INCORPORATING NATURAL CLIMATE PATTERNS INTO MANAGEMENT PLANS FOR SWINE WASTEWATER LAGOONS

[*]Charles L. Wax and [**]Jonathan W. Pote
[*]Department of Geosciences
[**]Department of Agricultural and Biological Engineering and Water Resources Research Institute
Mississippi State University

INTRODUCTION

The humid sub-tropical climate of the southern region is characterized by temperate winters, abundant radiation and consequent high temperatures and evaporation rates in summer, and rainfall more or less evenly distributed throughout the year. These climatic attributes strongly influence environmental and economic activities and thereby establish opportunities and constraints for human use of the region. Adjustment to this climatic setting has led to the present arrangement of agricultural and forestry practices and other land use patterns and resource use considerations.

Production of animals is particularly suited to this region's climate. Beef, poultry, and catfish have proven to be economically viable and have continued to grow in importance. All these livestock production activities are noted as potential causes of non-point source pollution with increasing regulations to control them (CAST 1996). Recent innovations in swine production methods resulting in highly concentrated facilities have rapidly begun to appear in the region.

Disposal of wastewater from swine production is becoming an increasing problem as production facilities increase and regulations governing disposal become more restrictive. The option of no-discharge systems is becoming attractive or even mandatory for many of these swine producers, especially in regions where disposal opportunities are limited or for those producers newly entering the undertaking (Martin 1995). These systems use a lagoon with land application of waste as the final stage to treat effluent (Loehr 1984). Typically, wastewater is pumped from the lagoon when a certain level of storage is reached, and proper disposal depends on infiltration into the soil and on a crop's ability to utilize some nutrient such as nitrogen or phosphorus at that time.

Climatic characteristics in many ways dominate considerations for land application. However, incorporating climate into design and management of this type of disposal method has been limited to sizing the lagoons large enough to carry producers through the longest expected wet season, essentially an entire year. Use of the lagoon as a storage space has largely been ignored in management strategies or the bases for such attempts have been unavailable.

In a land application system, the level in the lagoon rises during periods of precipitation, while the soil becomes wet and the net water requirement of plants decreases, precluding irrigation. Therefore, at the moment of greatest need, this type of disposal system is not operational. Conversely, during periods of clear weather, the level in the lagoon may drop from evaporation, the soil will become dry, and the water requirements of plants are immediate, allowing proper disposal of the wastewater. As a result, the climate may establish a pattern in which the supply of water to be disposed of and the water requirement of plants and soil are out of phase. Therefore, a climatological analysis can provide management considerations regarding the capability of this disposal method.

The objectives of this research were to: 1) develop analyses that account for climatological effects on design and performance of land application of swine lagoon effluent; 2) derive management strategies based on these climatological effects and demonstrate the impact of these strategies by computer simulation; and 3) define the optimum management strategies and probabilities of failures while employing these strategies in waste disposal.

BACKGROUND

Irrigation is the predominant method of choice for land application, even for municipal wastewater (Deese and Hudson 1980). However, those municipal systems are designed for daily irrigation of effluent when possible (Pote and Wax 1995). The Natural Resources Conservation Service of the U.S. Department of Agriculture (NRCS) designs swine lagoon irrigation systems for pumping of the wastewater as seldom as once a year (NRCS 1996; 1993).

The lagoon and application system used in the simulations for this study were based directly on an actual design completed for operation in Mississippi by NRCS. The system was designed for a facility housing 3,520 animals with an average weight of 135 pounds each. In this design, a constant daily volume of 1037 ft^3 of wastewater was transferred to the treatment facility via slotted floors over pits. The design volume of the lagoon was 908,064 ft^3 with surface area dimensions of 450 X 290 feet. Based on waste flow and precipitation, the system was designed with an application rate of 515,623 ft^3 over 61 acres (2.3 inches/acre), as determined by total nitrogen concentration. The frequency of application was designed for irrigation occurring when the lagoon filled, only once per year most of the time.

