National Park Service
U.S. Department of the Interior

South Florida Natural Resources Center
Everglades National Park

RESOURCE EVALUATION REPORT

SFNRC Technical Series 2008:2

Estimates of Flows to Meet Salinity Targets for Western Biscayne National Park

Estimates of Flows to meet Salinity Targets for Western Biscayne National Park

June, 2008

Department of the Interior

EXECUTIVE SUMMARY

This paper uses several methods to estimate the flow volume of freshwater needed to reach salinity targets in Biscayne National Park. The salinity targets were developed previously, based on a determination of desired ecological conditions in a seagrass-dominated area of 10,000 acres in the western Bay zone of Biscayne National Park (DOI Discussion Paper April 2006). The seasonally-based salinity targets are: less than 30 ppt from November through March, from 15 to 25 ppt from March through August, and less than 20 ppt from September through October.

Analytical and empirical methods were applied to arrive at estimates of the flows necessary to reach these target salinities. It was determined that approximately 960,000 acre-feet/year of freshwater flows would be required to meet the salinity targets described above in the 10,000 acre area of seagrass habitat. In the absence of adequate circulation models to provide greater detail, an analysis of seasonal targets was done at a basic level: about 37 K acre-ft per month is needed during the dry season, and 149 K acre-ft per month in the wet season.

Recent time series of flows into Biscayne Bay were analyzed. A time-series comparison of the target with the existing flows showed that some transient peak-flow freshwater deliveries met or exceeded the targets. It is, however, apparent that the stable estuarine conditions desired in Biscayne Bay are not achieved by current freshwater inflows, both because the total volume is too little and because the timing and distribution are too unnatural. The restoration of natural timing of flows could produce stable estuarine conditions, but without an increase in the volume of water available, the salinity targets cannot be achieved throughout the year. Increasing the total volume of flows, and in particular providing adequate flows throughout the dry season, would provide significant benefits to the ecological system in Biscayne National Park.

INTRODUCTION

In the discussion paper, entitled "Ecological Targets for Western Biscayne National Park" (April 2006), the Department of the Interior presented descriptive and quantitative ecological targets in the estuarine zone based on biological communities in Biscayne National Park. Two key elements of the ecological targets paper are pertinent to the development of hydrologic targets for Biscayne National Park.

Element 1: Target Area

There are many possibilities for a target area for restoration within Biscayne Bay and Biscayne National Park. The Southern Estuaries team from the Comprehensive Everglades Restoration Plan's (CERP) Restoration Coordination and Verification (RECOVER) committee developed salinity performance measures for Biscayne Bay (see www.evergladesplan.org) that proposed and defined such an area. These performance measures suggested a nearshore target area that reached 250m from the coastline during the dry season, and 500m from the shoreline during the wet season (Figure 1.) This target area is appropriate for some important ecological functions in the estuarine zone. However, the 250/500m nearshore bands do not take into consideration all available information about the current and historical geomorphology of the Bay which help define the extent of the estuarine zone in Biscayne National Park.

For the current analysis, maps of substrate type in the Bay were examined, as were maps of the current distribution of seagrasses within the Park. Substrate type is a good indicator of the both the historical and the future bottom community: areas that are currently hardbottom are more likely to have supported hardbottom communities such as soft corals and sponges, whereas areas that are covered with soft sediment are an indication of the presence of seagrasses in the past.

Examination of this information revealed an area of 10,000 acres in the Western Bay which shows evidence of the influence of significant freshwater flow, and which has supported productive estuarine seagrass communities in the past. Anecdotal and paleoecological evidence indicates that this 10,000 Western Bay Zone is probably significantly smaller than the estuarine area that was affected by freshwater flows in the historical past (Wingard et al., 2004). However, the re-establishment of stable estuarine conditions in the 10,000 acre Western Bay Zone would provide significant restoration of the natural values of Biscayne National Park.

Additional information and maps of the geographic areas of the Bay referenced in this document can be found in the April 2006 document.

Element 2: Desired Ecological Conditions for the Western Bay Zone of Biscayne National Park

The desired condition for the Western Bay Zone of Biscayne National Park is defined as a range of salinities that is consistently estuarine for support of a productive, diverse benthic community based on seagrass. These environmental conditions also support Federally-listed endangered species, such as the American crocodile (*Crocodylus acutus*) and West Indian manatee (*Trichechus manatus*), and create productive nursery habitat that sustains local and regional (e.g. Florida Keys) fishery resources. Species which would be supported under these conditions include gamefish such as the spotted seatrout (*Cynoscion nebulosus*), forage fish such as mojarras (*Eucinostomus spp.*), and mollusks like the Eastern oyster *(Crassostrea virginica).* The decline during the last several decades of the abundance of these species, as well as the increased presence of marine species such as bonefish (*Albula vulpes*) and permit (*Trachinotus falcatus*), in the Western Bay Zone is thought to be due to the loss of sufficient extent and stability of estuarine conditions.

A more detailed description of desired ecological conditions can be found in the April 2006 Discussion paper cited above, or in SFNRC Technical Report 2006 (1). It should be emphasized that the desired ecological and salinity conditions described for the western Bay zone of Biscayne National Park are not equivalent to pre-drainage conditions. Rather, the pre-drainage estuarine area is likely to have extended farther east, where submerged aquatic vegetation and soft bottom substrate can still be found as far out as Featherbed Bank (Figure 1).

The current discussion paper utilizes several methods to estimate the freshwater flows needed to achieve the desired salinity targets and produce stable estuarine conditions over the 10,000 acre Western Bay Zone of Biscayne National Park.

HYDROLOGIC TARGETS FOR BISCAYNE NATIONAL PARK

Two pragmatic metrics exist for the physical conditions needed to reach the target ecological conditions for Biscayne National Park: 1) measurement of salinities in the estuarine zone and 2) quantification of the flows themselves through the coastal structures.

Though quantification of flows is easily attained, how these flows influence the salinity distributions throughout the Western Bay Zone (WBZ) is a complex physical question that depends on currents, winds, vertical and horizontal shear, insolation, tidal exchange, and mixing rates, among other variables. The coastal freshwater flows to Biscayne Bay are almost entirely managed and are a calculated parameter in current water management planning tools. We explored the link between these managed freshwater flows and the salinity in the WBZ using a variety of estimations.

Salinity

In several ways, salinity is the best metric to use as a base for the calculation of flows needed to produce the target ecological conditions. Evidence of the requirements of a number of species presented demonstrates that salinity is a key habitat factor for the bay ecosystem.

