MOSQUITO PRODUCTION AND HYDROLOGICAL CAPACITY OF SOUTHEAST FLORIDA IMPOUNDMENTS USED FOR WASTEWATER RETENTION

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ABSTRACT. In Indian River County, Florida mosquito control impoundments, larval mosquito sampling and hydrological measurements demonstrated the importance of careful consideration of these factors when developing management plans for impoundments used for wastewater retention. Discharging secondarily treated wastewater into an impoundment resulted in only minor mosquito production. However, a treatment plant failure produced extremely high *Culex* densities in the impoundment. Average water loss rates in impoundments studied were due to evapotranspiration (0.25 cm/day) and percolation (0.38 cm/day). Greatest percolation (0.68 cm/day) was measured when the impoundments were maximally flooded. Under the conditions of this study, the impoundments can assimilate approximately 124 cm/year of wastewater (1.52 million liters/day) over a 50 ha area without overflows.

INTRODUCTION

In Florida, natural wetlands that have been used to receive treated wastewaters include cypress swamps (Dierberg and Brezonik 1984), hardwood swamps (Boyt et al. 1977, Winchester and Emenhiser 1983), freshwater marshes (Bayley 1985, Knight et al. 1986) and mangrove swamps.[3] More recently along the central east coast of Florida, a few mangrove dominated estuarine mosquito control impoundments are being used to provide tertiary treatment of secondarily treated wastewater (Carlson 1983a) and this use of impoundments is being proposed in other states as well (Mortensen 1982).

Mosquito control impoundments are located in coastal wetlands historically dominated by *Avicennia germinans* (Linn.) (black mangrove), *Batis maritima* Linn. (saltwort) and *Salicornia* spp. (glasswort). The wetlands were diked and flooded with estuarine water to deny oviposition sites for the salt-marsh mosquitoes *Aedes sollicitans* (Walker) and *Ae. taeniorhynchus* (Wiedemann). While this source reduction technique effectively and economically reduces mosquito populations (Clements and Rogers 1964, Provost 1977), the construction of impoundments may interrupt the natural exchange of organisms and detritus between these wetlands and the estuary, and stress or change vegetation by excessive or prolonged flooding (Gilmore et al. 1982). Innovative water management methods applied to impoundments that have the potential to reestablish many of their natural functions are being investigated and implemented (Carlson and Carroll 1985, Carlson et al. 1985). Using impoundments for treated wastewater retention is a management method being proposed for more central east coast Florida impoundments.

To assess the potential for the occurrence of a freshwater mosquito problem when salt-water impoundments receive wastewater, mosquito production from an Indian River County (IRC), Florida impoundment currently receiving secondarily treated wastewater (Fig. 1) (Carlson 1983a) was documented during the unusual conditions of a treatment plant failure (March, April 1983) and also when the treatment plant was operating properly (April 20, 1983 to April 10, 1985).

At a second site in IRC, the use of four mosquito control impoundments for wastewater retention has been investigated from a hydrological perspective. To determine the capacity of these four impoundments to receive wastewater without overflows, a study analyzing water levels and water chemistry was conducted from March 23 to June 20, 1984. This study was coordinated with the routine pumping activities of the Indian River Mosquito Control District (IRMCD), to allow observation of percolation under differing hydraulic head conditions. To determine the salt-marsh mosquito producing potential of these impoundments under the current water management regime, one of the impoundments was sampled for immature mosquitoes from January 30 to October 29, 1985.

This paper documents those conditions that can result in mosquito production from impoundments receiving wastewater and reports the findings of the hydrological site-specific study. Based on this work, the feasibility of using impoundments to accept secondarily treated wastewater is presented from an impoundment management standpoint.

MATERIALS AND METHODS

MOSQUITO PRODUCTION—WASTEWATER REGIME. *Study site*: Vista Royale, a 1500-unit con-

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[3] Sell, M. G. 1977. Modeling the response of mangrove ecosystems to herbicide spraying, hurricanes, nutrient enrichment and economic development. Ph.D. dissertation, University of Florida. 390 p.