Much of the literature concerning land application systems has been devoted to determining the fate of the nutrients (Barbarick et al. 1982; Palazzo 1981; Thoma et al. 1993; Mancino and Pepper 1992). Nutrient analysis is also an integral part of the design of irrigation systems for swine lagoon effluent (NRCS 1993). While design based on nutrient loading alone has been acceptable for arid climates, when this method of disposal is considered in humid areas, the water balance and other climate characteristics of the region become the dominant factors in operation of these systems (Midwest Plan Service 1985). Al-Omari (1989) examined probabilistic design options based on five years of data in Texas, producing results in terms of field size and holding pond size for municipal disposal systems. Wax and Pote (1996) expanded this probabilistic approach to include longer periods of data and several climate regimes.

Poor management decisions and methods may result in long-term, chronic problems related to nutrient disposal, but the immediate and dramatic failures with the lagoon and land application system are related primarily to water issues. For example, lagoons typically are too full in the winter season, with only two alternatives: 1) a catastrophic spill event, or 2) a forced pumping at a time when neither the plants or the soil can accept the water.

An active management plan that prevents lagoons being full at the wrong time of the year is needed so that maximum use can be made of both the water and nutrients during land application. The performance of such a management plan could be simulated by running several years of actual daily weather data through a computer model of the system in operation, determining the incidence and severity of failure, and testing management alternatives. Recent availability of digitized long-term daily weather records makes this a viable alternative.

METHODOLOGY

Simulation of Daily Water Level and Pumping Requirement

Daily precipitation (P) and pan evaporation (E) data from State University, Mississippi, were obtained from observations of the Cooperative Network of the National Weather Service stored on CD-ROM (Earthinfo 1992). This location was representative of the southern region climate and had the most complete record of the climatic elements needed for the simulation. A factor of 0.8E was used to correct measured E to a more realistic estimate of evapotranspiration losses (ET) from small bodies of water or lagoons (Schwab et al. 1981). On a daily basis, this climatic demand for water (ET) might be partially or totally satisfied by P and incoming wastewater (W), and an increase in volume could even result if P+W was greater than ET that day. On days with little or no P, there would be a water deficit (P-ET) which could cause the lagoon level to drop, depending upon the amount of W arriving -- a constant daily volume of 1037 ft^3.

Daily computation of P-ET+W was conducted for the 20-year period 1961-1980 to simulate the operation of a lagoon purely under the influence of climate. Cumulative summation of these daily values provided patterns of water volume in a lagoon allowed to overflow in lieu of planned pumpings. This volume and pattern of discharge would be analogous to that occurring when no land application of effluent was attempted and thus represents a "no management" situation in which a full lagoon simply leaked or trickled effluent into the surrounding environment.

In order to test various management options, the daily simulation computations were modified to model resulting wastewater volume in the lagoon when land application by pumping of effluent (A) was incorporated into operation of the system. The model was constructed to let the volume of wastewater in the lagoon determine when pumping occurred as follows: V=P-ET+W-A, where

V = initial volume of wastewater in the lagoon
P = water gain by precipitation into the lagoon
ET = water loss by evapotranspiration from the lagoon
W = water gain by wastewater inflow (1037 ft^3 daily)
A = water loss by pumping from the lagoon

Using a maximum lagoon volume of 908,064 ft^3, the model was set to pump out 515,623 ft^3 whenever the volume exceeded 890,000 ft^3. This particular scenario represented a plan to pump only when the lagoon was full -- a "pump when full" management strategy. Results of this model were used to determine: 1) the day-by-day volume in the lagoon over the 20-year period; 2) the number of times the lagoon filled and had to be pumped during that period; and 3) the month in which the pumpings were necessary.

Four additional management strategies which employed "fixed-date" pumpings from the lagoon on one specific date each year were tested with consequent runs of the model. Dates selected were the 15th day of June, July, August, and September. Under these strategies, the model was set to pump either 515,623 ft^3 or 80% of that day's volume, whichever was less, on these dates only. An additional pumping was conducted if the lagoon volume reached 890,000 ft^3 at any other time during the year. Results of these model runs were used to determine for all four strategies: 1) the day-by-day volume in the lagoon over the 20-year period; 2) the number of times the lagoon filled and had to be pumped on a "when full" or "emergency" basis in addition to each planned annual pumping during the period; 3) the month in which the emergency pumpings were necessary; and 4) the resulting total number of pumpings conducted over the period.

