ARTICLES

THE USE OF SALT-MARSH MOSQUITO CONTROL IMPOUNDMENTS AS WASTEWATER RETENTION AREAS

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ABSTRACT. In Indian River County, Florida a 2-cell salt-marsh mosquito control impoundment flooded since 1976 with secondarily treated wastewater has produced mosquitoes in negligible numbers, although some inland holding ponds produce *Culex* mosquitoes in great densities. The use of impoundments to provide tertiary treatment to nutrient-rich wastewater reduces nitrates but not orthophosphates. Salinity, nitrate, and orthophosphate levels differ significantly from other impoundments not receiving wastewater as is evidenced by vigorous growth of some salt-marsh and freshwater vegetation. This method of wastewater disposal can be economically beneficial to mosquito control districts in helping control mosquitoes while at the same time improving water quality.

INTRODUCTION

In the 1950's and 1960's, 1129 ha of high salt marshes in Indian River County (IRC), Florida were impounded to control populations of *Aedes taeniorhynchus* (Wiedemann) and *Ae. sollicitans* (Walker). Because gravid females of these mosquito species oviposit on moist soil of the high marsh, flooding these areas with water from the adjacent Indian River lagoon eliminates ovipositional sites.

On the central east coast of Florida, the use of impoundments as a method of source reduction has proven to be an effective and economical technique for controlling salt-marsh mosquito and sand fly (*Culicoides* spp.) populations but has changed the flora and fauna from a preimpounded high marsh state to that more resembling the low marsh. Impounding has interfered with the exchange of organisms and detritus with adjacent bodies of water (Provost 1977). In IRC, a 2 cell salt marsh impoundment has been used since the spring of 1976 to provide tertiary treatment to wastewater. This has further altered the salt marsh.

Some inland wastewater retention ponds in IRC have been shown to be especially attractive habitats for *Culex nigripalpus* Theobald and *Cx. quinquefasciatus* Say, both vectors of St. Louis encephalitis (Carlson 1982). Impoundments used as holding ponds could become suitable *Culex* habitats. The concern is valid since the Indian River Mosquito Control District's (IRMCD) present larviciding methods for salt marsh mosquitoes are inefficient for controlling *Culex* spp.

To assess the effect of flooding impoundments with wastewater, several studies were conducted comparing the flora and water quality parameters in 7 impoundments (which use a variety of water management techniques) with the 2 impoundment system receiving wastewater. In addition, immature mosquitoes present in this impoundment wastewater system were sampled and results compared to those of a mosquito abundance study of IRC inland evaporation-percolation ponds (Carlson 1982). This paper reports on these findings and considers the economic impact of this impoundment use.

MATERIALS AND METHODS

STUDY SITES. 1) Vista Royale is a 1500 unit condominium development where a 3.2 ha impoundment receives secondarily treated wastewater from the holding pond of a 1,892,500 liters per day activated sludge wastewater treatment plant. During peak discharge or heavy rainfall periods, water spills from this impoundment across the dike into an adjacent 17.6 ha impoundment (Fig. 1). At no time is there any direct exchange of water with surrounding ditches or the Indian River lagoon although some seepage through the dike may occur.

The flora within the dikes of this 2 impoundment group consists primarily of *Laguncularia racemosa* Gaertn. (white mangrove), *Rhizophora mangle* L. (red mangrove), *Ruppia maritima* L. (widgeongrass), *Acrostichum aureum* L. (leather fern), *Typha domingensis* Pers. (cattail), *Najas quadalupensis* (Spreng.) (southern naiad), *Lemna* spp. (duckweed), *Chara* spp. (stonewort), and *Cissus sicyoides* L. (a grape vine in the Vitaceae family). On the dikes, white, red and black mangrove (*Avicennia germinans* (L.)), *Conocarpus erecta* L. (buttonwood), leather fern, *Baccharis halimifolia* L. (saltbush), *Schinus*

