THE SAINT LUCIE COUNTY MOSQUITO CONTROL DISTRICT

SUMMARY WORKPLAN FOR MOSQUITO IMPOUNDMENT RESTORATION

FOR THE SALT MARSHES OF SAINT LUCIE COUNTY.

PREPARED FOR

THE SOUTH FLORIDA WATER MANAGEMENT DISTRICT

INDIAN RIVER LAGOON

SURFACE WATER IMPROVEMENT AND MANAGEMENT PROGRAM

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SECTION 1.0. INTRODUCTION

This Summary Workplan for Impoundment Restoration in Saint Lucie County, is intended to provide the South Florida Water Management District (SFWMD), Indian River Lagoon Surface Water Improvement and Management (IRL SWIM) Program, with a brief review of the history and current management practices implemented by the Saint Lucie County Mosquito Control District (SLCMCD), in the Management of Impoundments for Mosquito and Sandfly Control, in Saint Lucie County, Florida. Current impoundment management practices and impoundment restoration techniques, are directed at restoring biological integrity and reducing pesticide use in the managed marshes of Saint Lucie County. Maps of the individual impoundments (from Rey and Kain, 1989) are provided, which pictorially indicate all structures currently in-place within each impoundment (addendum 1). Brief accounts of studies are also provided, for those studies which evaluated the management and restoration practices, and aided in the development of Best Management Practices for Impoundment Management (addendum 3).

SECTION 2.0. BACKGROUND

SECTION 2.1. LOCATION

Saint Lucie County is centrally-located along the Atlantic shoreline of the east coast of Florida (see attached map). A 20-mile-long barrier island forms the eastern boundary of the County, which is known as Hutchinson Island. Hutchinson Island's eastern shore borders the Atlantic Ocean. The western shore of the barrier island meanders along the Indian River Lagoon (a micro-tidal estuary with less than 3 meters of tidal range), and possesses over 5000 acres of estuarine-fringing wetlands.

SECTION 2.2. HISTORY OF BARRIER ISLAND

The stratigraphic sediment base of Hutchinson Island is a sub-tidal, Pleistocene, non-marine setting of skeletal quartz sand intercalated with shell hash. The barrier island complex migrated landward to its present location, via sand over-wash and/or flood tidal delta formation, under the influence of the Holocene sea level rise (the Holocene transgression) between 3000 and 5000 years before present. Then the sub-tidal coastal marine sediments shallowed upwards along the western shore of the barrier island, and were replaced by back-barrier salt marshes and mangrove swamps. These wetlands created muddy quartz sands, which then accreted through vegetational rooting and organic debris deposition, to produce the fibrous peat soils found in many of the swamps today (White, 1992).

SECTION 2.3. TOPOGRAPHY

The 5000 acres of wetlands which fringe the western shore of Hutchinson Island, in Saint Lucie County, are generally flat, or gently sloping, and lie at elevations

varying from approximately +0.3 feet NGVD, to approximately +2.5 feet NGVD (MHW is approximately +1.0 feet NGVD in this area). They are reticulated with many tidal creeks, swales, ponds and old mosquito ditches. From 1927-1935, 285 miles of ditches were constructed for mosquito control, in the barrier island salt marshes of Saint Lucie County, and the remains of many of these ditches are still present today. The wetlands are peripherally bounded by earthen borrow dikes. The dikes are approximately 30-50 feet in width, and approximately +2.5 to +5.0 feet NGVD in elevation. The dikes were constructed between 1935 and 1966, using marsh borrow-material. The borrow-material was removed from the marsh substrate and placed along the perimeter of the wetland, at the approximate location of the Mean High Water Line (and site of the wave-action levee). The construction of the dikes created a perimeter ditch system along the borrow area, approximately 3-6 feet in depth, and 25-50 feet in width. The natural red mangrove marsh-fringe was left untouched along the perimeter of the berm, in order to protect the dikes from the erosion effects of wave-action in the estuary.

SECTION 2.4. NATURAL MARSHES INUNDATION FREQUENCY

Tidal water rarely inundated the natural un-impounded wetlands of Saint Lucie County. High, wind-tides, generated by northeasterly and easterly winds occurring during 4-6 weeks of the fall season (late-September to October), were nearly the only period in which the estuarine tides inundated the natural marshes. Tidal exchange at lower water levels than the fall wind-tides, was checked by an accumulation of storm-tossed shells and vegetative debris (termed a wave-action levee), which formed at the Mean High Water Line (Clements and Rogers, 1964; Provost, 1973). In the case of the salt marshes of Indian River Lagoon, this wave-action levee was formed at the extreme water-ward limit of the marsh, not at the narrow transition zone between the uplands and the marsh observed in other coastal marsh areas.

