FRESHWATER INFLOW TO THE CALOOSAHATCHEE ESTUARY AND THE RESOURCE-BASED METHOD FOR EVALUATION

R.H. Chamberlain[1]
P.H. Doering[1]

ABSTRACT

The Caloosahatchee River is the major source of freshwater for the Caloosahatchee Estuary and southern Charlotte Harbor aquatic environment. Development of an intricate system of canals within the watershed, in conjunction with regulatory discharges from Lake Okeechobee, has resulted in a drastic alteration in freshwater inflow to this ecosystem. The resulting large fluctuations of salinity and water quality can adversely impact estuarine biota. This paper will describe: (1) important physical and hydrologic features of the Caloosahatchee Estuary and the potential environmental problems associated with extremes of high and low freshwater inflows; and (2) the South Florida Water Management District's (SFWMD) resource-based strategy for establishing an optimum distribution of freshwater inflows (quantity), in order to provide a suitable salinity range (envelope) for a healthy ecosystem.

SITE DESCRIPTION

The Caloosahatchee River bisects its watershed and now functions as a primary canal (C-43) that conveys basin runoff and regulatory releases from Lake Okeechobee (Figure 1a). The canal has undergone a number of alterations to facilitate increased freshwater discharge, including channelization, bank stabilization, and the addition of three lock and dam structures. The final downstream structure, Franklin Lock and Dam (S-79), demarcates the beginning of the estuary. This structure maintains specified water levels upstream, discharges freshwater into the estuary, and acts as a barrier to salinity and tidal action, which historically extended upstream to the La Belle area.

The Caloosahatchee Estuary and associated sub-basin downstream of S-79 drains about 1,200 km^2 (Figure 1b). The estuary length is approximately 42 km from S-79 to Shell Point. The city of Fort Myers is located about half way down the estuary on the south shore, whereas the city of Cape Coral is on the north shore. Water leaving the Caloosahatchee passes Shell Point and enters San Carlos Bay, which is at the confluence of Pine Island Sound, Matlacha Pass to the north, and the Gulf of Mexico (Figure 1b). Most of the freshwater that enters southern Charlotte Harbor comes into San Carlos Bay from the Caloosahatchee. Much of this freshwater normally leaves the system by moving south under the Sanibel Causeway to the Gulf of Mexico (Goodwin 1996). However, when freshwater inflows are high, some of this freshwater is pushed by Gulf of Mexico tides up into Pine Island Sound and Matlacha Pass.

The estuary width between S-79 and Shell Point is irregular, ranging from 160 m in the channelized upper portion of the estuary to 2,500 m downstream (Scarlatos 1988). The narrow portion extends about 12 km downstream from S-79 to Beautiful Island and has an average depth of about 6 m, while the overall mean depth of the estuary in the section downstream of Beautiful Island is 1.5 m (Scarlatos 1988).

The Orange River enters the estuary just upstream of Beautiful Island (Figure 1b). Although it is the only substantial tributary downstream of S-79, it contributes only a very small amount of the total freshwater entering the ecosystem (Scarlatos 1988,

[1]South Florida Water Management District, Ecosystem Restoration Department, 3301 Gun Club Road, West Palm Beach, FL 33406