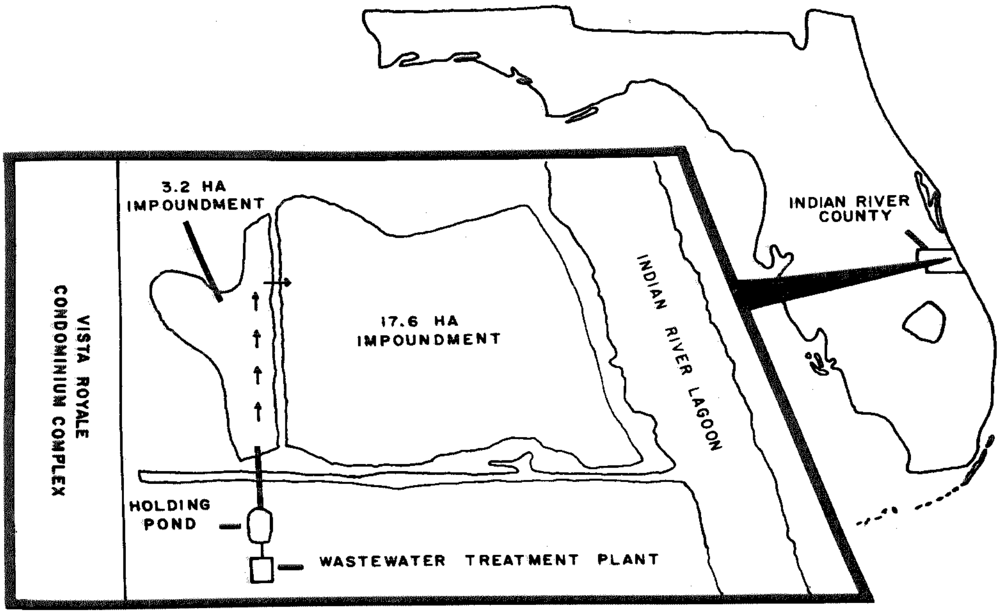

Fig. 1. Direction of wastewater flow into a 2 cell salt-marsh mosquito control impoundment.

terebinthifolius Raddi (Brazilian pepper), *C. sicyoides*, and *Borrichia frutescens* (L.) (sea daisy) are common.

2) Seven impoundments not receiving wastewater make up the second study area group. An impoundment is referred to as managed if water is pumped into it from the Indian River lagoon and unmanaged if it is not artificially flooded. These 2 categories (managed and unmanaged) encompass the follow 4 management types:

a) Maintenance of adequate water levels to prevent salt-marsh mosquito oviposition during the main mosquito producing period (April–October), by pumping water from the Indian River lagoon,
b) Maintenance of adequate water levels to prevent oviposition year-round by pumping water from the Indian River lagoon,
c) No water management (at the property owner's request) necessitating chemical control of mosquito larvae, and
d) Maintaining an opening in the dike to the river in unmanaged impoundments requiring chemical control of mosquito larvae.

Table 1 shows characteristics of the 7 impoundments.

Major vegetation differences between managed (i.e. flooded) and unmanaged (i.e. nonflooded) impoundments occur within the dikes. On the dikes of both managed and unmanaged impoundments, white mangrove, red mangrove, black mangrove, buttonwood, saltbush, sea daisy, *Limonium carolinianum* (Walt.) Britt (sea lavender), and Brazilian pepper are the dominant vegetation types. Within the dikes of managed impoundments, most vegetation has been eliminated by flooding. While on some higher elevations red, white, and black mangroves are occasionally present, widgeongrass is a common submerged plant. In the nonflooded impoundments which have dried for at least several months, surface marsh vegetation (primarily *Salicornia virginica* L. (perennial glasswort) and *S. bigelovii* Torr. (annual glasswort), *Batis maritima* L. (saltwort), *Philoxeris vermicularis* (L.) R. Brown (samphire), and red, white and black mangrove) is present. In flooded impoundments these species are usually not present within the dikes.

SAMPLING. Water temperature, dissolved oxygen (D.O.), pH and salinity were measured monthly in the morning from August 1979 through July 1980 at permanent sampling sites. Samples were obtained approximately 1 meter from the dike at the water surface with a 300 ml D.O. bottle. Dissolved oxygen was determined by the azide modification method. Salinities

Table 1. Characteristics of a cross section of IRC impoundments not receiving wastewater used in the study.