Several assumptions were included in this model. First, the entire model was based on the NRCS plan for an actual swine lagoon in Mississippi, resulting in the specific values used to determine pumped amounts of water and nutrients. In addition, the plan specified that the waste generated over an entire year would be stored and then pumped at one time. Second, pumpings in the management options modelled were conducted on the dates indicated by the simulations regardless of weather conditions at that time. Third, loss of wastewater by infiltration from the lagoon was not addressed in the model. This makes the model more conservative and more accurate for low infiltration soils.

Analyses of Simulated Record

Analyses of the "no management" situation consisted of determining patterns of average monthly overflow volume and total annual overflow for the period using results of the simulations. The number of days on which overflow occurred in each year was also determined.

Analyses of the "pump when full" management strategy consisted of determining the number of pumpings each month over the 20-year period. Additionally, probabilities of the volume in the lagoon on the first of each month were determined. This was done by extracting the simulated volume on the first of each month and then ranking these 20 numbers in descending order to establish probabilities by quantiles.

Analyses of the "fixed-date" pumping management strategies consisted of determining the number of unplanned ("emergency") pumpings in addition to the one annual planned event over the 20-year period and the month of occurrence of the emergency pumpings. Also, probabilities of the volume in the lagoon on the first of each month were determined in the same manner as above.

RESULTS AND DISCUSSION

Results of the "no management" analysis document the regional climate's potential to influence, naturally, the annual volume of overflow and the corresponding number of days on which it occurs (Figure 1). The results show that in an unmanaged system, overflow occurs routinely on about 100 days per year with a total volume of around 500,000 ft^3. In the wettest year (1979) the number of days of overflow was relatively higher (155), but the amount of overflow was remarkably higher (800,000 ft^3). Therefore it is virtually certain that lagoons will overflow in large amounts each year in this climate regime.

The pattern of overflow in a system thus controlled only by climate in the natural setting of this region is shown in Figure 2. This is a very distinctive pattern, closely tied to the regional P-E regime which dictates that the largest amounts of overflow from lagoons will occur in the winter and spring months with much lesser amounts expected in summer and fall. Assuming that the effluent is to be applied to a growing crop, the distribution of available water through the year is diametrically opposed to the pattern of crop need. Corn is an example of a crop likely to be used in the southern region for land application of wastewater and its pattern of water need, mainly May through August, is typical of other crops in the south (Figure 3). This conflict in timing between demand and supply is therefore the basis of a management problem in land application of animal waste in the humid subtropical climate region.

In the simplest management system, "pump when full" lagoons do not overflow but are pumped when they fill to a certain level, occurring about once a year. This minimizes the number of pumpings required, but does nothing to address the above problem. Figure 4 shows results of the 20-year simulation of this management plan. The pattern of required pumpings in the figure follows the same distribution in time as the unmanaged system -- they all come during winter and spring when the environment and the plants cannot use the water or the nutrients. The probability analysis further confirmed that the probable volume of waste in lagoons is high at the wrong time, considering the water balance of soils and the need of plants for water and nutrients. This information is displayed at the 90%, 80%, and 50% probability levels in Figure 5. These probabilities of volume are quantitative indicators of risk that pumpings will be required at the wrong time of year under this management scheme. Each pumping under this plan should also be considered an emergency pumping since an imminent overflow will be prevented by the pumping.

In order to address the problem of mis-timing between demand and supply of wastewater for land application, simulations of the "fixed date" pumping strategy were analyzed. Figure 6 compares the numbers of emergency pumpings required under each of the "fixed date" plans with those required under the "pump when full" plan. It can be seen that these management plans slightly increase (by one, two, or three) the total number of pumpings required (Figure 7). However, all of the pumpings (emergency and planned) under each of the four "fixed date" plans come between April and August, solving the problem of supply and demand for the wastewater still prevalent in the "pump when full" plan.