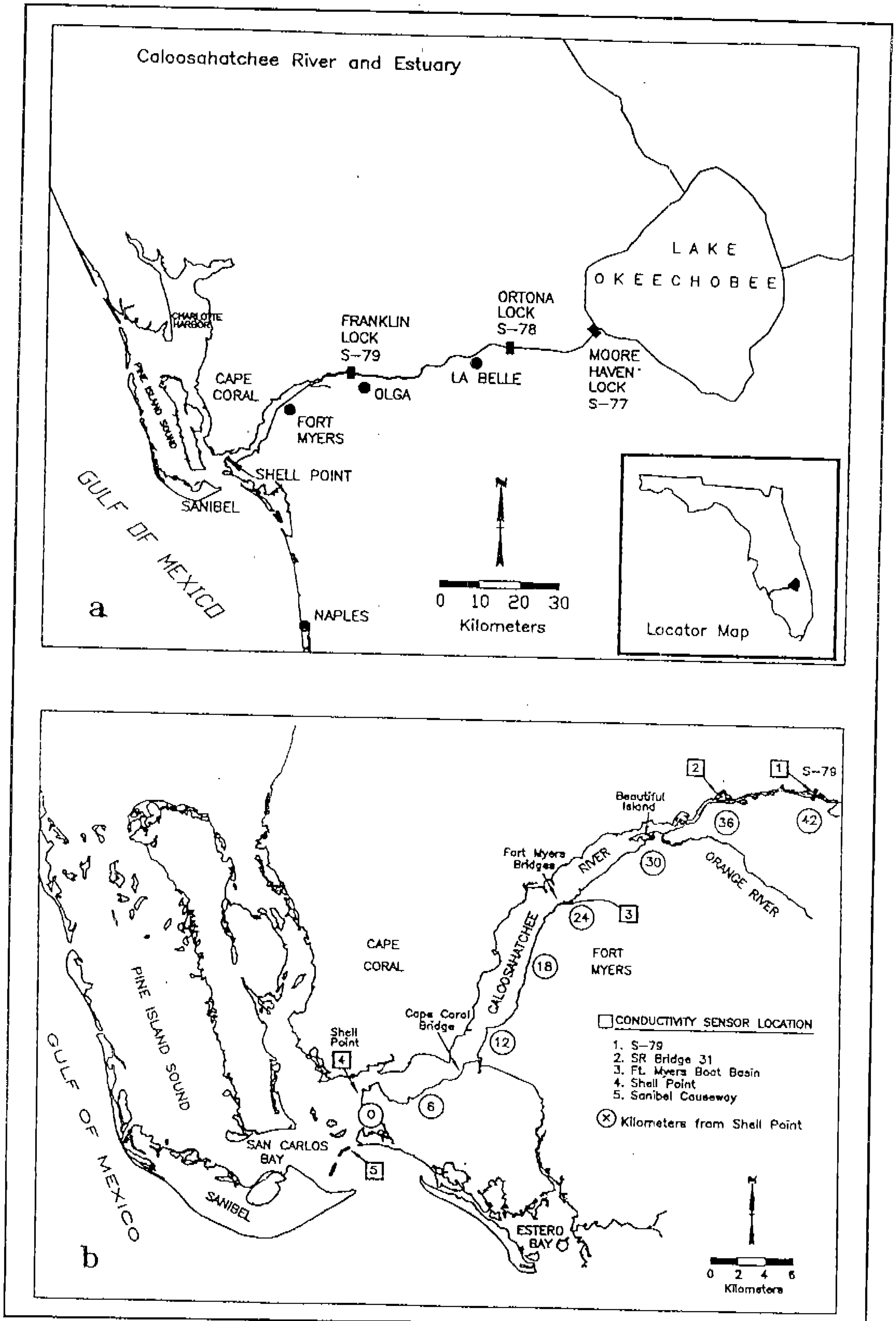

Figure 1. a) Caloosahatchee River and Estuary system. (b) Caloosahatchee Estuary and location of five conductivity (salinity) sensors.

Bierman 1993). The Orange River is probably most famous for the large number of manatees in the winter that seek the warm water effluent from the Florida Power and Light Power Plant.

An important estuarine feature of this area is the submerged aquatic grass, *Vallisneria americana* (tape grass), which normally is located near the shoreline to a depth of 0.5–1 m. Its greatest coverage occurs from Beautiful Island to just past the Fort Myers bridges (Figure 1b). However, this distribution varies as controlling environmental factors (such as salinity and light penetration) change with the amount of freshwater input (Chamberlain et al. 1996, Hoffacker 1994). The presence of *V. americana* is associated with a greater density of benthic invertebrates, and offers habitat, protection and foraging sites for many fish and invertebrates, including juvenile blue crabs. Manatees also have been observed in the grass beds, indicating this area might be an important feeding location close to a warm water refuge. However, during times of extended low to no inflow conditions, when salinity may be too high, this grass becomes very sparse and can disappear completely.

At the downstream end of the system, sparse to moderately dense beds of the seagrass, *Halodule wrightii* (shoal grass), extend up from San Carlos Bay to nearly the Cape Coral Bridge (Figure 1b). Like *V. americana*, it is restricted to the shoreline margins and represents a valued ecosystem component of the estuary.

The last substantial upriver oyster reef also exists near the mouth at Shell Point. Historical accounts of the river suggest that oysters were once a more prominent feature in this area. Sackett (1888) described difficulty surveying channels through oyster bars that obstructed the lower portion of the river between Redfish Point (river km 10) and Punta Rassa, where the Sanibel Causeway now connects to the mainland. The reduction in oyster coverage in this portion of the estuary was largely due to shell mining, altered freshwater inflow and changes in hydrodynamics, which was probably exacerbated as the oyster bars were physically removed.

San Carlos Bay's dominant biological features are its numerous mangrove islands and many kilometers of mangrove shoreline, which are often closely associated with seagrass flats. Small oyster bars also are plentiful. These features provide a physical structure for a diverse population of aquatic organisms (Chamberlain et al. 1996) and function as both a source of food and a place to feed and seek protection. Because of its biotic richness and aesthetic appeal, San Carlos Bay supports a wide variety of recreational and fishery activities with significant economic value, which must be considered along with agriculture and other upland interests when developing future water management policies.

When alterations to the natural system are made without adequate environmental consideration, the resulting physical and hydrologic changes in the estuary can have an adverse impact on the ecosystem and economy of the region. This was demonstrated by the previously described decline in oysters and again in the mid-1960s, when: the S-79 structure became operational; the Okeechobee Waterway was excavated through the estuary; and the construction of the Sanibel Causeway was completed. These actions combined to convey more colored freshwater downstream and then restrict its natural exit to the Gulf of Mexico. Soon after the causeway was constructed, the previously flourishing bay scallop (*Argopecten irradians*) industry in this region collapsed, which the U.S. Fish and Wildlife Service (1960) predicted would occur due to lower salinity. Twenty years later, the Florida Department of Natural Resources (Harris et al. 1983) reported a significant decrease in seagrass cover in deeper areas: probably at least partially caused by a decrease in light penetration related to an increased amount of colored water.