Figure 2 summarizes the optimal salinity ranges for Biscayne National Park ecosystem indicators, including primary producers, primary consumers, and predators. While these estuarine species can survive at least for short periods in a wide range of salinities, the majority of these indicator species prefer salinities between 5 and 20 ppt for growth and reproduction. Based on this observation and taking into account that other species (such as seatrout and oysters) may require periods of time with slightly higher or lower salinities, we propose the following salinity targets to achieve the ecological goals for the WBZ of Biscayne National Park:

- From November through March (early dry season to late dry season), average daily salinities should not exceed 30 ppt. It is particularly critical to measure and track salinities during this time period in order to determine the spatial pattern of estuarine and marine conditions within the Western Bay Zone. Current salinities in the Park frequently exceed 30 ppt in much of the Western Bay Zone during this time period (Biscayne National Park, 2006). Re-establishment of salinities under 30 ppt would create conditions important to the recovery of important fishery species with life-cycles that require estuarine conditions:
    - recreational and commercial fish species that rely on the forage fish for prey, such as adult sea trout, as well as snapper and grouper species
    - forage species (mojarras, pinfish), post-larval juvenile shrimp, and oysters, which rely on brackish water as a refuge from marine predators.
- From March through August (late dry season - early wet season), average daily salinities should range between 15-25 ppt. This would allow recovery of:
    - key spawning habitat for sea trout, adult habitat for forage species (mojarras, silver perch)
    - a healthy, productive, and diverse seagrass community that can be sustained in a zone that is subject to freshwater runoff
    - an extensive brackish water refuge from marine predators. Seagrass cover is a required feature of nursery habitat for important juvenile fish species.

- From September through October (late wet season), daily salinities should average less than 20 ppt. Creation of these conditions would provide:
  - a benefit to juvenile crocodiles that have a stringent physiological requirement for low salinity conditions.
  - conditions that promote the recovery of important forage fish species in coastal mangroves that do best at oligohaline to mesohaline conditions (such as sheepshead minnow, gold-spotted killifish).
  - indirect benefits to all upper trophic level species that consume these forage fish in the mangrove zone, including wading birds, mammals, and crocodiles.

There are considerations other than the average daily salinities which are important ecologically. The salinity changes should be gradual and reflect changes in hydropattern that approximate a natural system. All vegetation, fish, and invertebrate species benefit from gradual changes in salinity that avoid physiological stress. The salinity gradient should extend away from the coastline, from lowest salinities nearest the coast to higher salinities towards the sea.
And perhaps most importantly in an estuary:

- at no time should daily average salinities exceed 30 ppt.

This threshold defines estuarine conditions, as compared to marine conditions, and so is a bare minimum requirement. Exceeding the threshold of 30 ppt in the Western Bay Zone results in environmental conditions that negatively affect all of the Park's estuarine resources at some point in their lifecycle.

From Salinity Metrics to Estimates of Freshwater Target Flows

Salinity provides a dynamic link between the biological and physical coastal environments because it is an accurate and integral measure of the net results of the total freshwater inputs, mixing rate of marine and freshwater flows, wind mixing, net evaporative losses, and amount of tidal exchange. The freshwater inflows needed for maintenance of ecologically-required target salinities can be calculated in a number of ways. Ideally, a computer-based simulation that provides estimates of the spatial and temporal salinity distributions under various conditions would be used to arrive at estimates of freshwater flows to meet spatially-dependent salinity targets. A verified hydrodynamic model of Biscayne Bay that is forced by observed atmospheric and marine inputs and that is coupled with a hydrologic model to provide surface water and groundwater inputs would be such a tool. Though tools like this are currently under development, at this date an operational tool is not yet available. Therefore, we used several alternative approaches, including statistical models, dynamic box models, other modeling studies, and static volumetric estimation based on analytic estimates of water budgets and the balance of advective/diffusive processes. These different methods provide a range of freshwater flow quantities within the WBZ given the salinity targets described above. The limitations and advantages of each are discussed and reasonable approximations of freshwater flow quantity are provided.

Spatial Distribution and Timing: Much of the available information on flow is based on current canal discharges, which do not mimic natural conditions either in spatial distribution or in timing. The analyses of required volumes of water included here assume the current distribution system, where the freshwater reaching Biscayne Bay is delivered via canals (through structures S-22, S-123, S-21, S-21A, S-20G, S-20F, S-20, and S-197). The current distribution system is less than optimal for achieving estuarine salinities in the nearshore area of the Bay, because much of the freshwater is transported from these point-source discharges via plumes that bypass the WBZ and are transported offshore to the marine environment. The optimal distribution system to target the WBZ would be that which existed in the pre-drainage past: a large volume of surface water elevated inland behind the coastal ridge which induces a large, broad groundwater seep into the marsh all along the coastline, with surface waters entering into the bay via many dozens of small creeks. This type of distribution system is ideal since it delivers fresh water to the WBZ in a highly efficient manner, resulting in a larger impact on nearshore salinities for the same volume of water than would be provided by a series of large point-source discharges.

The desired persistent salinity gradient oriented parallel to the coastline can be most economically maintained by the steady flow of waters away from the coast and all along the coastline, as would be provided by a coastal freshwater/brackish marsh such as the historic coastal wetlands of BISC (this phenomenon is explained more fully in Appendix A). An approximately constant freshwater flux is likewise desired at the historic river and creek mouths in order to maintain the estuarine salinity targets and avoid ecological damage that is similarly caused by cessation of flows or large pulses of freshwaters. Under current conditions, pulsed discharges of large volumes of freshwater are typical following large rain events and often result in locally low salinities near canal discharge points. The desired spatial and temporal distributions apply to all of the target flows derived in this section.

Flow Volume:

Until sufficient results are compiled from the desired hydrological models, which are coupled to a range of inflow conditions, some alternate performance measures and targets can be developed to estimate flow volumes that produce target salinity values. We examine five different methods to estimate flow volumes: 1) RECOVER Southern Estuaries sub-team performance measures, 2) Advection-Diffusion estimates, 3) Hypersalinity prevention estimate, 4) TABS-MDW hydrodynamic model estimate, and 5) Volumetric estimate. The RECOVER performance measures are currently accepted for use in the design of CERP projects: the additional estimates examined here provide information to test the utility of and/or potentially modify the RECOVER targets. Estimates 2) and 3) are rough estimates of target flows across wet and dry seasons, gleaned from simple calculations of the flows required to maintain a persistent salinity gradient parallel to the coastline, and no periods of hypersaline conditions. These two estimates are minimal targets, but they must be achieved first in order to reach other, more voluminous, desired restoration target flows. The flows needed to achieve the restoration targets are calculated in 4) an analytical estimate, and 5) a more refined, seasonally-varying volumetric estimate driven by ecosystem requirements that parameterizes the mixing and flow in the bay in order to arrive at more robust target flows.