SECTION 2.5. VEGETATION HISTORY

As a consequence of the low annual inundation frequency, vegetative dominance was achieved by black mangroves, white mangroves, saltwort and glasswort (high-marsh halophytes). These plants were adapted to both minimum tidal inundation frequency resulting in the desert-like, salt-concentrating conditions, which ensued from evaporation of tidal saltwater during non-wind-tide periods (which also led to the creation of a number of sand barrens on the marsh floor). The marshes were designated as "High Salt Marsh" habitat, based upon the dominance of these vegetation types, and the low annual frequency of tidal inundation which they experienced (Hull and Shields, 1943; Hull and Dove, 1939; Provost, 1957; Provost, 1973).

SECTION 2.6. NATURAL SALT MARSH ESTUARINE-RELATED FUNCTIONS

Prior to dike construction, direct and indirect export and import of biomass took

place between the estuary and the natural marshes through biological, chemical and physical means. Direct tidal and rainfall inundation-related export of plant and attached bacterial matter occurred through sheet-flooding and below-ground, interstitial water transport. Fiddler crabs reworked and oxidized sediments along the margins of the marsh, which resulted in increased rates of export, and increased turnover of water-borne dissolved and particulate organic materials during tidal and rainfall inundation events. Fiddler crabs were also prey for marine species (also along the perimeter of the marshes). Wading birds, shorebirds, and waterfowl imported and exported organic materials through feeding, excretion and predation upon the marsh organisms.

Transient (denoting seasonal use of the marsh) marine organisms, exported and imported organic materials by participating in functions which included nursery, reproductive and predator/prey use of the marsh floor during wind-tide periods. The salt marshes along the Indian River Lagoon were seasonally used as fall nursery grounds for young transient fishes such as Snook and Tarpon. Marsh fringe and tidal creek "ecotonal/fringe effect" use by fisheries, also occurred.

These wetlands were also utilized as breeding grounds for marsh resident fishes, during the wind-tide periods of inundation, and in low areas retaining water for longer periods. Such species included, the Sheepshead minnow, the Mosquitofish and Sailfin molly (Harrington and Harrington, 1982).

SECTION 2.7. SALT MARSH MOSQUITO LIFE HISTORY

The female salt marsh mosquitoes, oviposit their eggs in wetland sediments, that are not inundated more than four days per month (two days per spring tide) (Provost, 1977). The salt marsh mosquitoes oviposit their eggs in depressions in muddy sediments, or in leaf-litter, and produced synchronous broods following heavy rainfalls and/or wind-tides which penetrated into in the natural marsh. Therefore, the reduced inundation frequency of these marshes was highly favorable to the success of the salt marsh mosquito. Frequent, repeated mosquito oviposition could occur during the prolonged periods of sediment exposure.

Salt marsh mosquitoes generated great numerical abundances in the natural salt marshes. These mosquitoes then dispersed or migrated as many as 20 miles away (including areas inhabited by human populations). The original control efforts were directed at eliminating the enormous nuisance impact of Salt marsh mosquitoes on the human population in Saint Lucie County.

The Entomological Research Center (ERC, now the Florida Medical Entomology Laboratory, or FMEL), sampled the marshes for salt marsh mosquito larvae during a number of pre-impoundment studies. Their collections yielded larval densities of 17-87 larvae/0.1 sq. ft./year, or approximately 7.4-37.9 million larvae/acre/year (Rogers et. al., 1961 and 1962). The inundation of the natural

marshes by rainfall or tides, could then result in the hatching of billions of mosquitoes, from the thousands of acres of salt marshes in Saint Lucie County. These large, annual mosquito population abundances, were amassed through population recruitment (in logarithmic fashion), as a result of the year-round oviposition in the salt marsh sediments. The female salt marsh mosquito has the capacity to recruit its numbers through its ability to oviposit up to 200 eggs per egg batch, over several egg batches. Salt marsh mosquito egg densities were found to average as high as 2383/sq. ft. in the natural salt marsh (Provost, 1960).