FRESHWATER INFLOW

When the magnitude of freshwater entering the estuary through S-79 from both the basin and Lake Okeechobee is evaluated for the period of record from 1966–1990, the greatest frequency of mean monthly inflows are in the 0–300 cfs range (Figure 2). The overall mean monthly inflow was in the 900–1,200 cfs range for this period of record. Since 1990, there has been an increase in the frequency of mean monthly flows in the high flow categories.

The long term (1966–1994) mean daily discharge through S-79 (from the watershed only, as well as from all sources combined) usually falls between 300 cfs and about 3,000 cfs, with lower discharge occurring during the dry season (Figure 3). There also are high and low flow periods within each of the two seasons. This is largely related to the source of the water: Lake Okeechobee accounts for only about 25% and rainfall runoff from the basin normally contributes the remaining 75% of the total discharge through S-79 during the wet season. If these percentages were constant throughout the year, then total daily discharge would be much lower in the dry season than depicted in Figure 3 (closer to the basin only trend). However, the actual percent contribution in the dry season of basin-only discharge is much less. This is due to the occasional regulatory discharges from Lake Okeechobee, which are most likely to occur during the dry season in order to lower the lake by the beginning of the hurricane (wet) season in June.

Daily and even monthly average inflow can be highly variable. To illustrate this point more clearly, Figure 4 compares daily wet season inflow in 1995 with the long term average. If 300 and 2,800 cfs are used to bracket the normal daily wet season inflow range, then flows in 1995 began below 300

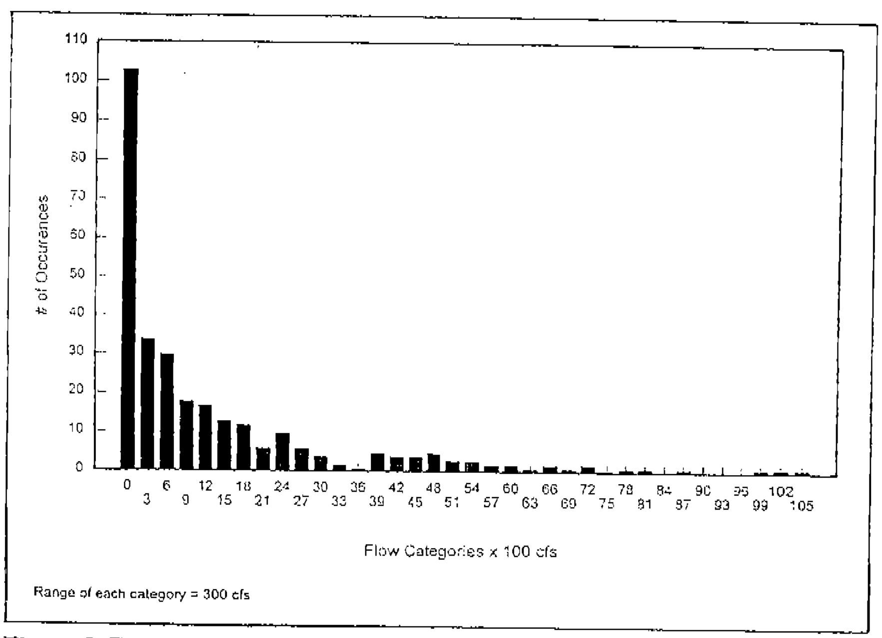

Figure 2. Frequency of mean monthly flow (cubic feet per second) from S-79 during the period 1966–1990.