1) RECOVER Target Estimates. There are a number of RECOVER performance measures that apply to specific areas of Biscayne Bay for which flow or salinity targets have been developed by the Southern Estuaries sub-team, and are currently in use as targets for CERP projects. For the purpose of estimating target flows for Central to Southern Biscayne Bay, the current Southern Estuaries Salinity Performance Measure (PM) is applicable. This PM specifies a persistent salinity gradient parallel to the southern coast of Biscayne Bay at 250 m (dry season) and 500 m (wet) from shore by meeting oligohaline to mesohaline nearshore targets, and it was estimated by Meeder et al. (2002) that about 65 K acre-ft/month in the wet season and 21 K acre-ft/month in the dry season (470 K acre-ft/yr) are required to meet these salinity requirements. Alleman (2003) arrived at a similar figure of 40 K acre-ft/month in the wet season and 23 K acre-ft/month in the dry season (325 K acre-ft/yr) for the RECOVER PM targets from a historical data analysis, which lends support to the range of this estimate. In addition, the Southern Estuaries Salinity PM stipulates persistent flows of 1.25 K acre-ft/month (15 K acre-ft/yr) out of Snapper Creek and into Central Bay to maintain the ecosystem found at the creek mouth. Thus the RECOVER total for these target flows for South Bay and nearby waters is 66 K acre-ft/month for the wet season and 22 K acre-ft/month in the dry season, for a total volume of 485 K acre-ft/yr. Note that estimates of flows needed to reach estuarine salinity targets for the 10,000 acre WBZ will be much greater because it is 5,800 acres larger than the area used in the RECOVER performance measure for southern Biscayne Bay.

2) *Advection Diffusion Estimate.* Due to urban coastal development, the only area in which CERP projects could restore coastal marsh conditions and natural spatial distribution of flow to the park is from Deering Estate to Mangrove Point. If water could be distributed all along the 26 km of park coastline at a steady rate under the aforementioned optimal distribution system, a one-dimensional advection versus diffusion approach would be applicable. As developed in Appendix A, a persistent salinity gradient can be maintained by balancing the advection of freshwater flows away from the coast with the diffusion of salt from the marine waters offshore towards the fresher waters inshore. Given these assumptions, it is found that a sufficient net seaward flow to overcome shoreward diffusive effects all along the park shoreline is over 60 K acre-ft/month, regardless of season, or 800 K acre-ft/yr.

Other estimates of required volumes to reach target conditions have been developed independently as well. To just meet the 250 m- and 500 m-from-shoreline salinity requirements put forth by RECOVER, another advection versus diffusion estimate was developed by Downer, Klochak and Mullins (2005), and Nuttle and Downer (personal comm.). They used long-term averages of modern salinities measured at several points at different distances from the coast in Biscayne National Park and an assumed logarithmic shape of the seaward salinity gradient to arrive at an effective diffusivity of 12 m^2/s. In light of this relatively high rate of mixing, to maintain just the 250 m/500 m salinity targets they estimated between 60-117 K acre-ft/month (700 – 1,400 K acre-ft/yr) of freshwater needed to be provided along the coastline through the marshes between Shoal and Turkey Points. Since the area considered for this exercise was confined to the nearshore zone, the estimate for the full 10,000 acres would likely be much higher still.

3) Hypersalinity Prevention Estimate. Another type of rough estimate may be developed by considering the volumes required to prevent hypersalinity in the bay. The estimated flow needed to avoid reaching the hypersalinity threshold gives a lower bound on the amount of freshwater needed to maintain living natural resources characteristic of any current areas of the Bay, and provides a context for the estimates of the flows required to reach restoration goals.

The net water budget is,

$$dV/dt = P - E - FW_{in} + GW_{in} - GW_{out} + SW_{in} + SW_{out}$$

where V is the total volume of the coastal basin, P is precipitation, E is evaporation, FW is fresh surface water, and GW is the groundwater volume. The net seawater volume, SW_{in} - SW_{out}, over several tidal periods will be small except when there are significant freshwater inputs or outputs, since any excess of freshwater will be moved to sea, and any evaporation-induced deficit of estuarine water within the bay will be replaced by seawater if no surface or groundwater is available. A deficit of water induced by any excess of evaporation over precipitation (P-E < 0) can be replaced by seawater which will drive the salinities even higher by adding more salt to the bay, or by freshwater flows which will maintain or lower the salinity.

The outcome of this dynamic process depends largely upon the efficiency with which the tides move seawater into the bay, mix with the bay waters, and export this mixed water back to sea. Biscayne Bay is a semi-enclosed shallow basin with an average depth of about 10 ft and an area of 141,000 acres. All exchange with ocean water is limited to certain areas (Safety Valve, Government Cut, Baker's Haulover Cut, Norris Cut, Bear Cut, and the ABC Creeks), with the 9 km opening at Safety Valve by far the largest source of ocean waters (Wang et al. 2003). The tidal mixing in Biscayne Bay is generally efficient, with a tidal prism (inter-tidal volume) of about 250 K acre-ft – this means that, in theory, the entire volume of the bay could be exchanged with only six tidal cycles (three days). In practice the less-voluminous North Bay is even more easily flushed by virtue of the many cuts opened to the Atlantic, while South Bay is not flushed as easily, with exchange restricted by the three narrow ABC Creeks to the east and at the northern end by the shallow Featherbed Banks that stretch into mid-bay perpendicular to the long axis to the bay. Consequently, South Bay frequently has been frequently been observed to be hypersaline in recent years while North Bay has not experienced hypersalinity periods.

Even with a large annual rainfall, there is a net annual loss of water to evaporation for Biscayne Bay. Considering the entire Bay as a whole, the estimated mean evaporation rate of 1.66 m/yr (Royal Palm measurements) contrasts with 1.27 m/yr (Mowry Canal, chosen for its proximity to the bay) of precipitation, giving a net evaporative loss estimate of about 180 K acre-ft per year over the 141,000 acres, or about 1.25 ft per acre. Though these E and P estimates are highly variable and not equally applicable to all areas of the bay, it clearly illustrates the importance of the distribution of flows, and the different exchange rates at work in Biscayne Bay. With an evaporative loss of only 16% of the bay's total volume, a total average freshwater input of 92 K acre-ft/month (1,100 K acre-ft/yr) from canals would at first glance seem more than sufficient to protect against hypersalinity. However, parts of South Bay now routinely become hypersaline, which indicates that the 1,100 K acre-feet/yr is not distributed adequately in time and space. To compound matters, groundwater levels in the Biscayne Coastal Wetlands are maintained at artificially low stages to provide flood protection in the urban area, and are even further reduced entering into the dry season to benefit agricultural interests – such practices ensure that freshwater flows to the bay via groundwater are minimized.