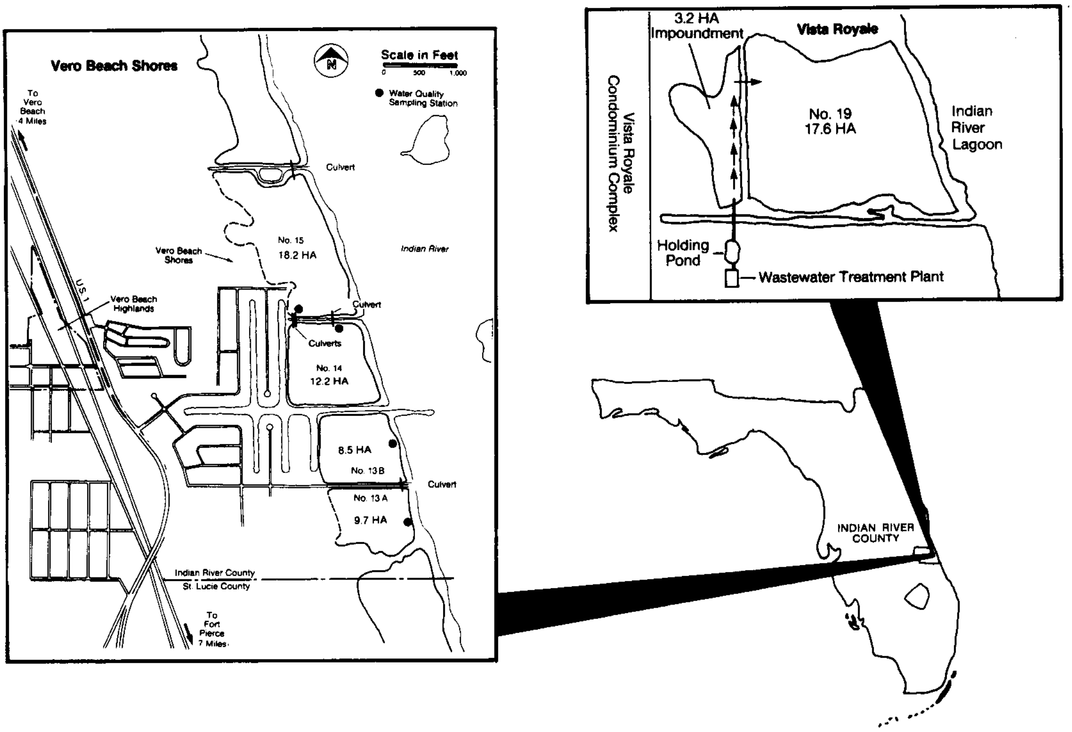

Fig. 1. Location of study sites in Indian River County, Florida.

dominium development in IRC (Fig. 1), has discharged up to 1.89 million liters/day (0.50 million gallons/day) of secondarily treated wastewater from an activated sludge wastewater treatment plant into Indian River Impoundment No. 19[4] since 1976. During periods of heavy discharge or rainfall, water flowed from this 3.2 ha (8 acre) impoundment into an adjacent 17.6 ha (44 acres) impoundment (Carlson 1983a). During this study period, water periodically overflowed the dike of Impoundment No. 19, into the Indian River Lagoon.

As reported in Carlson (1983a) the flora in this impoundment system consists primarily of *Laguncularia racemosa* Gaertn. (white mangrove), *Rhizophora mangle* Linn. (red mangrove), black mangrove, widgeon grass, *Acrostichum aureum* Linn. (leather fern), *Typha domingensis* Pers. (cattail), *Najas quadalupensis* (Spreng.) (southern naiad), *Lemna* spp., *Chara* spp. (stonewort), and *Cissus sicyoides* Linn. (possum grape). In addition, *Panicum hemitomon* (maidencane) and *Lemna* spp. are very common near the wastewater discharge point into the impoundment.

[4] W. L. Bidlingmayer and E. D. McCoy. 1978. An inventory of the salt-marsh mosquito control impoundments in Florida. Unpublished report to Fish and Wildlife Service, U.S. Dept. of Interior. 103 p.

SAMPLING REGIME. To quantify mosquito production from the Vista Royale impoundments under normal plant operating conditions, immature mosquitoes were sampled weekly from April 20, 1983 to April 10, 1985 by taking two 350 ml dips at established stations. These sampling sites were at the outfall pipe, at 10 m intervals between 10 and 110 m, at 20 m intervals between 120 and 240 m, at 480 and 600 m from the discharge point.

During late February until March 14, 1983, a treatment plant failure at Vista Royale resulted in the discharge of untreated wastewater into the impoundment. Beginning on March 8, the day after the plant failure was first observed, a sampling program for immature mosquitoes began. Twice per week two 350 ml dips at the established stations listed above were taken from the dike from March 8 to April 12.

On March 8 and March 11, surface water samples were analyzed in the morning for dissolved oxygen (DO), salinity, ammonia nitrogen (NH_3), total kjeldahl nitrogen (TKN), nitrite (NO_2), nitrate (NO_3), and fecal coliforms at the point of wastewater entry and at 60, 120, 180, 240, 480, and 600 m from the discharge point. On March 8, pH and biochemical oxygen demand (BOD) were also measured. Dissolved oxygen was measured with a YSI Model 57 Oxygen Meter, salinities were measured with a hydrometer. American Public Health Association (APHA 1980) methodology was used for all other measurements.