SECTION 2.8. HISTORICAL ACCOUNTS OF MOSQUITO PROBLEMS

In a passage of Jonathan Dickinson's Journal (1696-1697), is given the following description of the arthropod nuisance problem on Hutchinson Island, "Abundance of mosquitoes and sandflies hindered our rest, to remedy which we digged holes in the sand, got some grass and laid it therein to lie upon, in order to cover ourselves from the flies." During the Civil War, John Taylor Wood (the Sea Ghost of the Confederacy) and his companion Breckinridge, described burying themselves in the sand if on land, and wrapping themselves in sail if in their boat, to escape mosquitoes during their dramatic escape from Union forces at the Indian River Inlet. Wood declared that he, "could have filled a bucket with mosquitoes, by swinging it about my head", and Breckinridge stated that, "a man could not survive if he were exposed to two nights of the pests". At the end of the Civil War, the 1865 survey maps depicted Saint Lucie County as "Mosquito County", which appears to support their observations.

Many, long-time residents of Saint Lucie County still recall the smudge pots, that made it possible for residents to sit outdoors on the porch during the evening hours. Historical accounts also recount incidents in which cattle and horses were suffocated by enormous broods of salt marsh and fresh- floodwater mosquitoes.

SECTION 3.0. HISTORY OF CONTROL MEASURES

SECTION 3.1. DITCHING

From 1927 to 1935, 285 miles of ditches were constructed for mosquito control purposes in the salt marshes of Saint Lucie County. This ditching program was successful, in the short-term, in partially controlling the salt marsh mosquito production. The success was short-lived, because the ditch maintenance required to ensure the effectiveness in controlling the mosquitoes proved to be impossible to sustain under the manpower and economic constraints of wartime. Wave and storm deposition of shells and other debris, which made-up the wave-action berm, filled in the ditches at the water-ward limit of the marsh, and actually transformed the ditches into mosquito breeding habitat by restricting flushing of individual ditches.

Salt marsh sandflies continued to pose a significant nuisance problem after the ditching was constructed, as well. In fact, the ditches might possibly have exacerbated the problem (Hull and Dove, 1939). Linley (ERC, unpublished) found that up to 308,100 sandflies could be produced from a 2 ft. wide, ditch bank, over a distance of 0.5 miles. Factoring this production over the approximately 285 miles of ditches constructed in the marshes, results in an estimate of total abundance of (approximately) 70 million sandflies per day, and up to 25 billion sandflies per year.

SECTION 3.2. EXPERIMENTAL DIKING

An experimental diking program was implemented to examine the effectiveness of diking on sandfly production in 1935. The initial diking experiment attempted to de-water the marsh, and proved to be unsuccessful. The marsh water could not be drained quickly enough to prevent successful sandfly breeding from occurring along the ditch banks. An attempt was then made to flood the marsh, when a quipster suggested that "they should turn the pumps around". The artificial flooding was found to be successful, not only in realizing 99 percent control of sandflies, but it also successfully achieved 99 percent control of the salt marsh mosquitoes (Hull and Dove, 1939; Hull and Shields, 1943).

SECTION 3.3. PESTICIDES

Although the impoundment experiment in sandfly and mosquito control proved successful, and one impoundment was partially maintained until after WWII, pesticides became the control method of choice for the SLCMCD in the 1940's and 1950's. The advent of DDT, provided an economical and effective means of controlling mosquitoes, and DDT became the chemical of choice for mosquito control of coastal Salt marsh mosquitoes. It was found to be highly effective as both an adulticide and a larvicide, and was heralded as the agent which would ensure the demise of the mosquito as a nuisance and disease problem.

By the late 1940's, however, salt marsh mosquitoes had developed resistance to DDT, possibly from its use on both larvae and adult stages. Treatment of both early and late stages of insects can increase selection pressure for resistant strains. When resistance issues were combined with the discovery of harmful environmental effects, DDT quickly ceased to be a viable control alternative.

Following the failure of DDT, additional organo-chlorine compounds were sought for mosquito (BHC, etc.), and sandfly (Dieldrin, etc.) control. However, they too became rapidly unusable, due to development of resistance (BHC), or due to negative environmental impacts (Dieldrin). Parkinson et. al. (1992), has found that residues of DDE, Lindane and Dieldrin persist in the marshes to this day, tightly bound to the organic matter within the sediments. These breakdown products do not appear to be exported from the marshes in detectable amounts (less than 0.01 ppb).