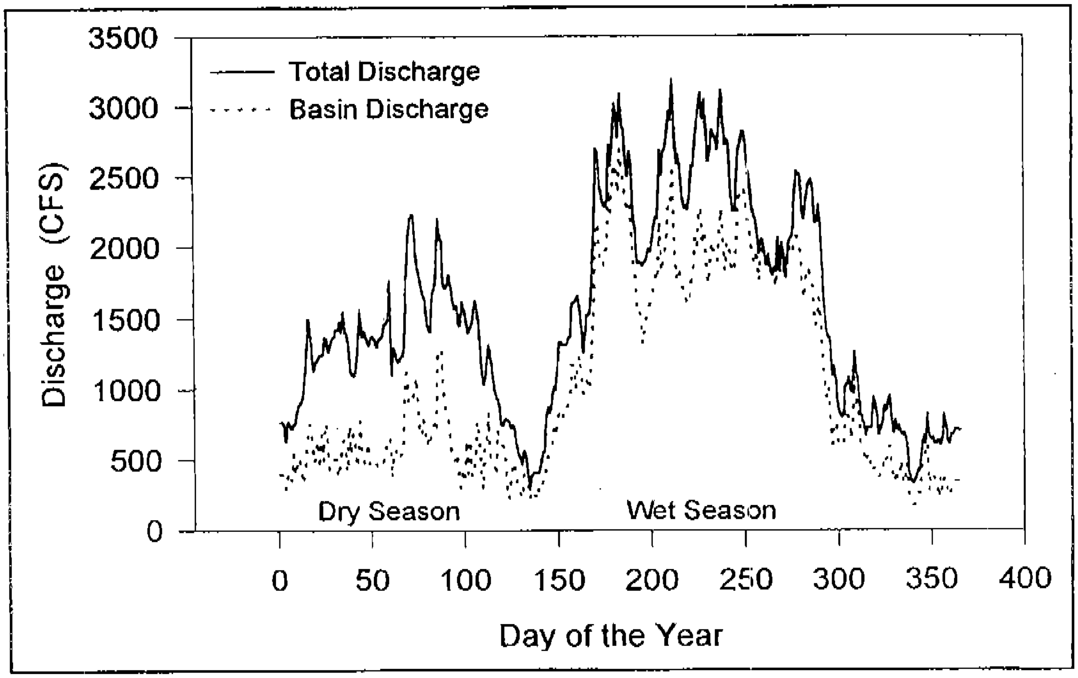

Figure 3. Average daily freshwater discharge (cubic feet per second) to the Caloosahatchee Estuary through S-79 for each day of the year during 1966–1994 (n=29 for each day). Both total (Lake Okeechobee plus basin) discharge and basin only discharge depicted. Wet season (day 121–304) and dry season (day 305–129) indicated.

cfs, bounced above 2,800 cfs several times, then remained well above normal (7,000–17,000 cfs) during the later portion of the wet season. This was largely because of uncharacteristic wet season releases from the lake. Without the lake releases, S-79 daily discharges would have returned twice to the bracketed range and some measure of normal salinity could have returned to the lower estuary.

SALINITY

Many agencies, including SFWMD, have periodically sampled salinity in the estuary. The earliest records are prior to the completion of S-79 (Phillips and Springer 1960; Gunter and Hall 1962). Most of the historical collection efforts were for a short duration, usually at least a month apart and at different locations. So, in 1992 the District installed five continuous temperature and salinity sensors along the longitudinal axis of the estuary from S-79 to the Sanibel Causeway (Figure 1b). These sensors collect data every 15 minutes at 20 and 80% of the mean water depth, then store it until retrieval via cellular telephone. The continuous data allow water managers and researchers to view salinity throughout the system at any time and for any period of time. For example, Figure 5 displays the average daily salinity from those recorders for the 1995 wet season discussed earlier. As expected, the large inflow that year and high variability in discharge resulted in major changes in salinity. This can be best seen at Shell Point where salinity declined from full strength seawater (≥35 ppt) to nearly freshwater conditions (≤5 ppt). Even farther downstream, Sanibel Causeway demonstrated a similar trend.

ECOSYSTEM RESEARCH AND MANAGEMENT

Discharge and salinity vary naturally in an estuary and exert a profound influence on the survival and distribution of estuarine organisms, especially early life stages (Pattilo