Figure 8 shows the patterns of probable monthly volumes for each of the simulated "fixed date" plans at the 90%, 80%, and 50% probability levels. These results show that no overflow occurred and no lagoons had to be pumped outside the growing season in any of the four simulations.

Figure 9 summarizes the impact of management decisions to pump on specified dates on the supply and demand problem in land application of swine waste. It can be seen that changing the date of pumping progressively shifts the period of maximum lagoon volume further and further into the growing season. Therefore, management by controlled and pre-selected pumping dates offers a clear solution to the hydrologic aspects of the supply and demand problem of waste disposal inherent in the region's climate. A final decision on the most appropriate fixed pumping date for a specific production facility should include consideration of nutrient need and uptake potential of particular crops, as well as economic aspects of the slight increase in number of pumpings resulting from this management plan.

SUMMARY AND RECOMMENDATIONS

Using the 20-year daily simulation of a swine disposal lagoon operation, several characteristic aspects of such operations in the southern region became evident: 1) demand for the wastewater (hydrologically and agronomically) is highest in the growing season; 2) availability of the wastewater to meet the demand is highest in the winter and spring, creating an offset distribution; 3) using the simplest management scheme ("pump when full") minimizes the number of pumpings required but amplifies the time distribution problem created by the natural climate rhythms; 4) using the "fixed date" management scheme allows a shifting in time of the supply of wastewater so that it matches the demand of the crop and the climate for nutrients and water, solving the time distribution problem; and 5) selection of the optimum pumping date can vary according to type of crop used and economics of pumping.

It is recommended that maximum advantage of the climate regime in disposal of swine wastewater can be gained by use of the September 15 "fixed date" pumping plan. Figure 10 shows that this management scheme completely shifts the volume of available wastewater into the growing season, in direct opposition to the "pump when full" scheme. Assuming no overriding agronomic or economic constraints to adoption of this date, pumping every September 15 seems to be the optimum management plan for swine operations in the southern climate region.

REFERENCES

Al-Omari, K. A. 1989. Stochastic design of wastewater storage for land application. M.S. Thesis. University of Cincinnati.

Barbarick, K. A., B. R. Sabey and N. A. Evans. 1982. Application of wastewater effluent of a rural community to a mountain meadow. Journal Water Pollution Control Federation 54(1): 70-76.

CAST. 1996. Integrated animal waste management. Council for Agricultural Science and Technology. Ames, IA.

Deese, P. L. and J. F. Hudson. 1980. Wastewater management facilities for small communities. Washington, DC: U.S Environmental Protection Agency. 17.

Earth Info, Inc. 1992. NCDC summary of the day CD-ROM. Boulder, CO.

Loehr, R. C. 1984. Pollution control for agriculture (2nd Ed.). Academic Press, Inc.

Mancino, C. F. and I. L. Pepper. 1992. Irrigation of turf with secondary sewage effluent: Soil quality. Agronomy Journal. Madison, WI. American Society of Agronomy. July/August. 650-654.

Martin, J. G., III. 1995. Waste management options to meet new environmental regulations. Gainesville, FL.

Midwest Plan Service. 1985. Livestock waste facilities handbook (MWPS) (2nd Ed.). Ames, IA: Iowa State University.

Natural Resources Conservation Service, U.S. Department of Agriculture. 1996. Worksheet for waste treatment lagoon. Form #MS-ENG-359 (Revised 1-96).

Natural Resources Conservation Service, U.S. Department of Agriculture. 1993. Waste utilization worksheet. Form #MS-ENG-633 (Revised 6-93).

Palazzo, A. J. 1981. Seasonal growth and accumulation of nitrogen, phosphorus, and potassium by Orchardgrass irrigated with municipal wastewater. Journal of Environmental Quality. 10 (1): 64-68.

Pote, J. W. and C. L. Wax. 1995. Climatic criteria for land application of municipal wastewater effluent. Water Research. 29 (1): 323-328.