SECTION 3.4. DIKING

As a result of the failures of ditching and pesticides to control salt marsh mosquitoes and sandflies, further experiments with diking and impounding of waters in salt marshes were performed in Brevard County in the mid-1950's. Following the success of these experiments, in which 99 percent control was achieved, the State of Florida, Department of Health and Rehabilitative Services, fostered a program of impoundment construction for mosquito control. Approximately 6000 acres of salt marsh were impounded in Saint Lucie County, from 1958 to 1966, in this program, and over 41,000 acres were impounded along the central-east coast of Florida.

SECTION 4.0. IMPACTS OF IMPOUNDMENT CONTROL MEASURES

The impoundment program successfully reduced levels of nuisance arthropods, improving the quality of life and permitting the expansion of human development to take place in Saint Lucie County. However, the improvement in the quality of life for the human population was originally environmentally costly to the impounded wetlands and to the estuary it bordered.

SECTION 4.1. VEGETATION LOSSES

Impoundment management practices, which included long-term flooding with stagnant water and unrestricted trapping of rainfalls, resulted in flooding to excessively high water level and negative impacts from unbuffered drops in pH. The excessive water level heights destroyed much of the High Marsh vegetation. It was later learned that permanent submergence of the entirety of the black mangrove pneumatophores, and the low-profile, marsh halophytes, such as the saltwort and the glasswort, could not be endured by the plants.

Following destruction of the original marsh vegetation by over-flooding and possibly acidification, red mangroves became dominant in over one-half of the impounded marshes. In a study by White et. al. (1992), the invasion by the red mangroves was followed by a 2-4 fold increase in soil accretion rates. These accelerated accretion rates, resulted in increased elevations of the marsh floor, and further reduced the inundation frequency for those marshes impacted by the red mangroves. The increased rate of accretion, also served as an indicator of the diked-impoundment status as a carbon sink. Such factors (increased accretion rate and transformation of the marshes to carbon sinks) created serious questions as to whether the original impoundment diking program was having a long-term impact upon estuarine productivity.

SECTION 4.2. LOSSES OF ESTUARINE-RELATED HABITAT FUNCTION

The construction of the dike led to the historic loss of most of the estuarine-related habitat functions of the salt marshes, as a consequence of the physical isolation from the estuary that they imposed on the marshes. Harrington and Harrington (1982) discovered that fish species diversity on the marsh surface declined following impounding, from 16 species to 5, during the 4-6 week natural flooding fall period when they commonly used the marsh floor. This drop in species diversity reflected a reduction in transient species use. The implication was then formulated, that impoundment of the salt marshes resulted in a seasonal impact on estuarine-related, wetland nursery functions. The construction of the dikes, appeared to prevent the 4-6 weeks of access to the salt marshes by juvenile transient fishes, which occurred in the natural marshes during the wind-tide inundation periods.

Gilmore et. al. (1981) repeated the Harrington experiment (with a greater intensity of sampling), and confirmed reduced access to the impounded marsh by transient fishes due to dike isolation factors. Gilmore et. al. (1981) also compared the impounded marsh which Harrington studied, with a formerly impounded marsh. The formerly impounded marsh was open year-round to the estuary, via a solitary, 30 inch diameter culvert. The data from the open marsh, revealed that 38 species of marine fish utilized the man-made perimeter ditch system which was constantly open to the estuary, compared with 12 species for the isolated impounded marsh. It is important to note that the perimeter ditches created by the impounding process (being the borrow-area from which the dike fill material was removed), appeared to function similarly to tidal-creek-like habitat, when remaining open year-round. This finding suggested that culvert installations in the perimeter dikes, combined with seasonal openings of tide gates, could re-introduce the estuarine fish nursery function to the marsh, and result in tidal-creek-like functions inside the bermed area.

The seasonal pattern of the fish use of the salt marsh ditch (peaks in numerical abundance in March, April and September) (Gilmore, 1981), helped to formulate the beginnings of a restoration plan. The data suggested that the flooding and tide-gate operations could be timed to allow natural seasonal juvenile fish use of the marsh during the mid-spring, late-summer and fall. The conversion of the marsh mosquito management program to a multi-species management format was thus begun with the effort to include restored estuarine connectivity functions of marine fish nursery use, and Rotational Impoundment Management (RIM) was born.

In the same study, Gilmore et. al. (1981) also found that the marsh floor of the un-managed open marsh was capable of vegetative re-colonization. This datum was significant, in that it demonstrated that denuded marshes could be vegetatively restored with improved water management protocols directed at control and duration of water flood height. Jackie Salmela (Director Brevard Mosquito Control District, pers. comm.) had previously demonstrated that the marsh vegetation was actually capable of surviving the summer artificial flooding conditions within the impoundments, provided that the pneumatophores and low-

profile, marsh halophytes were not completely submerged. This information was important in demonstrating the potential to restore and maintain healthy marsh vegetation, should seasonal management with strict water control heights adhered-to.