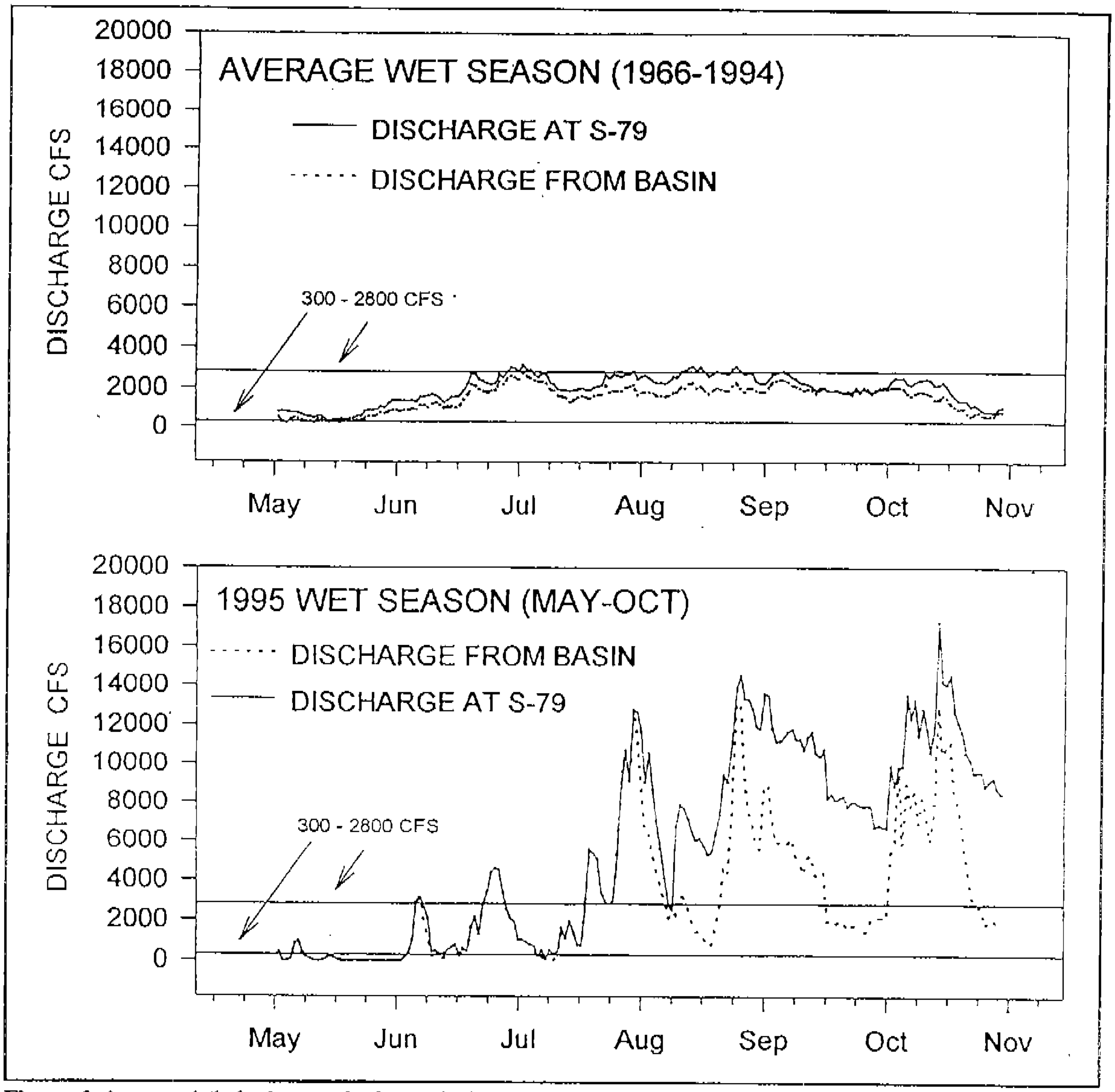

Figure 4. Average daily freshwater discharge (cubic feet per second) to the Caloosahatchee Estuary through S-79 during the average wet season (May–October)1966–1994 (n=29; top), and 1995 only (bottom). Both total (discharge at S-79: Lake Okeechobee plus the basin) and basin only discharge depicted.

et al. 1997). The importance of freshwater inflow to estuaries has been suggested to derive from: (1) the input of nutrients and organic matter for an adequate food supply; (2) protection from predation by more mature life stages that can't tolerate lower salinity or can't find prey in the naturally turbid estuarine waters; (3) the range of salinity conditions available for a variety of organisms with different requirements for growth and development; and (4) the regulation of larval transport and retention. However, excessive variation in salinity can maintain estuarine biota in a constant flux between those favoring higher salinity and those favoring lower salinity (Bulger et al. 1990). At the extreme, appropriate salinity conditions do not last long enough for organisms to complete their life cycle and the estuary can become devoid of some self-sustaining populations and communities.