MOSQUITO PRODUCTION—NORMAL WATER MANAGEMENT REGIME. *Study area*: Indian River Impoundment No. 14 was studied (Fig. 1), which consists of a mosaic of open water areas dominated by *Ruppia maritima* Linn. (widgeon grass) and algae; and by heavily vegetated areas dominated by red mangrove, white mangrove and black mangrove. In addition, it also contains a dense bed of *Salicornia virginica* Linn. (perennial glasswort) and *B. maritima* in the southwest corner.

The potential for mosquito production from this impoundment (which was part of the system used for the hydrological study) under the current water management regime of estuarine pumping from late spring to early fall was assessed. Five sites in Impoundment No. 14, which appeared most likely to produce salt-marsh mosquitoes based on work by Carlson and Vigliano (1985), were sampled weekly from January 30 to June 6, 1985. Pumping commenced on June 10 and mosquito sampling was then conducted daily from June 11 to June 21, 1985. From June 26 to October 29, 1985, samples were taken weekly. On each sampling visit when water was present, five 350 ml dips were taken at four sampling sites located along the impoundment dike with mangrove cover. Ten dips were taken in the *Batis/Salicornia* bed at the southwest corner of the impoundment on each sampling visit, an area known to be a prolific salt-marsh mosquito producer from past experience. Mean number per dip ($\bar{X}$) over the synchronous brood duration was determined.

HYDROLOGICAL STUDY. *Study area*: Indian River Impoundments Nos. 13A, 13B, 14, and 15[4] (Fig. 1), constructed in 1959 and 1960 by the IRMCD, were the study sites. They are partially or entirely enclosed by earthen dikes constructed of dredged material obtained adjacent to the dikes. The dikes range in elevation from approximately 2.1 to 4.5 ft. NGVD[5], but in some locations are low and in poor repair. The dikes are constructed of marl-like clays, sand and broken lime rock. Impoundments Nos. 13A and 15 have no dike along their upland (western) edge.

These impoundments are part of two pumping systems. Water is pumped into Impoundment No. 13A and flows north into No. 13B through a culvert. To flood Impoundments No. 14 and 15 water is pumped into No. 16 (which was not one of the study sites). It then flows south into Impoundment No. 15 through one culvert and then south through three culverts into Impoundment No. 14. The culverts remained open during the study.

Like Impoundment No. 14, the other 3 impoundments also consist of a mosaic of open water areas dominated by widgeon grass and algae; and by heavily vegetated areas dominated by red mangrove, white mangrove and black mangrove.

WATER LEVEL MEASUREMENTS. Water levels in each of the four impoundments were monitored with Stevens Type F water level recorders from March 23 to June 20, 1984. Operational problems, which included plugging of holes in the stilling wells by detritus, and numerous mud-dauber wasp nests on pulleys, cables, and chart drums resulted in some incomplete records. However, based on periods with complete data and on frequent measurements at staff gauges installed in each impoundment, nearly continuous water level records during the 3-month study period were obtained for each of the four impoundments.

To monitor rainfall, data were collected by daily observations of a rain gauge just west of Impoundment No. 14. As a check, rainfall measurements were also obtained from two other monitoring points, the Vero Beach Highlands wastewater treatment plant (approximately 1.7 km west of the study area) and the official NOAA weather station located approximately 14.4 km northwest of the study area. Pan evaporation data were also obtained from the NOAA station.

Other than rainfall, the only significant input of water to the impoundments was from IRMCD pumping of estuarine water to maintain water levels necessary to control salt-marsh mosquito populations during the mosquito producing season. Pumping times, at a flow rate of approximately 380 liters/sec (6000 gallons/min), were reported by the IRMCD.

WATER QUALITY SAMPLING. Monthly water quality data were collected in the morning for 3 months from 4 stations which appeared representative of the impoundments sampled (Fig. 1). Water samples were measured for: alkalinity, BOD, total organic carbon (TOC), color, coliform bacteria (fecal and total), nitrogen (NH_3, $NO_3 + NO_2$ and TKN), total phosphorus, solids (dissolved and suspended) and sulfate.