SECTION 5.0. IMPOUNDMENT RESTORATION PROGRAM AND DEVELOPMENT OF BEST MANAGEMENT PRACTICES

Gilmore et. al's (1981) findings on re-introduction of fish nursery use of impounded salt marshes (following culvert installation), and the re-vegetation potential of the denuded marsh, led the Subcommittee on Managed Marshes (SOMM) to develop a Rotational Impoundment Management (RIM) protocol. The RIM program for the impoundments addressed seasonal management and reduction in pesticide use. The SLCMCD added a list of their own restoration goals, including; tidal range approximation through increased hydrological connectivity; water quality improvements; restoration of vegetation; specialized tide-gate, aeration and pumping operations; draw-down operations for wading bird enhancement; block or regional impoundment management for multiple-species use of the impoundments; and flooding season recruitment via open tide-gate scenarios.

SECTION 5.1. SEASONAL MANAGEMENT

Gilmore et. al. (1981, 1987, 1987) documented the numerical abundance of juvenile transient fish exchanging between salt marshes and the estuary. The data demonstrated that there were large peaks of larval and juvenile fish recruitment to the salt marshes, in the spring and fall of each year. The spring peak generally ended in mid-April, while the fall peak began in late-August and September. Since the major breeding of salt marsh mosquitoes and sandflies occurred from April through October, a seasonal impoundment management strategy was adopted by the SLCMCD, which designated the closure period for the impoundments to be from May through August. The marshes remain open to natural tidal exchange the remainder of the year (September through April).

SECTION 5.2. REDUCTION IN PESTICIDE USE

Mosquito eggs accumulated from nearly constant, summer-long female mosquito oviposition, in the natural or un-managed marshes. Large broods of mosquitoes and sandflies were produced when the wind-tides flooded the marshes in the fall. The longer the mosquito oviposition period, the greater the number of both aerial and ground pesticide applications which were required. Aerial adulticiding was performed several times per year. Ground adulticiding was performed several hundred times annually on the barrier island. Annual aerial larviciding of the salt marshes was performed over as a many as 30,000 acres in the natural marshes and un-managed impoundments.

Seasonal management, however, significantly reduced the need to use pesticides in and adjacent-to the salt marshes. Often their use is completely eliminated for both the mid- and immediately-post-management periods, because of significant reductions in levels of oviposition. It is important to note that, when an impoundment has been managed during the year, salt marsh mosquitoes generally will not produce large broods in the fall months in which the wind-tides occur (October, etc.). This "control-carryover-effect" is achieved because summer management arrests summer mosquito oviposition on the marsh floor. The wind-tides which follow the management period, are then generally of sufficient height to frequently inundate the marshes, and thus, prevent new oviposition from taking place. This "control-carryover-effect", is only effective if sufficient culverts are in place in the marsh, to mimic the tidal heights occurring in the estuary.

SECTION 5.3. TIDAL RANGE APPROXIMATION

The seasonal management strategy calls-for culverts to be opened in late-August and early September, and remain open throughout the winter and early spring. This open period varies from 7-8 months in duration, and ends (for a particular marsh), when mosquito breeding is found to occur within the marsh. Therefore, each marsh is generally managed independently from the others (in as far as closure timing is concerned).

The degree of salt marsh oviposition which occurs in the managed impoundment during the un-managed period, is the determining factor governing the management decision concerning the extent or duration of the open period. It was reported by Provost (1977), that greater tidal inundation frequencies led to reduced mosquito oviposition, provided that frequencies of inundation exceed four per month at one to two week intervals. Therefore, with sufficient culverts installed to approximate the high estuarine wind-tides within the impoundment, an extended open season can maintain reduced mosquito populations. The comparative reduction in mosquito production, between the managed marsh and the natural marsh, for the fall, wind-tide, post-management period (in October), is a prime example of the effective mosquito control obtained from tidal replication of the estuary tide levels at that time. Pesticide use is reduced and nutrient export is increased by the addition of the multiple culverts, when they are sufficiently numerous to provide an approximation of high tide water elevations.