Thoma, K., P. A. Baker, and E. B. Allender. 1993. Design methods for the development of wastewater land disposal systems. Water-Sci-Technol-J-Int-Assoc-Water-Pollut-Res-Control. Oxford: Pergamon Press. 27(1): 77-86.

Schwab, G. O., R. K. Frevert, T. W. Edminster, and K. K. Barnes. 1981. Soil and Water Conservation Engineering (3rd Ed.). New York: John Wiley and Sons.

Wax, C. L. and J. W. Pote. 1996. Influence of climate on design of systems for land application of wastewater. Climate Research. 6: 71-78.

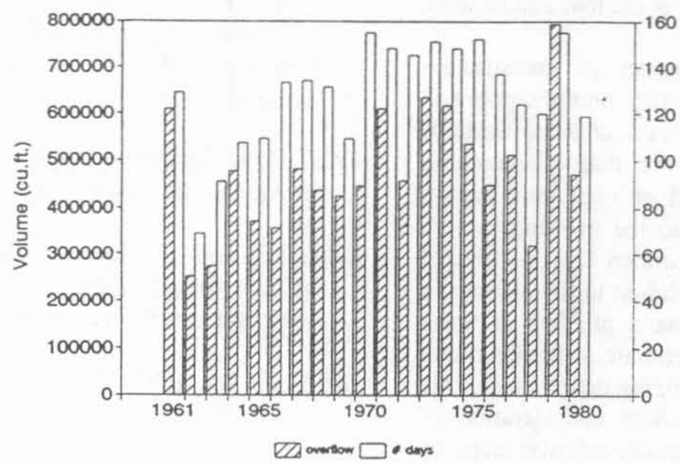

Figure 1. Annual Overflow Volume and Days, 1961-1980, Hog Farm Lagoon, No Management Scheme

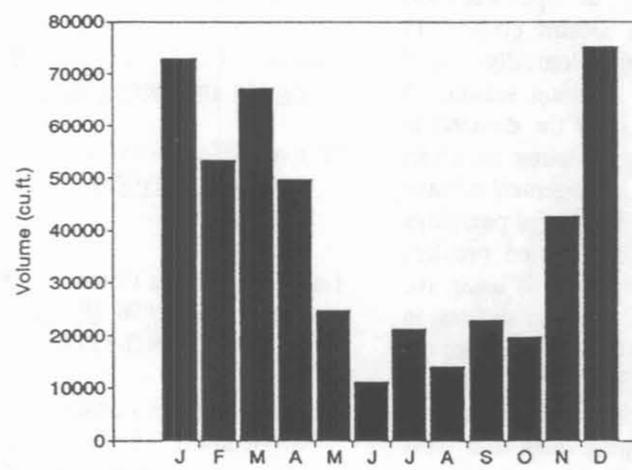

Figure 2. Average Monthly Overflow Volume, 1961-1980, Hog Farm Lagoon, No Management Scheme