In addition, dawn and dusk measurements of DO, temperature, salinity and conductivity were collected monthly at three stations within each impoundment. The exact locations of these stations varied during the 3-month study, but in each case two canal stations and one shallow interior station were monitored. Field measure-

[5] National Geodetic Vertical Datum, Vertical Control Data by the National Geodetic Survey, Sea-level Datum of 1929, U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

ments were made for temperature and DO by use of a YSI Model 57 DO meter and for salinity and conductivity by a YSI Model 33 SCT meter. Field pH was measured with a Markson portable field meter. All laboratory analyses were conducted according to APHA (1980) and EPA (1979).

RESULTS AND DISCUSSION

MOSQUITO PRODUCTION. Mosquito sampling in Impoundment No. 14 (n = 1,315) demonstrated that under the current water management regime of estuarine flooding during the summer months, salt-marsh mosquitoes (*Aedes* spp $\bar{X}$/dip = 41.2 and 0.2) were produced by rainfall on two occasions in the spring before pumping commenced. On the initial estuarine flooding event (June 10), *Aedes* spp. ($\bar{X}$/dip = 3.6) were produced in the *Batis/Salicornia* area in the southwest corner of the impoundment. Over the remaining 4 months of the study, only 13 larvae of *Anopheles* spp. were collected from 870 samples. No *Aedes* were collected during this period.

When properly treated wastewater is discharged into impoundments, no mosquito problem ensues (Carlson 1983a). However in south Florida, some wastewater retention areas are especially attractive habitats for *Culex nigripalpus* Theobald and *Cx. quinquefasciatus* Say (Carlson 1982, O'Meara and Evans 1983). Also, Carlson (1983b) demonstrated in a laboratory oviposition experiment that gravid *Cx. quinquefasciatus* were attracted to water taken from an impoundment receiving wastewater even when offered a known highly attractive alternative wastewater source. These facts leave the possibility that if not properly managed, such impoundments have the potential to produce a *Culex* problem.

This concern materialized in early 1983 when a treatment plant failure occurred at the Vista Royale system resulting in the discharge of untreated sewage at the maximum rate of approximately 1.89 mld into the impoundment. Prior to the treatment plant failure, the impoundment was a shallow, medium salinity, aquatic system with tannic-colored water and low nutrient concentrations. After the failure it changed to a foul smelling system with very opaque water and water chemistry measurements indicating poor water quality. The poorest water conditions measured were near the discharge point, with conditions improving proceeding away from it (Table 1). By 480 m away from the outfall pipe, all parameters except salinity were consistent with background levels from other impoundments (Table 2).

Mosquito sampling from March 8 to 11, prior to IRMCD treatment of the marsh and correction of the treatment plant problem, showed extremely high densities of immature *Culex* mosquitoes in the 3.2 ha impoundment which directly received the wastewater. During this first week of sampling, the $\bar{X}$/dip ranged from a high of 185.1 at the outfall point to 0 at 240 m from the discharge point. The relative increase in *Cx. nigripalpus* numbers at the 140 and 160 m distance appeared due to dike convolutions with exceptionally heavy leaf litter, which trapped wastewater and created more favorable oviposition sites (Table 1).

The 3.2 ha impoundment was treated with the monomolecular film ISA-20E (Arosurf 66-E2) on March 11 and the treatment plant problem was corrected on March 14. March 18 samples indicated a reduction in *Culex* densities but the presence of 1st instar larvae demonstrated that oviposition was still occurring. From March 8 to April 12, 3,443 mosquito larvae were collected (*Cx. nigripalpus* = 90.2%, *Cx. quinquefasciatus* = 7.4%, *Cx. salinarius* Coquillett = 2.2% and *Uranotaenia lowii* Theobald = 0.2%). After April 12, *Culex* mosquitoes virtually disappeared. Even though this plant failure occurred during a time of the year when *Cx. nigripalpus* populations are not usually at their highest (Provost 1969), it is interesting that this species quickly and successfully exploited this attractive habitat.

Sampling at the Vista Royale impoundment system over the next 24 months (n = 3,822) showed mosquitoes present in negligible numbers (*Culex* spp, $\bar{X}$/dip = 0.04; *Anopheles* spp, $\bar{X}$/dip = 0.03; *Ur. lowii*, $\bar{X}$/dip = 0.02).

IMPOUNDMENT WATER LOSS RATES. Precise water budgets for Impoundments Nos. 13A, 13B, 14 and 15 could not be prepared because 1) pumping rates were not continuously at 380 liters/sec and 2) uncontrolled surface overflows occurred over low spots along the dike during the final stages of pumping. Therefore, water loss in the 4 impoundments through percolation and evaporation was measured directly by water level changes during periods of little or no rainfall. Water level data during periods when the impoundments were overflowing due to overpumping were not used.