For South Bay alone on an annual basis, at least 125 K acre-ft/yr would, therefore, be required to offset the evaporative net loss of freshwaters and prevent hypersalinity. Most of this water, at a rate of about 16 K acre-ft/month, is required during the dry season when precipitation is scarce. During these periods, with no rainfall or canal discharges available, net salinity increases in coastal waters have been observed in excess of 0.15 ppt per day. These estimates of freshwater flows would prevent hypersaline conditions, but would not reach target restoration salinities.

4) TABS-MDS Hydrodynamic Model Estimate. The use of a hydrodynamic model for Biscayne Bay to estimate the necessary freshwater flows is advantageous since it can incorporate explicitly the impact of tidal exchange, mixing, bathymetry, and coastal currents as well as freshwater flows on the nearshore salinities at different points in the Bay. A 3-D version of the TABS-MDS (RMA10; see Brown, et al., 2003) hydrodynamic model for central and southern Biscayne Bay was recently used by Alleman and Parrish (2005) to calculate the volume of water necessary to reach the paleo-salinities estimated by Wingard, et al., (2004) from cores taken at three sites between Shoal Point and Turkey Point, two of which are within the proposed 10,000 acre target zone. The freshwater input distribution from the Natural System Model (NSM462) was increased until the modeled freshwater volumes for the years 1965-2000 produced salinities at these sites that were largely within the range of their circa-1900 salinities *(*Black Point, 5-18ppt; Featherbed, 25-35ppt; No Name Bank 18-30ppt). Parrish and Alleman concluded that the total (surface and ground) freshwater flow rate under such a 'natural' distribution necessary to maintain these salinities at these sites in South Bay was approximately 1,500 cfs. This instantaneous rate equates to about 91 K acre-ft per month to South Bay, or 1,100 K acre-ft/yr.

5) Volumetric Estimate. These estimates can be contrasted with a simple volumetric estimate of the freshwater flux needed to maintain a constant salinity (in the absence of wind mixing), which could be estimated by:

$$F = (\text{Area} * \text{Depth}) * (S_m - S_t)/S_m * X$$

where the product of Area and Depth is the volume of the target location, S_m is the marine salinity, S_t is the target salinity, and X is the tidal exchange factor. Geometries and the desired conditions determine all parameters except for the tidal exchange factor. Though the tidal exchange factor will be variable with space (both on/offshore as a function of distance from tidal inlets, and along the bay axis due to bathymetric variations) and even time (spring/neap tides, seasonal sea level fluctuations), a conservative estimate of 15% daily water exchange for nearshore conditions may be sufficiently representative of mean conditions in Biscayne National Park. Lee and Rooth (1976) estimated the residence time in southern Biscayne Bay during the summer months to be on the order of a week; if it would take seven days for a parcel of water to be exchanged, that would mean about 1/7 of the volume there (15%) is exchanged daily, neglecting mixing efficiency. In reality, the tidal mixing factor will be a function of the distance to the openings to the ocean, the rate of wind-induced mixing, and the distance from local embayments and shoals which restrict exchange. In contrast to the weekly residence time scale in Biscayne National Park, residence times in Northern Biscayne Bay are typically a few days (about 33% exchange daily), and may be as long as many months in Card and Barnes Sound at the extreme south end of the bay (<1% of waters exchanged daily by the tides).

A first volumetric estimate is based on RECOVER's wet/dry seasonally-variable salinity targets within Biscayne National Park, with 1600 acres within the 250 m zone at 5ppt/15ppt and 1600 acres within its 250-to-500 m zone at 10ppt/20ppt, and an average depth of 1.5 ft and 3.0 ft, respectively. When applied seasonally in the equation above these figures produce dry season estimates of a 16 K acre-ft/month, and a wet season estimate of 25 K acre-ft/month, for a total annual target flow of 244 K acre-ft/yr, given the daily mixing rate for the area of 15%. Since the volume estimate is directly proportional to the mixing rate, it is very sensitive to its value. To demonstrate the sensitivity of this estimate to the size of the mixing rate; if the estimate was increased to 20% the resulting flows would be approximately 20 K acre-ft and 33 K acre-ft per month for dry and wet seasons, with an annual total of 325 K acre-ft/yr for the limited 3200 acre area.

The second volumetric estimate presented here is based on the larger area of 10,000 acres of SAV habitat that are found in the WBZ, which we believe is a preferable target to the 250m/500 m salinity targets since it is representative of the geomorphic underpinnings and the ecological potential of the Bay, not just the distance from the shoreline. A similar application of the volumetric estimate to the aforementioned wet season/dry season salinity targets of 20 ppt/30 ppt (using 20 ppt as the mean of the 15-25 ppt range for the late wet season) over the 10,000 acres of grass beds included with the same 15% net tidal exchange provides a dry season estimate of 37 K acre-ft/month and a wet season estimate of 110 K acre-ft/month. Integrated over a year, the

10,000 acre are therefore requires a net total of about 960 K acre-ft/yr to meet the salinity targets outlined previously.

This second volumetric measurement also provides a means of estimating the amount of freshwater flow necessary to just maintain estuarine conditions, <30 ppt, throughout the year. Assuming at least an adequate dry season flow volume for 12 months, the volume to prevent marine conditions from dominating in the WBZ is estimated to be 440 K acre-ft per year.

Summary of Freshwater Flow Targets

These rough estimates of target flows have produced a range of values (Table 1) that encompass either the smaller RECOVER target area or the larger 10,000 acre target. The diffusive-process-based estimates span the range from 60 to 120 K acre-ft/month, but are sensitive to the magnitude of the effective diffusivities used. As a lower bound on the problem, it was shown that approximately 16 K acre-ft/month are required just to offset evaporation and avoid hypersaline conditions in the bay, so the actual target flows should be well in excess of that. The volumetric estimates arrived at an estimate of 37 K acre-ft/month in the dry season and 110 K acre-ft/month in the wet season for the full 10,000 acre target area. This is consistent with other estimates and is supported by estimates of the flows in the much smaller 3,200 acre target area (22 K acre-ft / 66 K acre-ft per month in the dry/wet season) required to meet a similar salinity requirement. The dry season monthly estimate of 37 K acre-ft/month also represents the flow required to simply maintain estuarine conditions. The fourth column of Table 1 provides the annual quantity of water per acre calculated to meet salinity targets, further demonstrating the consistency of the estimates. Thus the 37 K acre-ft / 110 K acre-ft per month flow targets represent a reasonable estimate of the required dry/wet season freshwater flows to meet ecological targets in the 10,000 acres area and will be adopted as the standard estimate, at least until such time that subsequent analyses are available that more properly take into account the dynamic nature of the flows within Biscayne Bay.