Impoundment name	Impoundment[1]	Size (in ha.)	Water management scheme
Pine Island	6	154	A
Sand Point	9	60	C
South Oslo	18	54	A
Golf Course	22	43	C
North John Knights	24	23	D
Morgans	29	29	A
Vickers	30	25	B

A) Managed seasonally (April-October) by pumping water from the Indian River lagoon sufficient to prevent salt-marsh mosquito oviposition.
B) Managed year-round by pumping water from the Indidn River lagoon sufficient to prevent salt-marsh mosquito oviposition.
C) Unmanaged at the property owner's request.
D) Unmanaged at the property owner's request but maintaining an opening to the Indian River lagoon.
[1] W. L. Bidlingmayer and E. D. McCoy. 1978. An inventory of the saltmarsh mosquito control impoundments in Florida. Unpublished report to Fish and Wildlife Serv., U.S. Dept. of Interior. 103 p.

were measured with a hydrometer. These 2 tests were conducted as described by the A.P.H.A. (1976). The pH was determined by Hach equipment.

Nitrate nitrogen (NO_3) and orthophosphate (PO_4) levels were measured at established sampling sites in all impoundments studied. Nitrates were measured with Hach Low Range Nitrate Test Kit (Model NI-14). Orthophosphate levels were determined by the A.P.H.A. 1976 titration method. Test results were verified periodically by a water analysis firm using A.P.H.A. 1976 methods.

In the Vista Royale impoundment receiving wastewater, an additional study compared nutrient levels at progressive distances from the point of wastewater entry. From June 1981 through April 1982, a series of 5 water samples was taken. The sampling sites were at the point of wastewater entry into the 2 impoundment system, and at 120, 240, 480 and 600 m from the discharge point. In this study, NO_3 and PO_4 levels were determined by A.P.H.A. procedures.

To assess the mosquito producing capability of the Vista Royale impoundments, sampling for preadult mosquitoes was conducted with a 350 ml dipper attached to a 1 m handle. Forty-five dips were randomly taken weekly over a 64-week period along the perimeter of the impoundments. Larvae were returned to the laboratory, counted and identified. Pupae were held for emergence and adults were identified.

RESULTS AND DISCUSSION

WATER QUALITY. Impoundment water quality can be influenced by detrital, chemical and freshwater input from nearby sources which vary greatly from one impoundment to another. The fact that the impoundments used in this study (except North John Knights (#24)- see Table 1) are not periodically opened to the adjacent lagoon through a water control structure (e.g. a culvert), enhances this input trapping effect. These factors help account for the intra- and inter-impoundment variability of D.O., pH and salinity (as evidenced by $\bar{x}$ values and ranges in Table 2). This is especially apparent with the unmanaged impoundment Golf Course (#22), where large differences in $\bar{x}$ values in both D.O. and salinity are evident as compared to all other impoundments studied not receiving wastewater. Nearby freshwater input accounts for the low salinities and extreme oxygen demand for detrital decomposition may account for low D.O. levels. Wide temperature fluctuations within impoundments are expected due to year-round sampling. Consequently, broad generalizations cannot be made linking levels of these parameters to water management schemes. On the other hand, some generalized statements can be made about differences between impoundments receiving wastewater and those not.

To analyze water quality differences between Vista Royale and the 7 other impoundments studied, a two-way analysis of variance was conducted on D.O., salinity, water temperature and pH. Table 2 reveals a significant difference in D.O. levels only between Vista Royale and Golf Course (#22-atypical of the impoundments studied in having an unusually low $\bar{x}$ D.O. reading) ($F_{[1,11]0.01} = 41.35$).

The pH was significantly different between Vista Royale and Sand Point (#39) ($F_{[1,11]0.05} = 7.04$). The pH difference may be due to this impoundment's lack of an upland dike making it highly susceptible to run-off from adjacent areas. Water temperatures differed signifi-

Table 2. Summary and comparison of water quality data between Vista Royale and 7 other impoundments studied (N = number of samples).