The data summarized during the period from March 23 to June 17, 1984 indicate that the average water loss rates for interconnected Impoundments Nos. 13A and 13B were very similar (0.61 and 0.64 cm/day, respectively) as were the loss rates for Impoundments Nos. 14 (Fig. 2) and 15 (0.69 and 0.64 cm/day, respectively), which were also connected by culverts.

To determine the relative magnitude of evapotranspiration and percolation in this total

Table 1. Mosquito production and water parameter extremes at an impoundment receiving wastewater during a treatment plant failure (Indian River Impoundment #19; March 8–11, 1983).

Mosquito production within impoundment during treatment plant failure

Species ($\bar{x}$/dip)	Number of samples	Distance from discharge point (m) 0	10	20	30	40	50	60	70	80	90	100	110	120	140	160	180	200	220	240	480	600
Cx. nigripalpus	4	135.3	103.3	34.8	31.0	63.0	0.5	8.8	13.5	16.8	8.3	7.5	6.0	8.8	67.0	50.8	1.8	3.0	0.3			
Cx. quinquefasciatus	4	43.3	8.5	0.8	2.0	0.8				0.3	0.3	0.3			0.5							
Cx. salinarius	4	6.5	3.3		0.8	1.0					0.3											
Ur. lowii	4		0.3	0.5	0.3	0.3																
Total		185.1	115.4	36.1	34.1	65.1	0.5	8.8	13.5	17.1	8.9	7.8	6.0	8.8	67.5	50.8	1.8	3.0	0.3	0.0	0.0	0.0

Water parameter extremes in impoundment during treatment plant failure.

Water Parameter	Number of samples	Distance from discharge point (m) 0	10	20	30	40	50	60	70	80	90	100	110	120	140	160	180	200	220	240	480	600
NO_2[a]	2	0.22						0.22						0.14			0.22			0.17	0.11	0.16
NO_3[a]	2	0.43						0.39						0.36			0.48			0.29	0.19	0.26
NH_3[a]	2	14.27						14.27						14.27			<0.11			<0.11	<0.11	<0.11
TKN[b]	2	17.54						17.54						17.54			11.04			7.94	0.80	<0.28
DO[b]	2	0.40						0.40						0.60			0.60			0.60	1.40	1.90
BOD_5[b]	1	40						32						38			30			26	9	10
pH	1	7.2						7.4						7.4			7.5			7.6	7.1	7.2
Fecal Coliform[c]	2	9600						3200						2200			1800			100	<100	<100
Salinity[d]	2	3.7						3.5						3.7			2.8			2.8	2.8	2.2

[a] Expressed in mg/liter as N.
[b] Expressed in mg/liter.
[c] Expressed in bacterial organisms per 100 ml.
[d] Expressed in ppt.

Table 2. Summary of water quality data from Vero Beach impoundments from March 22 to June 20, 1984.

Parameter[a]	Impoundment designation[b]							
	13A		13B		14		15	
Alkalinity (mg/liter as $CaCO_3$)	175	(4)[c]	180	(4)	257	(4)	249	(4)
BOD_5 (mg/liter)	6.7	(4)	5.3	(4)	8.6	(4)	11.1	(4)
TOC (mg/liter)	26.8	(4)	25.8	(4)	48.5	(4)	52.4	(4)
Color (APHA units)	141	(4)	210	(4)	273	(4)	325	(4)
Coliform bacteria (colonies/100 ml)								
Fecal	12	(3)	25	(4)	32	(4)	92	(4)
Total	447	(3)	403	(3)	450	(2)	2,500	(3)
Nitrogen (mg/liter as N)								
Ammonia	0.07	(3)	0.08	(3)	0.16	(3)	0.18	(3)
Nitrate and nitrite	<0.02	(4)	<0.02	(4)	0.02	(4)	<0.02	(4)
Total Kjeldahl	1.79	(4)	2.99	(4)	3.84	(4)	4.12	(4)
Total	1.81	(4)	3.01	(4)	3.86	(4)	4.14	(4)
Total phosphorus (mg/liter as P)	0.170	(4)	0.130	(4)	0.211	(4)	0.216	(4)
Solids (mg/liter)								
Dissolved	14,093	(4)	16,625	(4)	14,844	(4)	12,593	(4)
Suspended	18	(3)	13	(3)	34	(3)	12	(4)
Sulfate (mg/liter)	1,230	(4)	1,348	(4)	1,250	(4)	1,248	(4)
Salinity (ppt)	17.1	(30)	17.0	(30)	16.7	(30)	18.6	(28)
Conductivity (mmhos/cm)	28.5	(30)	28.8	(30)	27.9	(30)	30.8	(28)
Morning measurements (0600–1000)								
Water temperature (°C)	25.0	(15)	24.2	(15)	24.4	(15)	24.2	(14)
pH (units)	7.1	(15)	7.3	(15)	7.4	(15)	7.2	(14)
Dissolved oxygen	1.0	(15)	0.6	(15)	0.6	(15)	1.2	(14)
Afternoon measurements (1500–1900)								
Water temperature (°C)	27.8	(15)	28.2	(15)	27.1	(15)	27.7	(14)
pH (units)	7.6	(15)	7.7	(15)	7.8	(15)	7.5	(14)
Dissolved oxygen (mg/liter)	3.0	(15)	3.2	(15)	2.8	(15)	2.1	(14)