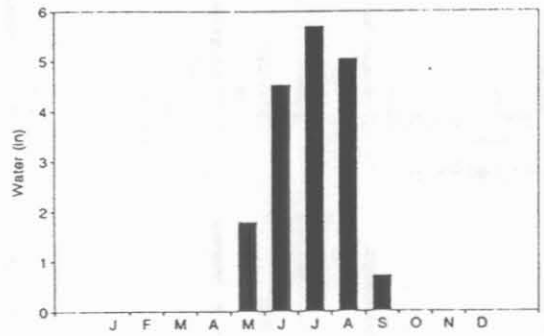

Figure 3. Monthly Water Need, Corn, 10 May Emergence Date

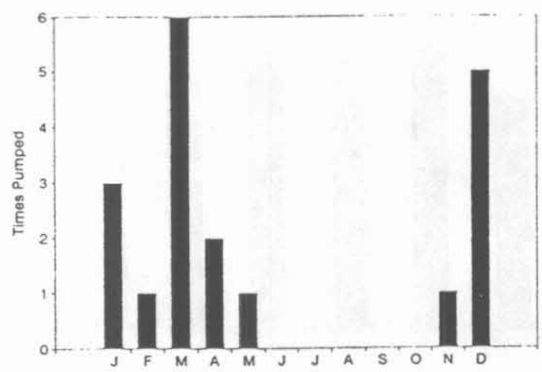

Figure 4. Number of Pumpings by Month, "Pump When Full" Management Plan

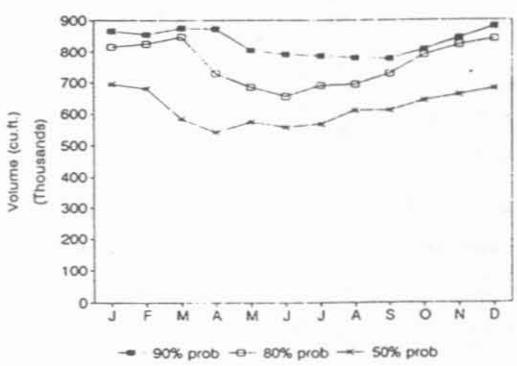

Figure 5. Probable Volume, First of Each Month, Three Levels, "Pump When Full" Management Plan

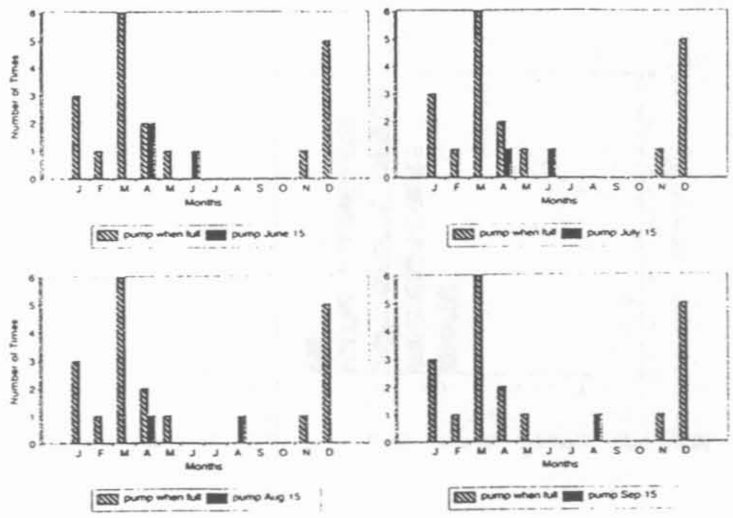

Figure 6. Number of Emergency Pumpings, Four "Fixed Date" Plans vs "Pump When Full" Plan

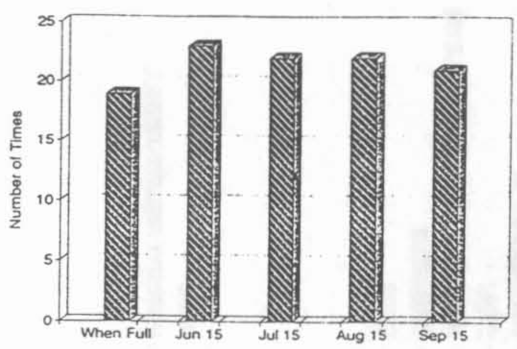

Figure 7. Total Mumber of Pumpings Under Different Management Plans, 1961-1980

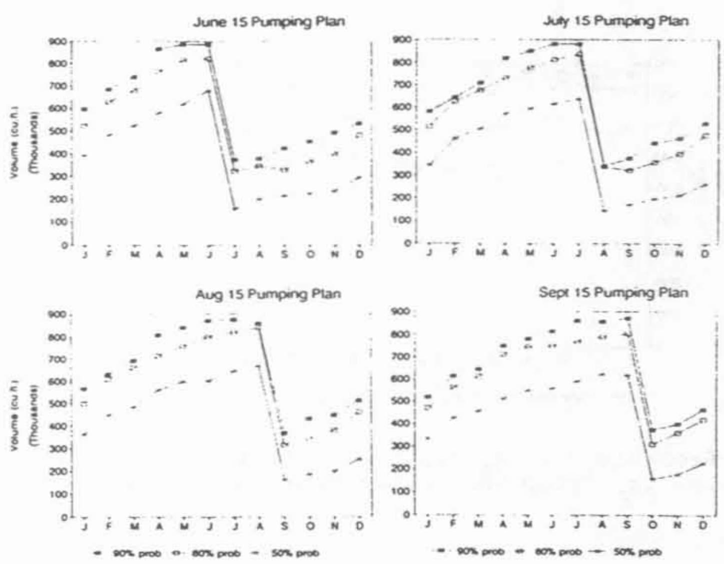

Figure 8. Probable Volume, First of Each Month, Three Levels, Four "Fixed Date" Plans vs "Pump When Full" Plan