	Estimates Average annual flow columes (K ac-ft per year)	Target Area (acres)	Estimated flow volume per unit area (ac-ft per acre of habitat)	Notes
RECOVER	325	3200	102	The estimate provides flows for RECOVER 250/500m region and utilizes the limitd salinity observations available in the WBZ; Alleman (2003)
RECOVER	475	3200	148	Provides flows for 250/500m targets area; Meeder et al. (2002)
Hypersalinity prevention	125	NA	NA	Prevents hypersalinity in the Bay but does no attempt to satisfy salinity targets
Advection-Diffusion	800-1,400	3200	250-438	Based on a range of diffusivities (A=1 m2/s to A=12 m2/s) applied using an advection-dispersion relation and applied to the RECOVER 250/500m target area
Hydrodynamic Model	1090	~10,000	109	Uses TABS-MDS model to calculate flows need to achieve ca. 1900 paleo-salinity targes from Wingard et al. (2004); Alleman (2005)
Volumetric	960	10,000	96	Provides flows for 10,000 ac WBZ using an effective tidal mixing of 15%

Table 1. Estimates of the average annual flow volumes required to enter Biscayne Bay between the S-22 and S-197 structures in order to reach the salinity ranges that support the biological targets.

Estimation of Current Flows

The hydrologic pattern in Biscayne National Park has been altered by regional drainage, canal construction and operation, and urban development, as well as construction of roads, levees, and other hydrologic barriers to surface flow. The bay currently receives freshwater inflow almost entirely as surface water in the form of canal flows, with only minor overland flow and very little groundwater flow.

Groundwater. When there are no surface flows or rainfall available, groundwater is the only possible source of freshwaters and is vital to counteract the onset of hypersaline conditions. Although the contribution of groundwater to total flows may have been quite large during pre-drainage conditions as anecdotal evidence suggests (Kohout and Kolipinski 1967), studies show that the modern fresh groundwater inputs into Biscayne Bay are very small (<10% of the surface flows; Langevin 2001). In addition, the saltwater intrusion line in south Florida has been stable or has encroached further inland over the past two decades (Sonenshein 1995) despite efforts to protect the water supply from saltwater intrusion, and hypersaline conditions are commonplace during droughts. Both of these observations support the understanding that groundwater flow to

Biscayne Bay is limited under current conditions. Because of the relatively small contribution groundwater makes to the total water budget and the limited availability of observed data, groundwater flows were not accounted for in this analysis. However, because of the importance of groundwater flow during the dry season and in drought conditions, these flows could be included in the estimates of mean annual water volume if a reliable means for quantifying the groundwater flows to the bay existed. Work underway to estimate groundwater flows may provide additional information for estimating comprehensive flow volumes in future analyses.

Surface Water. Canal flow estimates are derived from the head and tail water elevations across the coastal flow control structures maintained by the SFWMD and are stored in its DBHYDRO database. The observed flow data from the coastal control structures S197, S20, S20F, S20G, S21, S21A, S123, S22, S25B, G93, S26, S27, S28, S29, and S29Z for the time period 1985-2005 were examined. On average, 1,210 K acre-ft/yr (accurate to about +/- 5%, (Alleman, pers comm.)) of total surface freshwater flows enter any part of Biscayne Bay. For just the waters entering the boundaries of Biscayne National Park (direct flows through S20F, S20G, S21A, S21, and S123 at the northern coastal boundary are included, as are indirect flows from S22 Central Bay, S20 into Card Sound, and S197 into Barnes Sound all of which eventually pass through park waters), the average freshwater flux is much less, about 534 K acre-ft/yr or 44% of the total. These flows either directly or indirectly into Biscayne National Park in South Bay will be the focus of this discussion.

Figures 3 and 4 show the volume of flow contributed by each of the structures relative to each other. Of the annual average of 534 K acre-ft of canal flows that are discharged to southern Biscayne Bay from 1985-2005, 138 K acre-ft (26% of all annual flows) entered directly into Biscayne National Park through C-103 (S-20F), 113 K acre-ft (21%) through C-1 (S-21), 73 K acre-ft (14%) through C-102 (S-21A), and a minor amount through Military Canal. In addition, there were indirect flows to the park waters through C-100 (S-123) (46 K acre-ft, or 9%), and C-2 (S-22) (100 K acre-ft, 19%). Additional freshwater eventually enters the park through its southern boundary at the entrance to Card Sound. The freshwater in Card Sound and Barnes Sound section comes primarily from discharges from the Sea Dade Canal (S-20, 18 K acre-ft/yr, 3%) and the C-111 Canal (S-197, 28 K acre-ft/yr, 5%) into Manatee Bay in western Barnes Sound, with some additional unquantified contributions from overland runoff from extensive freshwater and coastal wetlands contiguous with the mainland shoreline of these two basins. Because no other significant or quantifiable source of surface or groundwater exists, these coastal structure flows into southern Biscayne Bay are considered in this analysis to be the only freshwater inflows along the coast.

The temporal variability of these flows and how they relate to the flow targets outlined above is of the utmost importance for the discussion of ecosystem restoration goals. The time series (1985-2005) of the South Bay flows (from S-22 in the north to S-197 in the south) and targets is shown in Figure 5. The average monthly flows from these input sources are depicted in yellow in Figure 6, as are the target flows (red) of 37 K acre-ft / 110 K acre-ft for the dry/wet season in the 10,000 acre WBZ region. The flows necessary to maintain estuarine conditions are shown as a dashed line. The 1st quartile (lowest 25%) of monthly flows, representing typical dry conditions during the 20 year time period, is depicted in green. Figure 7 shows the monthly deficit (target minus actual) of flows to Biscayne National Park in blue, with the dry conditions' deficit depicted in green. Though the wet season flow deficit is larger, when the same relationship is shown in Figure 8 and expressed as a percentage of the total mean monthly flow available to South Bay (blue), it is seen that the relative magnitude of the deficit increases throughout the dry season, peaking in April at over 250%, and is proportionally higher than the wet season deficit. During dry periods (green) these trends remain consistent. During a mean year, the fresh water deficit is a total of 20 K acre-ft (average of 5 K acre-ft/month) during the early dry season and 485 K acre-ft (60 K acre-ft/month) during the late dry and early wet season. An inspection of the time series and the targets reveals that during the 20-year time period, monthly wet season flows met or exceeded the target less than 10% of the time; meeting late dry season targets was even more infrequent. Paradoxically, early dry season statistics come closer to the targets due to seasonal water management practices that unnaturally reduce groundwater stages in southern Miami-Dade by inducing large outflows to Biscayne Bay during November and December (the southern "agricultural drawdown"; Kearns et al., 2008).