[a] All samples were collected at approximate mid-depth of water column.
[b] W. L. Bidlingmayer and E. D. McCoy. 1978. An inventory of the salt marsh mosquito control impoundments in Florida. Unpublished report to Fish and Wildlife Service, U.S. Dept. of Interior. 103 p.
[c] Number of samples in each average are noted in parentheses.

water loss, analysis of water level change data during daytime and nighttime periods was made. Detailed analysis of the water level recorder charts by enlarging daytime vs. nighttime portions shows a diurnal rhythm in water level changes (Fig. 3). Miller (1972) and Lugo et al. (1975) have reported that nighttime evapotranspiration losses in mangrove wetlands are nearly zero. These findings allow comparison of daytime vs. nighttime portions of these curves to determine percolation (nighttime water level changes) as compared to evapotranspiration plus percolation (daytime changes).

Percolation rates averaged 0.38 cm/day for the 4 impoundments studied. Percolation rates increase as water level increases, by the equation:

$$P = 0.33 * Y - 0.05 \ (r^2 = 0.59, n = 33)$$

where;

P = percolation in cm/day,

Y = water level in feet NGVD

The maximum water level possible in these impoundments without overflows is 2.08 ft NGVD (0.64 m). At this flooding elevation, the calculated average percolation rate is approximately 0.64 cm/day. However, a conservative estimate of sustainable, subsurface water losses under varying water levels is 0.38 cm/day. Assuming a continuation of this rate throughout the year, the annual sustainable percolation rate is approximately 140 cm/year. If water levels can be maintained at a greater depth, the maximum estimated percolation rate of 0.64 cm/day might be obtained. This rate would result in an annual percolation loss of approximately 230 cm.

Indian River Lagoon tidal data taken within 2 km of the study site from 1959 to 1981 demonstrate the seasonal tidal variation occurring

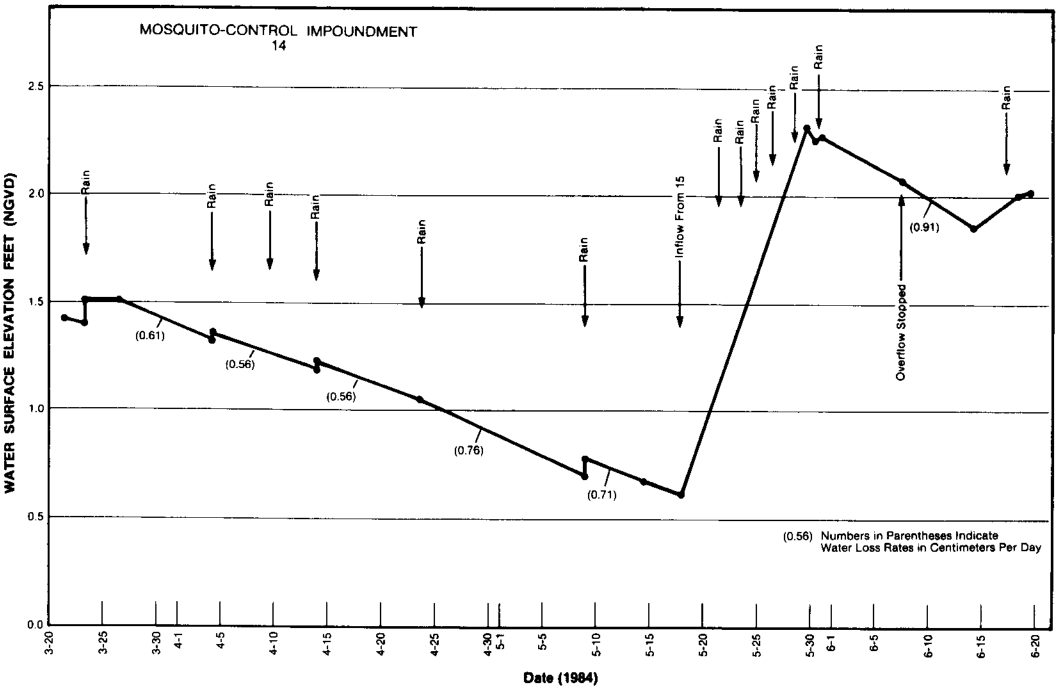

Fig. 2. Water level fluctuations in Impoundment No. 14 which are representative of the four impoundments studied.