Water management scheme	Impoundment (#)	N	Dissolved oxygen[a] $\overline{X}$±S D	Dissolved oxygen[a] Range	Salinity[b] $\overline{X}$±S D	Salinity[b] Range	Temperature[c] $\overline{X}$±S D	Temperature[c] Range	pH $\overline{X}$±S D	pH Range
Receiving secondarily treated wastewater	Vista Royale (#19)	24	3.0±1.9	<0.1–6.0	1.7±1.6	0.0–4.2	25.4±4.4	15–31	7.7±0.1	7.5–8.3
Managed	Pine Island (#6)	48	2.4±2.4	<0.1–11.8	26.5±6.0*	18.7–43.0	25.1±5.0	16–35	7.8±0.2	7.8–8.0
	South Oslo (#18)	24	2.6±2.9	<0.1–9.5	14.3±5.8*	9.7–43.0	26.0±5.7	15–35	7.8±0.2	7.5–8.5
	Morgans (#29)	24	4.0±3.1	<0.7–13.3	19.6±7.3*	12.7–32.8	24.0±6.1	12–30	7.8±0.1	7.8–8.3
	Vickers (#30)	96	3.4±2.4	<0.1–9.3	24.7±5.8*	14.6–33.5	22.7±5.9	10–32	7.8±0.2	6.5–8.0
Unmanaged	Sand Point (#18)	36	3.4±2.9	<0.1–10.2	15.0±4.4*	10.1–27.2	25.7±5.8	13–39	8.0±0.4**	7.8–9.0
	Golf Course (#22)	36	0.4±0.6*	<0.1–2.0	4.5±2.5*	0.6–14.6	26.1±4.4	14–31	7.7±0.1	7.5–7.8
	North John Knights (#24)	24	3.4±1.9	<0.1–7.2	22.0±6.6*	10.5–30.8	24.4±4.9	16–31	7.8±0.3	7.0–8.5

[a] Expressed in parts per million.
[b] Expressed in parts per thousand.
[c] Expressed in °C.
* Significant difference from Vista Royale at 0.01 level.
** Significant difference from Vista Royale at 0.05 level.

cantly over time in all cases as expected due to seasonal temperature fluctuations ($5.16 < F_{[1,11]0.05} < 18.08$). In all comparisons between Vista Royale and other impoundments, salinities differed significantly ($15.69 < F_{[1,11]0.01} < 190.32$) (Table 2).

Since vegetated wetlands have been shown to use nutrients introduced into them, some freshwater marshes have been used for tertiary treatment of wastewater (Frederico et al. 1982, Fritz and Helle 1982, Sheffield et al. 1982). Using marshes as evaporation-percolation ponds can be an economically beneficial wastewater disposal alternative for developers when large amounts of wastewater are to be treated. Analysis of nitrate nitrogen and orthophosphate are of interest in marshes receiving wastewater because they can serve as indicators of the nutrient load present in the system. To mosquito control interests, this analysis is important because nutrient-rich wastewater can be an attractive *Culex* ovipositional site (Provost 1969). Nutrient studies in freshwater flow-through wetland systems have shown that the longer the wastewater retention time, the greater the nutrient assimilative capability of the marsh (Fritz and Helle 1982). Since the Vista Royale system is not a flow-through system, retention time is not a limiting factor in nutrient uptake. Water exits the system only from evaporation, percolation or possibly some seepage through the dike.

Nutrient levels at progressively greater distances from the point of discharge illustrate the ecosystem's ability to lower nutrient concentrations (Table 3). Regression analysis of nitrate values reveals a concentration decrease described by the equation $y=1.59-0.003x$, $F=13.78$, $p=0.013$ which indicates that by 497 m from the discharge point, nitrate levels are reduced to the background readings of less than 0.1 ppm obtained in all other impoundments not receiving wastewater. Nitrate levels in Vista Royale were significantly different from other impoundments studied at the discharge point ($t=4.68$, df=13, $p=0.0002$), 120 m ($t=2.47$, df=13, $p=0.015$) and 240 m ($t=3.35$, df=13, $p=0.003$) from the point of wastewater entry. Freshwater wetlands have been shown to remove up to 98% of the total nitrogen without significant adverse environmental effects (Fritz and Helle 1982). Similar nitrogen assimilation appears to occur at Vista Royale.