Southern Biscayne Bay therefore is thus currently in a state of almost constant water deficit. Ongoing deleterious effects on the estuarine organisms within the western reaches of the Bay are to be expected, since the estuarine ecological functions in the Bay are inhibited both by the shortfall in freshwater volumes as well as the unnatural timing of those limited flows that are available. Though it appears that an adequate volume of fresh water is currently available to the bay on an *annual* basis to at least maintain the bare minimum estuarine conditions, the timing of this flow is inadequate to do so.

Salinity. The salinities present in Biscayne Bay are directly dependent upon these freshwater fluxes. Under the current water management scheme, large plumes of relatively freshwaters (<25ppt) extend away from the canal mouths towards the bay axis during periods of high rainfall. These fresher waters are then mixed into the other bay waters and are subject to partial exchange with marine waters (35 ppt) through tidal processes. The result in a typical year is an average bay salinity less than marine (<35ppt) during the wet season and approaching or exceeding marine during the dry season, though during years with less-than-average canal run discharges it is common to observe hypersaline (>37ppt) conditions through large portions of southern Biscayne Bay, including the western shoreline.

Time series of salinity data have been collected by Miami-Dade Department of Environmental Resources Management (DERM), Florida International University (FIU), and NPS at scattered points at different intervals within Biscayne Bay for more than 10 years. The salinity at a given station is largely a function of the efficiency of tidal exchange at that location (usually related to the distance from the ocean with its typical salinity of 35-37 ppt), the freshwater surface flow to the bay (mostly local but some remote influences dependent on location), the time history of evaporation and precipitation in the bay, the volume of intra-bay transports, and any wind events within the past few weeks that greatly influence mixing rates and on/offshore transports. These individual time series offer little help in assessing the synoptic distribution of spatial gradients within the bay, and very few are in the WBZ that is the region of greatest interest for salinity targets due to their ecological importance there. Taken as a whole, however, these salinity data can help elucidate the net result of all the influences on salinities in the bay.

If these observed data are integrated over 30 days, and grouped by their general location within the bay and their distance from the coastline (approximating the effect of both distance from the freshwater flows and the ocean influences), some interesting general trends emerge when correlated against the integrated observed flows from the coastal structures (Figure 9). Nearshore (<2 km from shore, but more than 0.7 km from any canal mouth to avoid aliasing from any freshwater plume emanating from it) there is a dramatic decrease in the monthly salinity with increasing flow. However, with increasing flows there is a proportionally decreasing influence on the salinity, with a fairly well-defined $1/x^n$ shape but with a significant random error about the mean. Beyond a flow rate of about 25-35 K acre-ft/month there is substantially less salinity reduction effect, so while it takes a flow rate of 25 K acre-ft/month to lower mean salinities by greater than 20 ppt over 30 days time in the very nearshore region, to reduce them a further 5 ppt appears to take about 60 K acre-ft/month more. This is consistent with the increased volumes required to meet wet season salinity targets, and is mostly a reflection of conservation of volume – the increased volumes of freshwaters displace the mixed and marine waters to sea as the bay's volume stays the same – coupled with the efficiency of tidal exchange and turbulent diffusion.

An important conclusion drawn from these results relative to the WBZ is that it would be expected that the northeastern corner of the WBZ would be most difficult to affect with additional flow volumes. Since this area is the farthest from the shoreline as well as from any existing source of fresh water output, this area would be an ideal location for monitoring efforts for future restoration programs that seek to redistribute large volumes of fresh water.

DISCUSSION

Prior to the significant changes in the freshwater flow patterns in south Florida caused by the creation of a water control system in the early 20th century, Biscayne Bay was a true estuarine system. Large amounts of freshwater in the form of both surface and groundwater were present throughout most of the year and supported a wide range of flora and fauna. When these freshwater sources were diminished and their distribution altered by water management practices, the vegetation in the bay, as well as the juveniles of many fish and invertebrate species, were adversely affected and the ecosystem in the bay changed drastically. The ecosystem that exists today in Biscayne Bay is largely marine in nature, as the volume, timing, and distribution of freshwater flows are insufficient to maintain an estuarine environment over ecologically-significant temporal and spatial scales. In keeping both with the Everglades restoration efforts and the NPS mandate to preserve unimpaired the nation's natural resources within the parks, this document provides targets for desired salinity conditions in Biscayne National Park in terms of salinity, and provides a range of estimates for the restoration target flows required to reach the desired salinity conditions that are necessary for the ecological targets within the park.

The spatial focus of the discussion of ecologic targets includes the Western Bay Zone (WBZ) of Biscayne National Park – the 10,000 acre area along the western shoreline which contains the portion of the ecosystem that most benefits from freshwater flows. The shallow waters of the WBZ contain thousands of acres of seagrasses as well as a fringing mangrove forest. The desired condition, or overarching goal, for the western zone of Biscayne National Park is the existence of stable estuarine conditions that persist through the dry season, to be achieved through more natural timing and distribution of freshwater flows. These stable estuarine conditions support a productive, diverse benthic community based on seagrass. These conditions will also support endangered species and sustain productive nursery habitat for local and regional fishery resources.

The appropriate restoration area to consider was discussed in this document. The existing RECOVER wet season performance measures for Southern Biscayne Bay focus on a narrow (500 m) strip of coastline that encompasses 3200 acres of park waters. The more-inclusive approach used here is to focus on existing geomorphological information to define an area of soft bottom suitable for seagrasses: this approach seeks to extend the area already identified by RECOVER to the wider WBZ. This target habitat in the WBZ includes roughly 10,000 acres of park area. This larger region was chosen as the target area for stable estuarine conditions because it is based on bay geomorphology, a factor that is fundamental to bay ecology.