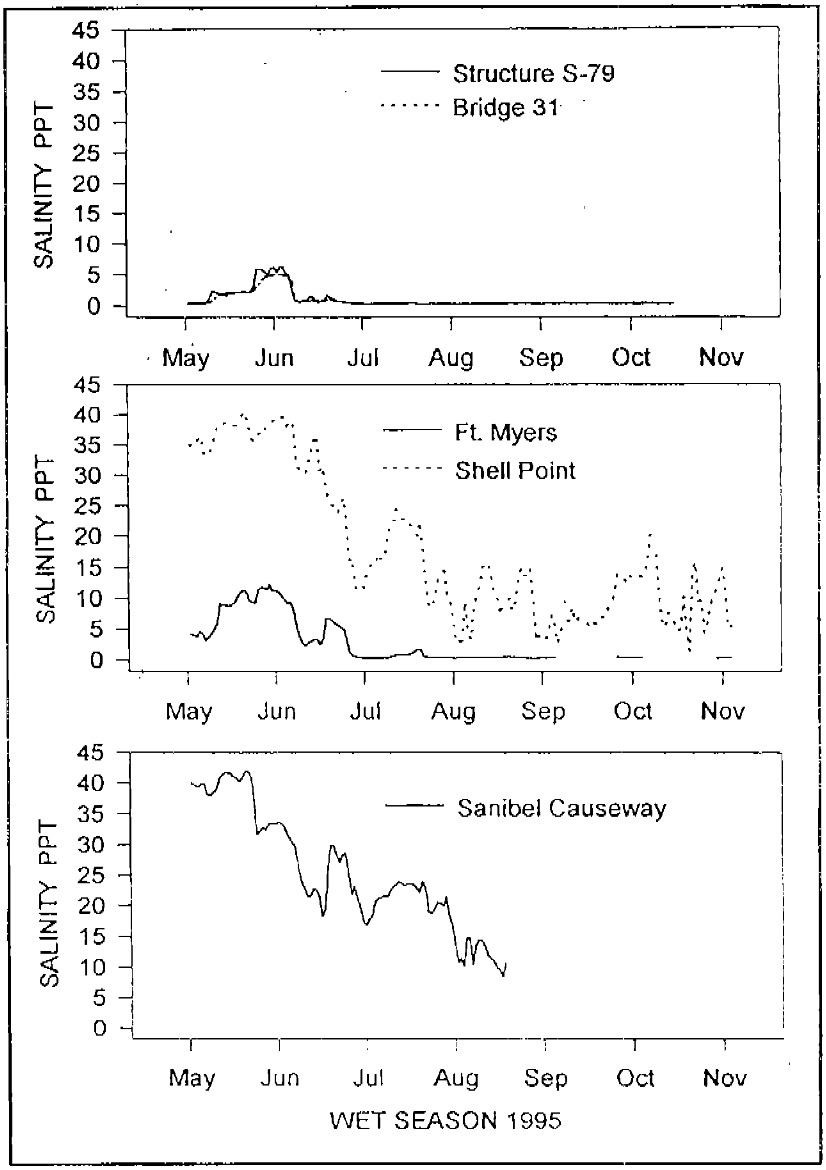

Figure 5. Salinity in the Caloosahatchee Estuary during the 1995 wet season. Data are from continuous conductivity recorders.

Proper management of water entering the estuary via the S-79 structure is the predominant requirement for a healthy Caloosahatchee Estuary, because the volume of freshwater passing through S-79 from the watershed and Lake Okeechobee overwhelms any other source. Therefore, SFWMD initiated an ongoing research program in 1985 to: (1) address impacts of basin and lake water management on the estuary; and (2) establish freshwater inflow limits and water quality targets for the estuary to guide future upriver activities.

The proper quantity will be defined by determining the optimum range of freshwater inflow that protects key biota. Key species, or valued ecosystem components, sustain ecological structure and function by providing food, living space, refuge and foraging sites for other desirable species in the estuary. Oysters and submerged aquatic vegetation (SAV), such as the seagrass and tape grass described earlier, are considered key species

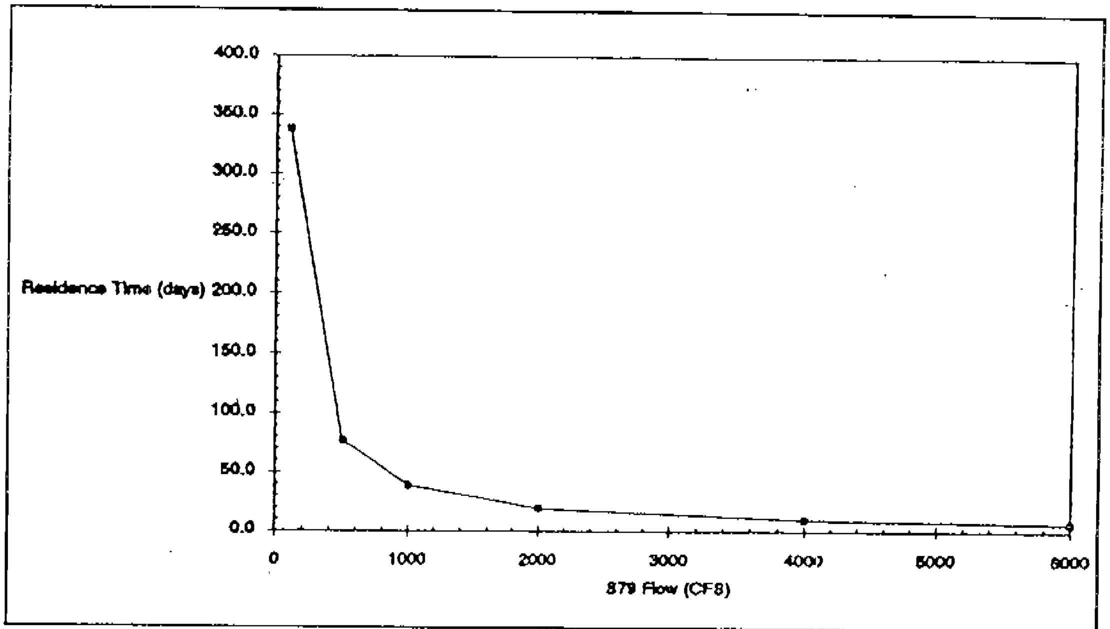

Figure 6. Hydraulic residence times: the amount of time (days) required to move a particle of water from S-79 to Shell Point due to freshwater flow from S-79 (Bierman 1993).

in the Caloosahatchee Estuary research program. Therefore, it is assumed that limits of water quantity and quality that protect and enhance oyster and SAV productivity will lead to a healthy and diverse estuarine ecosystem. Bottom invertebrates, SAV, plankton (including larval fish and algae) and water quality have been sampled during various inflows and salinity conditions since 1986 to verify this assumption and to assess impacts of basin and lake water management. More recently, field and laboratory experiments are focusing on seagrass salinity tolerances to better understand their inflow limits. In the future, development of more sophisticated mathematical models will better predict salinity and water quality at locations along the estuarine gradient based on freshwater inflows. Thereafter, biota requirements for salinity, water quality and habitat at key locations can be related to the inflows that match these requirements, based on model output, in order to determine the optimum inflow range. Finally, methods for assessing strategies and implementation success will be required. These methods will include biological monitoring, remote sensing techniques to detect change and the acquisition of instantaneous (real-time) information of environmental indicators such as salinity. This real-time information will be necessary for water managers to understand the potential environmental impact to the estuary when they consider adjusting inflows to meet water supply and flood protection requirements. Development of real-time management capability has already begun with the installation of the five continuous salinity sensors.