The exact ratio of marsh acreage to culvert, which generates this tidal matching effect, varies from marsh to marsh. Pandit et. al. (unpublished) evaluated the volume of exchange which occurs between the impoundments and the estuary (for the Indian River Lagoon SWIM program). The data suggests that there exist variations in impoundment-estuary tidal flow-rates, such that levels of tidal replication are both inversely proportional to tidal height, and proportional to impoundment substrate elevation. Marshes with lower substrate elevation (+0.3 to +0.8 feet NGVD), appear to require greater numbers of culverts, as many as 10

ac/culvert, to approximate high wind-tide elevations in the open period (impoundment #12). Those open impoundments with higher substrate elevations (+1.3 feet NGVD and above), appear to require less culverts, approximately 16 ac/culvert (+/-).

SECTION 5.4. WATER QUALITY IMPROVEMENTS

In addition, Gilmore et. al. (1987), discovered that the optimal distance between culverts for fisheries use was approximately 240m. Multiple culverts, spaced 240 m apart, significantly decreased fish faunal differences, over those spaced farther apart. Gilmore et. al. (in the same study), reported improvements in water quality, which correlated with increased volumes of exchange provided by the 240 m-spacing of culverts. The water quality improvements observed, may have been responsible for the reduced fish faunal differences between sites. Increased species diversity (up to 70 species when 7 culverts were present in a 188 acre marsh) was also recorded in several of Gilmore et. al's. other studies (1985, 1987). Many fish species have very specific dissolved oxygen or salinity (or other) water quality requirements which must be met for them to inhabit an area, and adequate culvert numbers and spacing appears to supply these requirements during the open period (addendum 3).

The SLCMCD has also recorded improved water quality, correlated with increased densities of culverts, over a nine year period. Dissolved oxygen, an important water quality perameter necessary for marine organism survival, increased from an annual average of 2.4 ppm (with an 80.7 ac/culvert ratio in 1984), to 5.8 ppm (with a 26.1 ac/culvert ratio in 1991). De-seasonalized trend analysis reveals that significant improvements in dissolved oxygen have been achieved, as increased numbers of culverts have been installed over the past nine years (addendum 3).

Dissolved oxygen has also shown a proportional increase in quality during the closed period, following increased numbers of pump hours per day-managed. Events of fish stress underwent a dramatic decline in number of occurrences and number of fish impacted, as a result of the increase in pumping capacity, improved pump design and redundancy, and as a corollary to the installation of aeration devices (addendum 3).

In addition, in July of 2001, experimentation began using a solitary open culvert during the summer management season, in an attempt to attract Tarpon to the impoundments during the otherwise “closed” period. That experimental work was successful, with Tarpon recruitment observed within days of the mid-season opening. In the following year, 2002, all impoundments were managed with an open or partially open culvert(s), using “flip-gates” to restrict flow during periods of low tides when water loss over-balanced the rate of pumping. Upon opening of the impoundments in late August, Tarpon (12- 24" TL +/-) were found to occur, apparently having been recruited through the open culvert(s) during the summer. Future studies are proposed to examine Tarpon recruitment mechanisms, such

as olfactory sensitivity and rheotactivity.

SECTION 5.5. VEGETATION RESTORATION

The impounded wetlands now consist largely of a mixture of high salt-marsh and mangrove swamp. Nearly half of the wetlands are monotypic red mangrove (Rhizophora mangle) swamps (approximately 90 percent coverage). These swamps have re-vegetated the areas which were denuded of the high salt marsh vegetation by earlier impoundment practices. The remainder of the impoundments are approximately 60 percent covered with the original salt marsh vegetation, a mixture of black mangroves (Avicennia nitida), white mangroves (Laguncularia racemosa), saltwort (Batis maritima) and glasswort (Salicornia virginica or bigelovii).

Attempts are on-going, to re-vegetate the high salt marsh vegetation in the remaining un-vegetated areas (40 percent of the area lacking vegetation coverage in the 2000 acres dominated by high marsh plants). Those efforts include prevention of plant submergence for specialized structures such as pneumatophores. The SLCMCD successfully maintained water levels below normal control height (impoundment #16A), and instituted reduced, or completely eliminated artificial flooding for one or more seasons (impoundment #24), in order to achieve vegetation regeneration in impoundments. Modified Tidegate Weirs (overflow tidegates) are also employed to automatically discharge excess freshwater which also exerts a control over salinity and pH, and to prevent overflooding of the natural high marsh plant species.