The ecological targets for the WBZ were based upon an approach that includes the benthic community, endangered species, and important fishery resources in the western bay. Because seagrass is important nursery and growth habitat for indicator species, a fundamental resource management and restoration goal is to maximize coverage by SAV beds at sustainable levels. Under appropriate salinity and water quality conditions, it is expected that this area will support excellent SAV growth where sediment and water depth are appropriate for such growth. One explicit restoration target is an increase in the vitality and diversity of the WBZ seagrass community, with wigeon grass as the dominant SAV species at the mangrove edge within the nearshore ecotone and shoal grass becoming co-dominant with turtle grass through much of the rest of the WBZ. Another explicit target is the restoration of the community of seagrass-associated fauna that have been largely extirpated from South Bay, and the enhancement of habitat for others, such as crocodiles and pink shrimp that will likewise benefit substantially from the target salinity conditions.

These ecological targets require freshwater flows that produce mesohaline conditions throughout most of the year at the bottom of the bay, with salinities ranging from 5 to 20 ppt over the soft bottom areas of the WBZ that have the substrate necessary to sustain SAV. In particular, in order to preserve the estuarine character of the WBZ, the measured salinity should not exceed 30 ppt anywhere in the zone. The ecological and salinity targets that link mesohaline conditions and associated seagrass and faunal communities for this area are not currently being met because current freshwater deliveries are insufficient in terms of quantity, timing, and distribution.

Simple volumetric estimates of the restoration target flows to reach these salinity goals in the 10,000 acres of the tidally-driven system result in monthly flows of 37 K acre-ft/month in the dry season and 110 K acre-ft/month in the wet season. This results in a target annual flow of 960 K acre-ft/yr. Other types of flow target estimates – diffusive, empirical, semi-empirical – discussed in this document fall close to this range as well. In the absence of more complete hydrological modeling results which could reduce the range of estimates, the volumetric estimate will suffice as a flow target for comparison against the existing flows. Future work should focus on hydrological modeling results that will not only help refine the volumetric estimates, but also provide information concerning the expected spatial and temporal distribution of the freshwater flows, including work to improve the distribution, timing and quantity of flow through the coastal wetland and mangrove shoreline areas of the Park.

The existing flows analyzed here are comprised of the managed water flows through the control structures at the end of the canals that empty directly in or adjacent to the WBZ. Groundwater flows were omitted from hydrologic analysis in this assessment because the built system has vastly reduced them and the likelihood of generalized groundwater increases to Biscayne is very small. Groundwater flows could potentially be beneficial in the dry season; however, for the last several decades early dry season groundwater flows have been actively eliminated from the study area by water management operations.

A comparison of the canal discharges from S-22 south to S-197 indicated that the waters reaching Biscayne National Park are well below the volumes determined by the salinity requirements for ecological targets. The mean deficit of fresh water flows to meet those restoration salinity targets is 5 K acre-ft/month (20 K acre-ft total) during the early dry season and 60 K acre-ft/month (485 K acre-ft total) during the late dry and early wet seasons. The percentage of the deficit as a function of the mean monthly volume of water available to BISC rises throughout the dry season and peaks in April at over 250%. During dry conditions (when canal discharges are within the lowest 25% of flows) these deficits are exacerbated, with the April deficit exceeding 350%. The frequency with which the flow targets have been met over the period of record is extremely low, less than 10% of the time.

The historical record of salinity in Biscayne National Park indicates that the current timing and distribution of canal discharge waters is largely ineffective at maintaining estuarine conditions or even preventing hypersalinity during the dry season. Volumetric estimates of the required flow to maintain minimal estuarine conditions of <30ppt are 440 K acre-ft per year, which is currently available on an annual basis from the water management system but has such an unnatural timing and distribution that these flows fall far short of maintaining the estuary. Without the pre-drainage groundwater flows and historic creeks that used to provide waters to South Bay during the dry season, there is not enough flow to South Bay to prevent evaporation-driven hypersalinity. The situation is even more pronounced in Barnes and Card Sounds, located immediately to the south of Biscayne National Park. With tidal inflows restricted to those spilling from South Bay over the shallow Cutter Bank at the mouth of Card Sound, characteristic long residence times (months), and with few freshwater surface inputs (C-111), Barnes and Card Sounds quickly become hypersaline during the dry season and periods of mild drought.

This paper has discussed the ecological targets for Biscayne National Park and provided annual estimates of freshwater flows needed to reach them. A gross estimate of how the annual flow is distributed between the wet and dry seasons was also provided. As restoration projects develop to provide additional flows to Biscayne National Park, further analysis will be needed to develop metrics for the seasonal and interannual variability associated with hydrologic restoration targets for the park, as well as to address spatial variability within Biscayne Bay. These ecological and hydrologic targets are critical for evaluation of potential benefits of restoration projects for Biscayne National Park and to assess progress toward ecosystem restoration.

Key Technical Conclusions and Management Implications for Biscayne National Park

1. To promote restoration of estuarine habitats (seagrasses) and estuarine species, salinities in the Western Bay Zone should range between 15-25 ppt from March through August (late dry season-early wet season), and should be consistently under 20 ppt during the end of the wet season (September-October). This report uses a variety of estimates to conclude that, given the current drainage canal-based distribution system along the coast, the volumes of water required to reach these targets are approximately 37 K acre-ft per month from December through April, and 110 K acre-ft per month from May through November, for a total annual volume of 960 K acre-ft.
2. To maintain minimal estuarine conditions, the fresh water reaching the southern Bay must have sufficient volume, adequate timing, and effective distribution to maintain salinities of less than 30 ppt (daily average) all year round in the Western Bay Zone. Salinities in the Western Bay Zone currently surpass this threshold, and cause a loss of estuarine ecological function. This loss of estuarine function may be reversed given adequate changes in fresh water deliveries to the Bay.
3. Analyses of existing flows indicate that essentially all the water currently reaching Biscayne National Park via the current distribution system is needed by the ecosystem to reach desired restoration conditions, including a healthy benthic community, endangered wildlife (American Crocodile) and important fishery resources in the Western Bay Zone.
4. Modifications to the distribution system that will produce a steady flow of waters away from the coast all along the shoreline, are needed to most efficiently create estuarine conditions with a given volume of water. These modifications will also serve to avoid the ecological damage that is caused by rapid cessation of flows due to management practice or large point-source pulses of freshwaters following storm events.