in this area[6]. Highest mean tides are generally observed from September through December when they average about 0.8 ft. NGVD (0.24 m). During the April through June study period, mean tides are generally 0.5 ft lower than the fall tidal levels. Therefore, percolation measurements may be higher during the spring than the fall because of this seasonal tidal phenomenon requiring that a conservative estimate for percolation rate be recommended for system design.

Based on the total average water loss measured in the impoundments during this study (0.64 cm/day) and the determined average percolation rate of 0.38 cm/day, the average evapotranspiration rate was estimated to be 0.26 cm/day. This value is consistent with other reported evapotranspiration values for mangrove wetlands in Florida: 0.15 to 0.43 cm/day (Brown 1982), 0.08 to 0.25 cm/day (Lugo et al. 1975) and 0.08 to 0.38 cm/day.[7] This is also consistent with the observation that evaporation and transpiration are lower in brackish than in fresh-

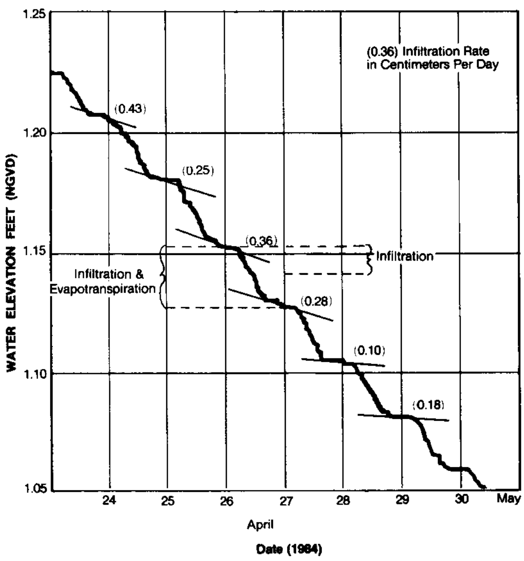

Fig. 3. Sample of water level record from Impoundment No. 14 showing diurnal rhythm in water levels.

water habitats (Bowman 1917, Scholander et al. 1962).

The ratio of evapotranspiration to pan evaporation (average pan evaporation during this study was 0.61 cm/day) for the 4 impoundments was 43%. Since the average annual pan evapo-

[6] Tidal records (Oslo Road, 1959–1981), Florida Medical Entomology Laboratory, Institute of Food and Agricultural Sciences, University of Florida.

[7] Lugo, A. E., R. R. Twilley and C. Patterson-Zucca. 1980. The role of black mangrove forests in the productivity of coastal ecosystems in south Florida. U.S. Environmental Protection Agency, Draft Report R80607910.

ration at the Vero Beach station is 163 cm, 60 cm/year are expected to be lost by evapotranspiration from the impoundments under brackish water conditions. However, if freshwater (e.g., secondarily treated wastewater) rather than brackish water is discharged into the impoundments, evapotranspiration rates are expected to increase, and be roughly equal to lake evaporation (77% of pan evaporation)[8] measuring 124 cm/year.

EFFLUENT DISCHARGE POTENTIAL. Based on an annual average rainfall of approximately 140 cm at Vero Beach and the water loss rates summarized above, the average annual sustainable water loss rates from these impoundments can be calculated for average and maximum percolation conditions during treated effluent discharge. Under average water level conditions, percolation rate is expected to be 140 cm/year, evapotranspiration rate is 124 cm/year, and rainfall is 140 cm/year, resulting in a net water loss of 124 cm/year. Over a 50 ha impoundment area, this rate could accommodate an annual average effluent discharge rate of roughly 1.52 million liters/day and not create overflows. For the possible scenario where water levels are maintained near their maximum, the percolation rate would be proportionately greater but with this flooding regime overflows might occur. Clearly many east coast impoundments provide the hydrological opportunity to serve as wastewater retention areas.