Regression analysis of orthophosphate levels at Vista Royale, as evidenced by a nearly horizontal slope and a very low variance ratio (F), shows an insignificant concentration reduction and large concentration variability ($y=2.45-0.0004x$, $F=0.058$, NS) over the 600 m

Table 3. Nutrient concentrations in a salt-marsh mosquito control impoundment receiving wastewater at progressive distances from the wastewater entry point (values determined from 5 samples at each location).

	Discharge point	$\bar{x}$±S D (in ppm)			
		120 m	240 m	480 m	600 m
NO_3	2.01±1.41	1.04±1.38	0.45±0.44	0.05±0.08	0.06±0.10
PO_4	2.52±1.30	1.76±0.56	3.33±3.47	1.51±0.45	2.51±2.52

sampling interval. Resultant levels are significantly higher than background levels of less than 0.93 ppm in other impoundments tested (t=3.95, df=34, p=0.0002). This is consistent with Fritz and Helle (1982) who showed phosphorus reduction to fluctuate greatly in freshwater wetlands receiving wastewater. They showed removal rates to reach a high of 97% but attributed some lower reduction rates only to dilution. These fluctuations at Vista Royale, and in other studies, can at least partly be attributed to sediments which have been shown to act as a buffer removing phosphorus from or releasing it into the overlying water column depending on its concentration in the sediments and in the water column (McLusky 1981).

While pH and D.O. differed significantly between Vista Royale and other impoundments in only a few cases (Table 2), salinity as well as nitrate and orthophosphate differences (as already shown) were significant and are evidenced by the Vista Royale flora. Certain plant species (*Chara*, cattails, southern naiad, and *C. sicyoides*) are present in Vista Royale but rarely found in other impoundments. Periodic blooms of duckweed are common but signs of rapid eutrophication are not apparent. Extremely vigorous growth of red and white mangrove, *C. sicyoides*, and Brazilian pepper is evident. The ecosystem supports a plentiful and diverse assortment of fish, water fowl and marine invertebrates[1].

MOSQUITO SURVEY. Of particular interest to mosquito control operations, mainly because of the proven ability of some local inland holding ponds to contain disease vectoring mosquitoes in great densities (Carlson 1982) is Vista Royale's mosquito producing capability. Sampling for immature mosquitoes revealed 9 species to occur in the Vista Royale impoundment system but in extremely low numbers. They were *Aedes atlanticus* (Dyar and Knab), *Ae. taeniorhynchus*, *Anopheles crucians* Wiedemann, *An. quadrimaculatus* Say, *Cx. nigripalpus*, *Cx. quinquefasciatus*, *Cx. restuans* Theobald, *Cx. salinarius* Coquillett and *Uranotaenia lowii* Theobald.

From 2880 dips only 51 were positive (1.8% of the sample) with only 171 mosquitoes collected. This was in marked contrast to IRC's worst case inland holding pond (Douglas Elementary School) where over a similar sampling period 77.9% of the dips were positive for immature mosquitoes with as many as 2421 in a single dip (Carlson 1982). Hagstrum and Gunstream (1971) associated $\bar{x}$ nitrate levels of 0.3 ppm with the occurrence of immature *Cx. quinquefasciatus* mosquitoes. At Vista Royale, nitrate levels varied from less than 0.1 to 3.54 ppm well within this acceptable reported range. Overall these levels are much less than the 0.6 to 46.7 ppm readings obtained at the Douglas School pond. The mosquito species composition in the Vista Royale impoundment and inland holding ponds is similar but since receiving wastewater, this area has posed no mosquito problem.