To date, a steady-state computational model of salinity vs. mean monthly flow has been developed by Bierman (1993). Mean monthly flow was determined as acceptable for initial evaluation because it adequately represents the approximate expected residence time for a variety of flow regimes observed in the system (Figure 6). The results of Bierman's model (1993) along with historical salinity samples have been used to plot salinity vs. distance down the estuary for a suite of selected mean monthly flow levels (Figure 7). Model output indicates the entire

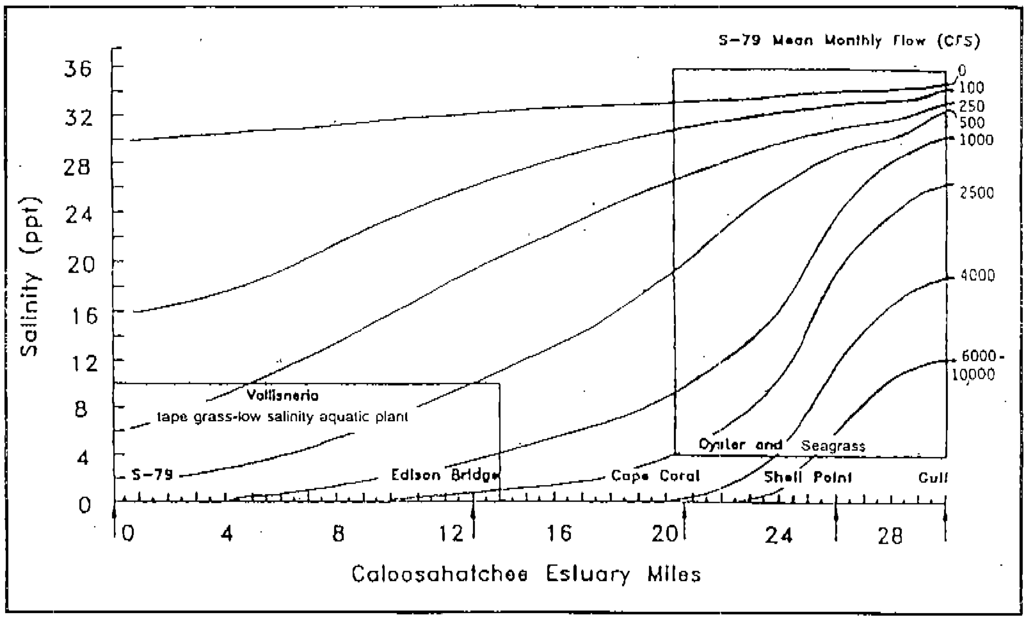

Figure 7. Projected longitudinal salinity distribution in the Caloosahatchee Estuary for selected mean monthly inflow volumes from S-79 (Bierman 1993). Literature reported tolerance limits for *Vallisneria americana*, *Halodule wrightii* and oysters indicated with estimated current spatial distribution.

range of salinity (0 to ≥35 ppt) is represented when discharge is around 500 cfs. In essence, this discharge provides a desirable salinity somewhere for all organisms. A well-represented range of salinity probably occurs up to about 1000 cfs. However, when mean monthly discharges drop below about 250 cfs for extended periods of time, salinity climbs so high that it excludes the lower salinity ranges, which can adversely affect those plants and animals that exist in the upper estuary. During the other extreme, almost the entire estuary turns to freshwater when inflows exceed 4,500 cfs. Large mean monthly flows above 4,500 cfs can physically displace a large portion of the planktonic organisms and force pelagic species to seek their required conditions downstream in possibly a less desirable area. An extended period of depressed salinity throughout the system also can cause mortality of many bottom, non-mobile species. If this kind of perturbation is frequent, then establishment of a viable estuarine community of desirable species may be impossible in many portions of the system.

The salinity tolerance of several key estuarine organisms was determined from field surveys (Chamberlain et al. 1996) and literature values. Their area of distribution in the Caloosahatchee Estuary was then overlaid on top of the salinity vs. discharge graph (Figure 7) to illustrate the District's resource-based management approach for estimating the proper freshwater inflow quantity (envelope). For example, if *V. americana* requires salinity ≤10 ppt to remain dense enough to provide habitat for other organisms (Batiuk et al. 1992, Day et al. 1989, Twilly and Barko 1990, Chamberlain et al. 1996), and if we desire to maintain it in this state down to Edison Bridge, then a minimum discharge of about 500 cfs will be needed. At the other end, if shoal grass and oysters can't tolerate salinity below about 4 ppt for an extended time (McMahan 1968, Cake 1983), and it is desired to continue having them viably distributed up to the Cape Coral Bridge area, then the maximum mean monthly discharge should not exceed about 2,500 cfs.

