quantifying lagoon solids on the basis of several sludge depth and solids content analysis can be subject to a variety of errors. As a result, it is also of interest to examine other means of verifying the quantity of solids which have accumulated in the lagoons. Two methods will be presented here: 1) the ratio of volatile to total solids in the accumulated sludge; and 2) the metals content of the sludge.The ratio of volatile to fixed solids in lagoon sludge may be an indication of the extent to which the solid has decomposed. If the contribution of soluble BOD to sludge volatile content is considered negligible, consistent with the high solids residence time in these systems, then the extent to which total solids quantities will be altered during degradation can be ascertained from Figure 5 which shows the fraction of solids remaining for different conditions of initial and final volatile fraction. To achieve the relatively high (i.e., 90%) reductions in solids, requires initially high degradable solid contents (i.e., 90%) for final volatile solids contents of 40-50%. For influents with relatively high VSS/TSS, such reductions may be possible, but for those systems with high fixed solids contents, the overall solids reductions will be much lower. For application to Bardstown, if an initial volatile solids content of 88% is assumed (average) and a volatile fraction of 0.4 is assumed for the solids in the lagoon, then approximately 20% of the influent solids would be expected to remain, while this exceeds the 9% which was calculated from the solids approach, it suggests that the extent of solid reduction observed is not unreasonable.

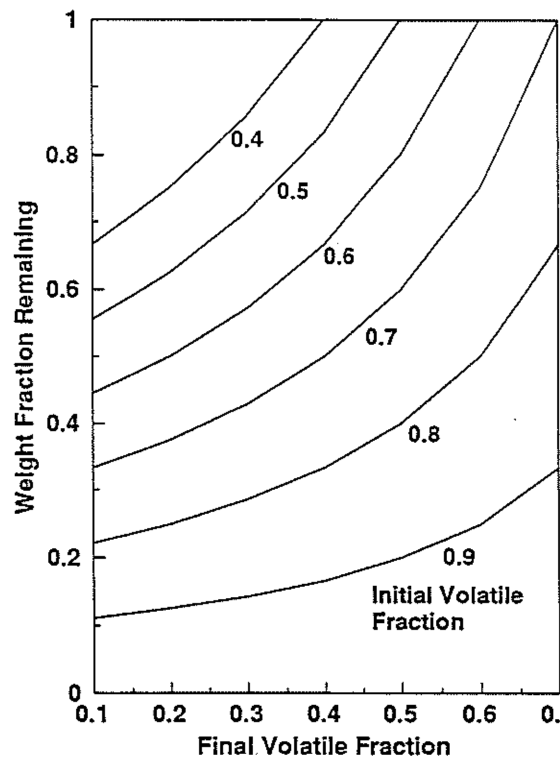

Figure 5. The extent of solid mass reduction at different initial and final volatile solids contents.

The concentration of pollutants in the sludge may also be another indication of the extent to which the solids degradation in the lagoon is operative. Because sludge pollutants are typically expressed per unit mass of sludge solids, decreases in the total solids quantity will be expected to lead to higher concentrations of pollutants in the sludge if the quantity of pollutant removed is unchanged. Keeling (1994) computed pollutant loading for the Bardstown lagoon system using influent and effluent metals concentrations obtained from annual sampling at the treatment plant. Using the median concentration for four different pollutants and converting that to an annual loading (initially assuming 100% removal), the resulting sludge concentrations can be calculated from our solids quantity. The results, shown in Table 3 indicate that the sludge pollutant concentration is only 10% of that predicted. Several possible explanations exist, including lower pollutant removal in the lagoon, although recent studies of the Bardstown lagoon show that 50-80% of some pollutants are removed across the lagoon. Other contributors to this discrepancy might include variations in influent metal concentration, underestimation of the sludge quantity and variations in metal concentration across the lagoon which was not discovered during the sampling. Current research efforts are attempting to determine sludge pollutant concentration distribution in the first lagoon.

Table 3. Estimated and Measured Sludge Pollutant Concentrations

Pollutant	Median Influent Conc. (mg/l)	Predicted Sludge Conc. (mg/kg)	Measured Sludge Conc. (mg/kg)*
Arsenic	0.04	4193	92
Cadmium	0.003	316	24
Chromium	0.023	2417	185
Zinc	0.17	17856	1467

* Keeling (1994) Sample Point #1 "bottom"

VI. Summary

Based on this review of the literature and evaluation of solids accumulation at Bardstown, KY, it is appears that lagoon treatment systems can produce a lower overall solids generation during the treatment of municipal wastewater in comparison to many other treatment types. The extent to which solids quantities will be reduced appears to vary, in part because of differences in the quantity of inert material in the wastewater, but in general, it appears that solids accumulation in deeper lagoons in Kentucky can be as low as 100-300 pounds of solid per million gallons of municipal wastewater treated. From a review of the literature it appears that variations in the wastewater and temperature and lagoon depth must still be considered in evaluating the anticipated solids quantity.

VII. Acknowledgements

The generous assistance of personnel at the Bardstown wastewater treatment plant, Jerry Riley chief operator, is greatly appreciated. In addition, on-going discussions with John Dovak and J. Scott Mello of the Kentucky Natural Resources and Protection Cabinet have been very important to guiding this study. The work was supported by the Kentucky Environmental Protection and Natural Resources Cabinet, the Kentucky Water Resources Research Institute, and the Department of Civil Engineering at the University of Kentucky.

VIII. References

Carre, J. et al. (1990) "Sludge removal from some wastewater stabilization ponds" Water Science and Technology 22:247-252.

Clark, S.E. et al. (1970) "Alaska sewage lagoons" Proceedings 2nd International Symposium for Waste Treatment Lagoons, Kansas City, MO.

Eckenfelder, W.W.,Jr. (1989) "Industrial Water Pollution Control, 2nd Ed., McGraw Hill, NY.

Gray, N.F. (1989) "Biology of Wastewater Treatment" Oxford Science Publications.

Hall and Associates (1993) "Wasteload Allocation Lagoon Study" prepared for City of Bardstown.

Keeling, J.D. (1994) "Solids Accumulation Analysis and Model Comparison for Aerated-Facultative Lagoons" Master's Thesis, Department of Civil Engineering, University of Kentucky.

Mello, J.S. and J.E. Sparks (1993) "An Evaluation of the Bardstown, Kentucky Wastewater Treatment Plant Lagoon System" Kentucky Division of Water Special Report.

Middlebrooks, E.J. et al. (1965) "Sludge accumulation in municipal sewage lagoons" Water and Sewage Works, February, 1965:63-68.

Narasiah, K.S. et al. (1990) "Sludge accumulation in aerated facultative lagoons operating in colder climate" Water Science and Technology 22:77-82.

Oligee, C., J. Keeling, and P.M. McGinley (1994) "Kentucky Municipal Wastewater Sludge, Generation, Management and Pathogen Reduction" Department of Civil Engineering, University of Kentucky.

Viessman, W., Jr. and M.J. Hammer (1993) "Water Supply and Pollution Control" Harper Collins, New York.

Vuillot, M et al., (1987) "French experience in the operation and maintenance of wastewater treatment plant lagoons" Water Science and Technology, 19:333-335.