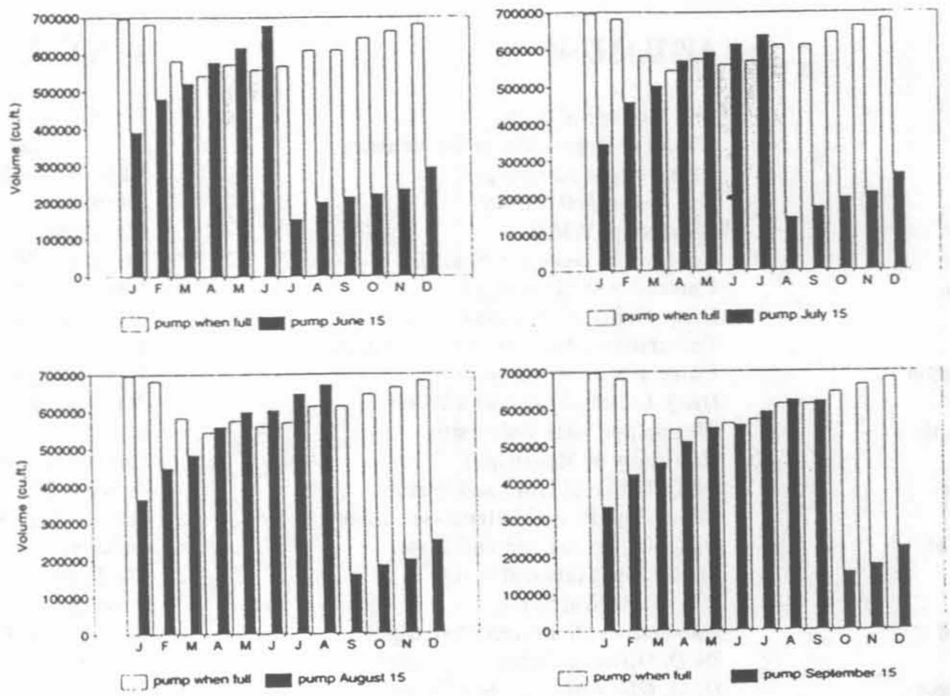

Figure 9. Probable Volume, First of Each Month, 50% Level, Four "Fixed Date" Plans vs "Pump When Full" Plan

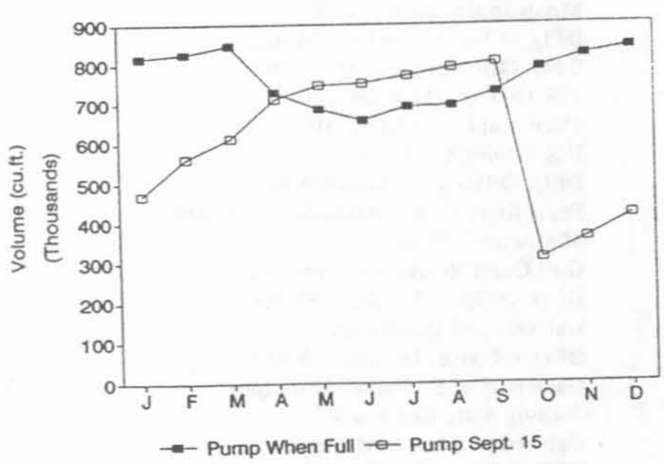

Figure 10. Shift of Available Wastewater Volume Resulting from Use of "September 15 Pumping" Plan Compared to "Pump When Full" Plan, 80% Probability Level