Lahmann (1988) reported that red mangrove above-ground production amounts for the impoundments were high for mangrove forests in general. Lahmann (1988), reported that the above-ground primary production of the monotypic red mangrove forests in a managed impoundment, an unmanaged impoundment and a fringe forest was 4,335 g/m^{-2}/yr, 4,016 g/m^{-2}/yr and 5,384 g/m^{-2}/yr, respectively. The success of the Red mangroves in the managed impoundment system, according to Lahmann (1988), may be due to the "energy subsidy", provided by end-of-season draw-downs, which release nutrients through sediment oxidation. In addition, the same study reported that, although the seasonal flooding temporarily reduced litterfall and biomass accumulation during the flooding period, the cumulative total for the year was greater for the managed swamp than for the unmanaged swamp). Lahmann (1988) also reported that recruitment of red mangrove seedlings was not affected by water management, because the opening of the impoundment coincided with the onset of propagule shedding.

An unexpected side benefit of the seasonal artificial flooding with estuarine saltwater (reported by Lahmann, 1988), was the prevention of invasion of the marshes by exotic species, such as Brazilian pepper and Australian pine, which are common to other disturbed sites in Florida.

SECTION 5.6. SPECIALIZED TIDEGATE, AERATION AND PUMPING OPERATIONS

It was reported by Gilmore et. al. (1987), that in order to obtain maximal exchange of transient marine fishes, tide-gates should be removed from the mouth of the culvert during the open period. The restrictions to physical passage through the culverts, imposed by closed tide-gates which opened only under head pressure from the tides, appeared to be significant for the marine fishes studied (Gilmore et. al., 1987). Therefore, tide-gates are tied open, and/or completely removed from the mouth of the culverts during the open period.

Stagnant conditions in salt and brackish waters can lead to build-up of hydrogen sulfide, which is a by-product of anaerobic respiration. Sulfuric acid build-up can occur following rainfalls, driving pH's as low as approximately 4.0. Hydrogen sulfide is toxic to marine fishes and other marine organisms, and sulfuric acid can be highly detrimental to marsh vegetation and marine fauna. This water quality issue was addressed, in part, by the Modified Tidge-Gate Weir's ability to automatically discharge excess surface water, thus exerting a control over the degree of "freshness" (which reflects buffering capacity) and therefore, on pH, by removing freshwater immediately after a rainfall has occurred.

In addition, the problem of hydrogen sulfide accumulation was also addressed by, increasing water turnover rates during the managed period (when the tide-gates are closed and no tidal exchange occurs), through a combination of constant pumping (one 7,000 GPM pump per 70 +/- acres) and utilization of a constant discharge of pumped water. The combination of pumping and constant release, generates a "flow-through" water movement. The constant water turnover provided by the flow-through design, replaces stagnant water with clean estuary water, before hydrogen sulfide or sulfuric acid can accumulate. This same flow-through technique generates a significant added benefit, resulting from continuous water exchange during the closed period with the estuary. This water exchange exports water-borne nutrients, and increases concentration of dissolved oxygen by reducing the Chemical Oxygen Demand (COD) otherwise imposed upon the water column by the hydrogen sulfide.

In 2001, experimentation focused on maintaining solitary open culverts in each impoundment during the management period. With 30 acre-feet of capacity per 7,000 GPM per pump per day, the 50 acre-feet of a typical culvert discharge can be balanced by multiple pumps, thus increasing the outflow of nutrient laden water from the marsh, while allowing ingress and egress of marsh transients and residents. Future studies will examine the nature of recruitment resulting from this modification, but simple observation suggests that water quality appears to be enhanced, since stagnant freshwater can no longer accumulate, and turnover is lowered to 3.5 days (approx.) from the previous 7-10 days.

When pumps suffer mechanical failure, the fish rheotactic response causes them to swim toward the direction of water flow, seeking higher water quality, which

brings them into confined areas at pump stations. The pump station and its adjacent canals are the location of the highest water level within the impoundment, and the direction from which water continues to flow even with the pump(s) off. This accumulation of large numbers of fish (tens of thousands up to several million), results in over-consumption of dissolved oxygen (D.O.) in this confined area. In response to this behavioral pattern, 3 Hp electric, aerators (AERO-2) have been installed at pump stations to provide the fish populations with constant aeration. These aerators are especially effective during periods of overcast. During one sampling period at impoundment #1, the aerated impoundment remained at 6.2 ppm of dissolved oxygen, while the estuary declined to 2.9 ppm (during a period of heavy and prolonged overcast). There have been no fish mortality at pump stations with aerator stations since the aerators were installed.