WATER QUALITY. Table 2 presents a summary of the ambient water quality of the 4 impoundments investigated during this study. Under a salt water pumping regime, the impoundments are shallow (generally up to 1 m deep), medium salinity ($\bar{X}$ = 17.4 ppt, n = 118), aquatic or mangrove wetlands with tannic-colored water that is enriched by decaying organic matter and has a moderate nutrient content (total nitrogen: $\bar{X}$ = 3.20 mg/liter as N, n = 16; total phosphorus: $\bar{X}$ = 0.18 mg/liter as P, n = 16). Dissolved oxygen is generally low ($\bar{X}$ = 1.8 mg/liter, n = 118) with a small diurnal fluctuation at any given station of 1–3 mg/liter. The water was slightly basic ($\bar{X}$ pH = 7.4, n = 118) and moderately alkaline ($\bar{X}$ = 3.20 mg/liter as $CaCO^3$, n = 16).

Carlson (1983a) reported that under a schedule of continuous secondarily treated effluent discharge into impoundments, water in the Vista Royale system had a much lower salinity ($\bar{X}$ = 1.7 ppt, n = 24), higher DO ($\bar{X}$ = 3.0 mg/liter, n = 24) and similar pH ($\bar{X}$ = 7.7, n = 24) compared to Impoundment Nos. 13A, 13B, 14 and 15. The Vista Royale impoundments also had significantly higher NO_3 values near the effluent discharge point. However, NO_3 was found to be removed by the wetland ecosystem to near background concentrations within 480 m. Phosphorus (as measured by orthophosphorus) was found to be considerably elevated at Vista Royale ($\bar{X}$ = 2.33 mg/liter as P, n = 25) and was not reduced with distance from the discharge pipe.

IMPOUNDMENT MANAGEMENT CONSIDERATIONS. The current consensus of impoundment managers is that impoundments should be reintegrated to the adjacent lagoon to provide many of their original estuarine functions (Carlson and Carroll 1985). To date, research is indicating this is best accomplished with a rotational impoundment management plan where the impoundment is seasonally connected to the estuary through culverts and allowed to dry during the late winter and spring when decreasing ocean water levels normally leave these areas exposed (Carlson et al. 1985). Although wetlands naturally assimilate nutrients and recent legislation in Florida allows for the use of certain wetlands for wastewater retention,[9] it is unclear if the mutual goals of reintegrating impoundments to the estuary and using them for wastewater retention can be accomplished politically.

A current impoundment management goal along the east coast of Florida is that revegetation of impoundments with historical marsh vegetation (i.e., black mangrove, *Batis* and *Salicornia* spp.) should be encouraged when possible.[10] In an impoundment effluent discharge system, estuarine pumping could augment the freshwater input to maintain salinities within predetermined limits. However, raising salinities would decrease the evapotranspiration rate and additional estuarine pumping would lower the volume of wastewater the impoundment could accept and increase operational costs. A photographic comparison of the Vista Royale impoundment system prior to wastewater discharge with current floral conditions reveals that continuously discharging wastewater into impoundments can contribute to changing the flora from predominately salt water tolerant plants to largely a freshwater system in a limited area adjacent to the effluent discharge pipe. This vegetation includes the plants maidencane, duckweed, cattails, and possum grape. At greater distances, the typical mangrove community was not noticeably changed except for scattered duckweed. Salinity regulation could reverse this trend of freshwater vegetation dominating near the wastewater discharge point.

Current impoundment management trends encourage minimum necessary flooding levels

[8] United States Weather Bureau. 1959. Technical paper No. 37.

[9] Warren S. Henderson Wetlands Protection Act of 1984, Section 403.918(4), Florida Statutes.

during the summer months to preserve existing vegetation while enhancing additional regrowth[10]. Thus, taking advantage of maximum percolation rates at high flooding levels in an effluent discharge system may not be compatible with a goal of restoring historic vegetation patterns. At Vista Royale, flooding is continuous with impoundment water levels in 1984 reaching 2.9 ft NGVD. This is far in excess of the 1.5–2.0 ft NGVD flooding elevation usually necessary for salt-marsh mosquito control. To avoid continuous flooding of an impoundment receiving wastewater, an acceptable management strategy could be to allow some of the impoundments in the system to dry down and then become intertidal on a rotating basis. This strategy would also allow for the oxidation of sediments, a normal yearly occurrence in these marshes.

An impoundment wastewater disposal system design must also include alternative disposal means for temporary conditions when the effluent water quality does not meet predetermined acceptable levels as was the case during the Vista Royale plant failure. Alternative discharge capabilities might also be necessary during periods of heavy rainfall. The inclusion of a pretreatment wetland in an upland area could provide this need.

This study shows that management methods for discharging treated wastewater into impoundments can be devised that allow for mosquito control and many natural resource and water quality considerations. Such a plan would provide economic savings for effluent discharge costs and mosquito control benefits while providing diversity of fresh and salt water wetland habitats adjacent to estuarine lagoons.

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