ECONOMIC IMPACT. The Vista Royale impoundment system is an innovative use of salt marsh mosquito control impoundments. By allowing wastewater to flow into impoundments, the need to flood them with water from adjacent bodies of water can be greatly reduced or eliminated. At Vista Royale the flow of wastewater has greatly reduced pumping in 1976 through 1978 and has curtailed it since 1979.

For the IRMCD, the marginal pumping cost (i.e. cost of maintaining an additional acre each year by pumping) is an estimated $6.50 while the marginal larviciding cost (i.e. cost of larviciding each additional acre each application) is approximately $7.00 and several applications per year are necessary. Consequently in IRC, a managed impoundment flooded with wastewater provides approximately a $6.50 saving per acre per year. Flooding an unmanaged impoundment with wastewater would save about $7.00 per acre each time a mosquito larvicide treatment would have been necessary. Although the amount of larviciding varies yearly, 1978–81 figures from an unmanaged impoundment nearby Vista Royale show an average of 4 complete treatments per year over that 4 year period. Flooding with wastewater would also reinstitute sand fly control in these

[1] Sverdrup and Parcel and Associates, Inc. and Beindorf and Associates, Inc. January 1980. Indian River County 201 Facilities Plan, prepared for the Board of County Commissioners, Indian River County, Florida.

areas, an important function of managed impoundments. Large savings to mosquito control districts from allowing secondarily treated wastewater to flow into impoundments will occur only if vast areas are so treated. Then decreased pumping or larviciding needs would translate into fewer personnel, less equipment and material requirements making for much greater savings.

Vista Royale has served as a model for proposals for similar systems. One site (a new section of the Vista Royale condominium complex) began discharging secondarily treated wastewater in November 1981 into a 36 ha impoundment which had been seasonally managed since 1957. Presently the wastewater flow must be supplemented by pumping. Also, a proposal on a greatly expanded scale in IRC has suggested using 119.4 ha of impoundments as a holding pond system for a proposed 21,953,000 liters per day wastewater treatment plant[1]. One major benefit of this plan is that this proposed treatment plant would service many sites presently using their own wastewater treatment facilities (commonly referred to as package plants) thus eliminating some inland holding ponds which have been shown to produce extremely high *Culex* densities.

Unlike Vista Royale, this proposal calls for both periodically draining part of the system and allowing alternating sections of it to be opened to the river. These features would allow compaction of organic material and the exchange of detritus and organisms with the Indian River lagoon. The draining and reflooding of inland holding ponds, when done in conjunction with the presence of large adult mosquito populations, has been shown to produce broods of *Ae. vexans* (Meigen), *Ps. columbiae* (Dyar and Knab), or *Ae. taeniorhynchus* (Carlson 1982). The draining and reflooding of impoundments used as holding ponds probably would produce similar results on a greater scale requiring appropriate larval control measures.

One additional suggested use of such areas is for aquaculture. Although this could allow for a long term economic benefit to be extracted from the system, such a use should proceed with caution. Some aquaculture projects where water hyacinths have been reared for biomass production in wastewater containing high nutrient concentrations have produced *Culex* mosquitoes in great densities (G. F. O'Meara, personal communication).

The Vista Royale 2 impoundment system has shown that some salt-marsh mosquito control impoundments can be used for tertiary treatment of wastewater for extended periods apparently without adversely changing the ecosystem or causing a mosquito problem. The fact that high nutrient concentrations in wastewater can contribute to the production of *Culex* mosquitoes is an important factor which must be considered when designing this type of tertiary treatment system for use on a larger scale. With the implementation of properly designed management techniques to adequately reduce nutrient loads, along with careful monitoring, this can be a beneficial impoundment use.

ACKNOWLEDGMENTS

I sincerely appreciate the comments of Mr. E. J. Beidler, Mr. W. L. Bidlingmayer, Mr. G. A. Curtis, Mr. G. D. Dodd, Dr. J. H. Frank, Dr. G. F. O'Meara and Dr. J. R. Rey in reviewing the manuscript. The assistance of Amy Beidler and Robert Vigliano of the Indian River Mosquito Control District and of Mr. Geoffrey Wolfe of Bioservices of Vero Beach is gratefully acknowledged.

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