This represents a simplification of the

approach, but serves to communicate the concept, which is the basis for the SFWMD research. The biological effects from freshwater input are felt directly (salinity) and indirectly (e.g. pulses of nutrients and organic material). To reduce uncertainty, the final target limits for the key species and other biota sampled will consider both types of impacts. Further analysis of monitoring efforts, and completion of experimental research, will lead to more sophisticated predictive models (SFWMD 1995).

ACKNOWLEDGMENTS

This manuscript was based on the general guidelines for estuarine research and management developed by Mote Marine Laboratory for the SFWMD. Application of their resource-based strategy to the Caloosahatchee was influenced by conversations with District staff, especially Dan Haunert, Al Steinman and Nick Aumen. The actual field work and data analysis, which provided the necessary support information, depended on the efforts of many SFWMD staff, most notably Dan Crean and Kathy Haunert.

LITERATURE CITED

Batiuk, R., R. Orth, K. Moore, W. Dennison, J. Stevenson, L. Staver, V. Carter, N. Rybicki, R. Hickman, S. Kollar, S. Bieber and P: Heasly. 1992. Chesapeake Bay submerged aquatic vegetation habitat requirements and restoration targets: a technical synthesis. USEPA, Chesapeake Bay Program, Annapolis, Md. 186 pp.

Bierman, V. 1993. Performance report for the Caloosahatchee Estuary salinity modeling. SFWMD expert assistance contract deliverable. Limno-Tech, Inc.

Bulger, A.J, B.P. Hayden, M.G. McCormick-Ray, M.E. Monaco and D.M. Nelson. 1990. A proposed estuarine classification: analysis of species salinity ranges. ELMR Report No. 5, Strategic Assessment Branch, NOS/NOAA. Rockville, Md. 28 pp.

Cake, F.W., Jr. 1983. Habitat suitability index models: Gulf of Mexico oyster. FWS/OBS-82/10.57. 37 pp.

Chamberlain, R.H., D.H. Haunert, P.H. Doering, K.M. Haunert, J.M. Otero and A.D Steinman. 1996. Preliminary estimate of optimum freshwater inflow to the Caloosahatchee Estuary, Florida. SFWMD draft manuscript.

Day, J.W., C.A.S. Hall, W.M. Kemp and A. Yanez-Arancibia. 1989. Estuary Ecology. John Wiley and Sons, Inc. 558 pp.

Goodwin, C.R. 1996. Simulation of the tidal-flow, circulation, and flushing characteristics of the Charlotte Harbor estuarine system, Florida. USGS Water-Resources Investigations Report 93-4153, 92 pp.

Gunter, G. and G.E. Hall. 1962. Biological investigation of the Caloosahatchee Estuary in connection with Lake Okeechobee discharges through the Caloosahatchee River. Consultant Report to the U. S. Corps of Engineers, Ser. No. 25, 59 pp.

Harris, B.A., K.D. Haddad, K.A. Steidinger and J.A. Huff. 1983. Assessment of fisheries habitat: Charlotte Harbor and Lake Worth, Florida. Florida Department of Natural Resources, Bur. of Marine Research, St. Petersburg, Fla. 211 pp.

Hoffacker, V.A. 1994. Caloosahatchee River submerged grass observations during 1993. W. Dexter Bender and Associates, Inc. Letter-report and map to Chip Meriam, SFWMD.

McMahan, C.A. 1968. Biomass and salinity tolerance of shoal grass and manatee grass in Lower Laguna Madre, Texas. J. Wildl. Manage. 33:501–506

Pattilo, M., L.P. Rozas and R.J. Zimmerman. 1997. A review of salinity requirements for selected invertebrates and fishes of U.S. Gulf of Mexico estuaries. Final Report of NMFS to the EPA, Gulf of Mexico Program.

Phillips, R.C. and V. G. Springer. 1960. A Report on the hydrography, marine plants, and fishes of the Caloosahatchee River area, Lee County, Florida. Fla. State Bd. Consev. Marine Lab. Special Science Report No. 5. 34 pp.

Sackett, J.W. 1888. Survey of Caloosahatchee River, Florida. Report to the Captain of the U.S. Engineering Office, St. Augustine, Fla.

Scarlatos, P.D. 1988. Caloosahatchee Estuary hydrodynamics. SFWMD Technical Publication No. 88-7. 39 pp.

South Florida Water Management District. 1995. Estuary research plan for the St. Lucie, Loxahatchee, Caloosahatchee and Indian River Lagoon. Okeechobee Systems Research Division, Ecosystem Restoration Department, 26 pp.

Twilly, R.R and J.W. Barko. 1990. The growth of submerged macrophytes under experimental salinity and light conditions. Estuaries 13:311–321.

U.S. Fish and Wildlife Service. 1960. Review of Board of Lee County Commissioners application for Department of the Army permit (Bridges 1057). *In*: E. Estevez, J. Miller and J. Morris. 1981. A review of scientific information Charlotte Harbor estuarine ecosystem complex and the Peace River. Mote Marine Laboratory, Sarasota, Fla.