SECTION 5.7. DRAWDOWN OPERATIONS FOR WADING BIRD ENHANCEMENT

Drawdowns have been proposed as management techniques designed to enhance wading bird foraging success. Drawdowns involve mid-season lowering of water levels within impoundments, by discharging greater amounts of water from impoundments, than are pumped into them. Once water levels drop below the typical substrate elevation of a marsh, most of the water remaining in the marsh lies only in ditches and low depressions. Resident fishes are concentrated in these areas by the draw-down of water levels, making them an easily accessible, concentrated food source for wading birds. Young birds benefit especially from these drawdowns, because they are not otherwise effective feeders during the early stages of their lives. Concentrating and making food more available for them during draw-downs, improves their feeding success in the summer management period. The possible movement of portions of the wading bird population of the Everglades, to Saint Lucie County, in the late-spring and summer, may include these young-of-the-year birds. This movement may also account for the discrepancy discovered by Swain (pers. comm.), between the number wading birds feeding in draw-down impoundments, and the number of birds nesting in the local area. Therefore, the impact of feeding wading birds in mid-summer in Saint Lucie County, may have far-reaching foraging enhancement consequences for wading birds, beyond the boundaries of the Indian River Lagoon.

Additional benefits of drawdowns may include; unrestricted exchange of marine organisms between the marsh ditches and the estuary during the closure period, and improvement of water quality through increased impoundment water turnover rates.

SECTION 5.8. REGIONAL OR BLOCK IMPOUNDMENT MANAGEMENT ALTERNATIVES AND MULTIPLE USE

Regional or block management objectives, attempt to increase the beneficial

impacts of specific forms of management, by focusing on individual species (or types of species) which have very specific habitat requirements, and designing management practices which meet those requirements. An example of such management is the waterfowl enhancement program, operated over approximately 20,000 acres, within the Merritt Island National Wildlife Refuge.

In Saint Lucie County, the block management concept has been developed to provide for the multiple uses of mosquito and sandfly control, minimization of pesticide use, optimal fishery exchange for approximately eight months per year, optimal fishery utilization 12 months per year (by improving water quality), stock enhancement and enhancement of wading bird summer foraging opportunities. All managed impoundments in Saint Lucie County are also seasonally block-managed for the shortest possible duration of closure necessary to achieve effective mosquito and sandfly control, which also encompasses the strategy of management for optimal fishery exchange and utilization.

Several managed impoundments (#1, #6W, #7&8A, #9&9Annex, #16A and #19B), however, are also now being developed for use as managed blocks, which are to be committed to mid-season drawdowns designed to enhance wading birds (creating foraging opportunities, safe resting areas, providing for predator avoidance, etc.). These impoundments are receiving Indian River Lagoon SWIM support to establish double pump stations, which are necessary for maintenance of high water quality, and to supply the pump-up capability for the post-draw-down period. Double pumps are needed to provide the capability to re-pump the draw-down impoundments. The Indian River tides are so low in mid-summer, that re-pumping to management height with a single pump is impossible to accomplish with the bottom-water release tide-gates in operation. The bottom-water release tide-gates continuously discharge too great a volume for the pumps to compensate for (when combined with evaporation and low tides that preclude 24-hour per day pump operation). Should the bottom-water releases remain closed during that time, re-pumping to management height with a single pump would, require weeks of pumping (versus days to accomplish that task by double pumps), in order to reach the water levels necessary for mosquito control. The slow rate of pump-up, with a single pump and closed bottom-water release, would result in degradation of water quality. The longer duration of sediment exposure could then result in mosquito oviposition taking place before control height could be attained. Following mosquito oviposition, the re-pump-up would then hatch mosquito larvae, thereby resulting in the need for additional pesticide applications (which are to be avoided).

Stock enhancement strategies have also been under study for managed blocks of impoundments (#19B, #17A and #18A). Combined goals of water quality improvement and fish and macrocrustacean stock enhancement are the objectives of these projects. Lower trophic level species under evaluation include: mullet; pink and white shrimp; clams; oysters; etc.. These species would be reared to provide food for those species higher in the food web.

Benefits of the mullet stocking, are the potentially valuable export of primary production from the marsh. The mullet are in a form that is rapidly available to estuarine, coastal and oceanic species (mullet plays and exceedingly important role in the coastal food web).

Higher trophic level species could also be reared for growout, such as: tarpon; redfish; spiny lobster; black drum; snook; ladyfish; etc.. These species would be reared in order to mitigate possible impacts of management, or to restock fisheries which have been depleted beyond their ability to regenerate their own stock.

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