FIGURES

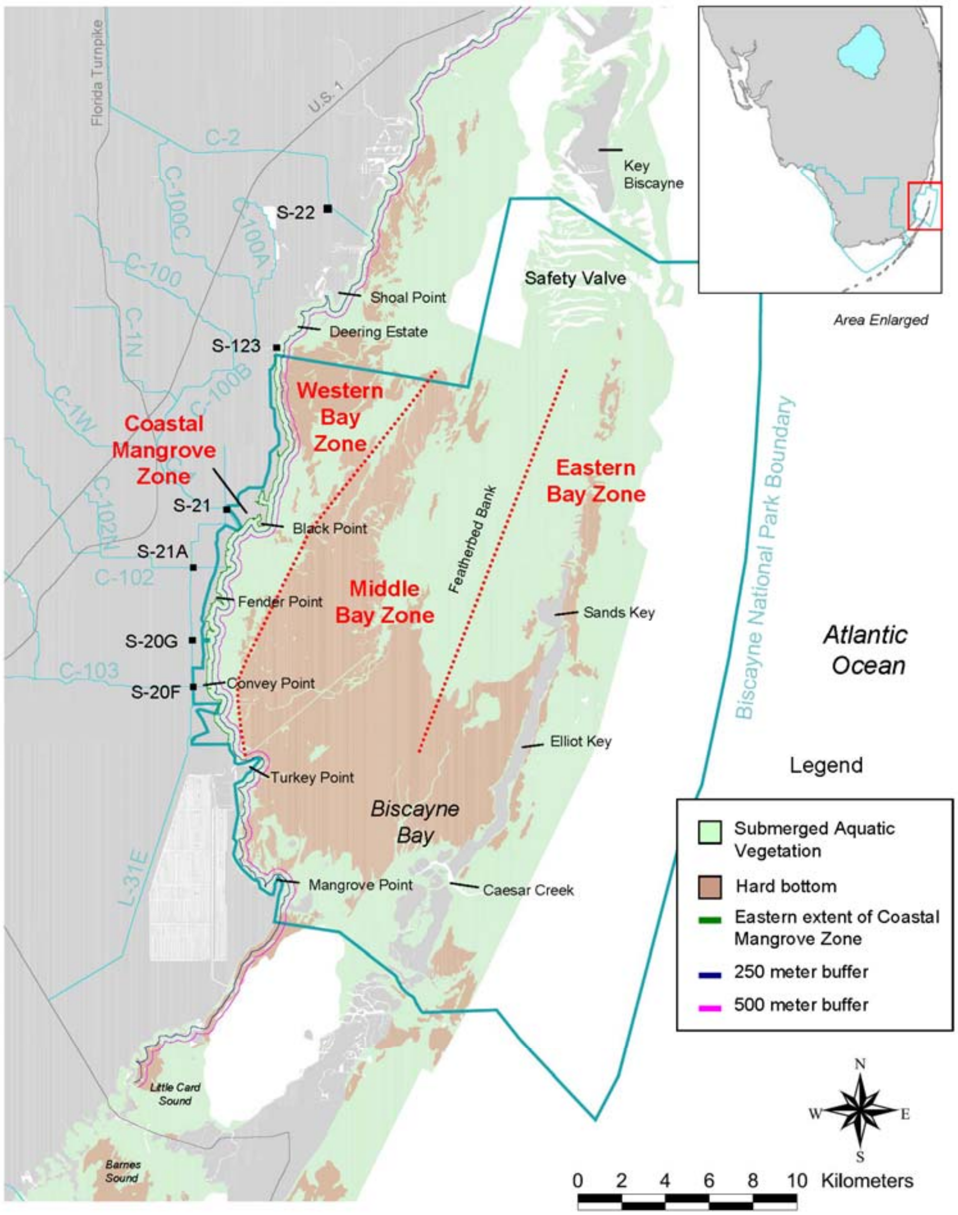

Figure 1. Biscayne National Park, showing the Western Bay Zone that was described based on the current and potential distribution of submerged aquatic vegetation on the bay bottom.

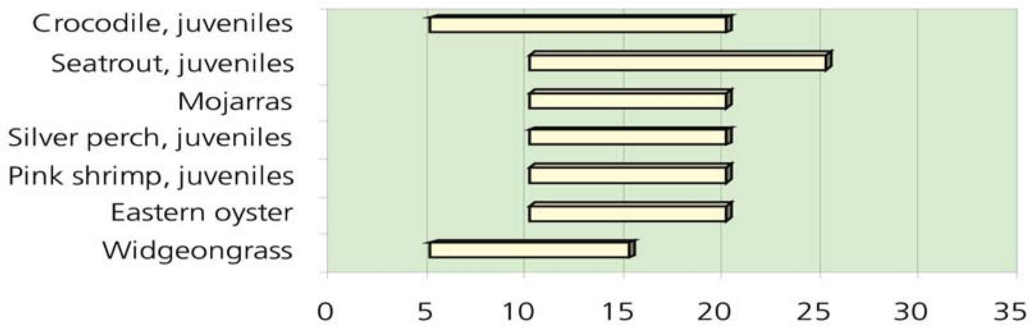

Figure 2. Optimal salinity ranges (units in ppt) for Biscayne National Park ecosystem indicators.

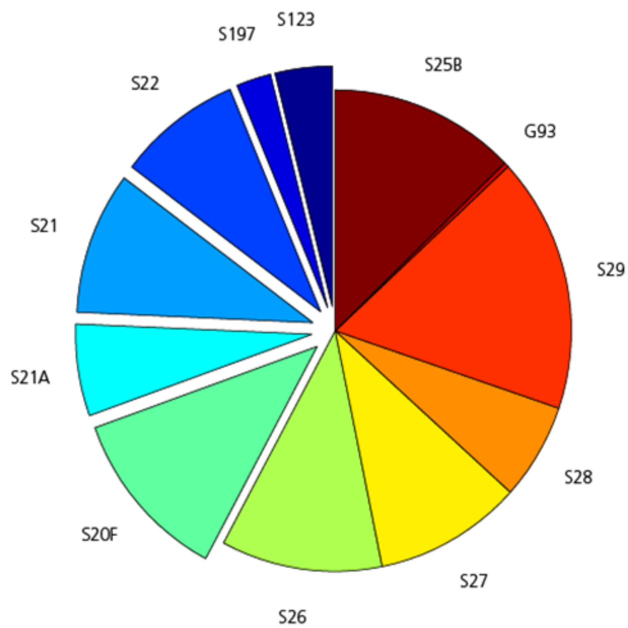

Figure 3. Average distribution of total annual canal flow (1,210 K ac-ft) to all of Biscayne Bay by SFWMD structure for 1985-2005. The highlighted portions represent those structures which discharge a total of 534 K ac-ft into Southern Biscyane Bay.

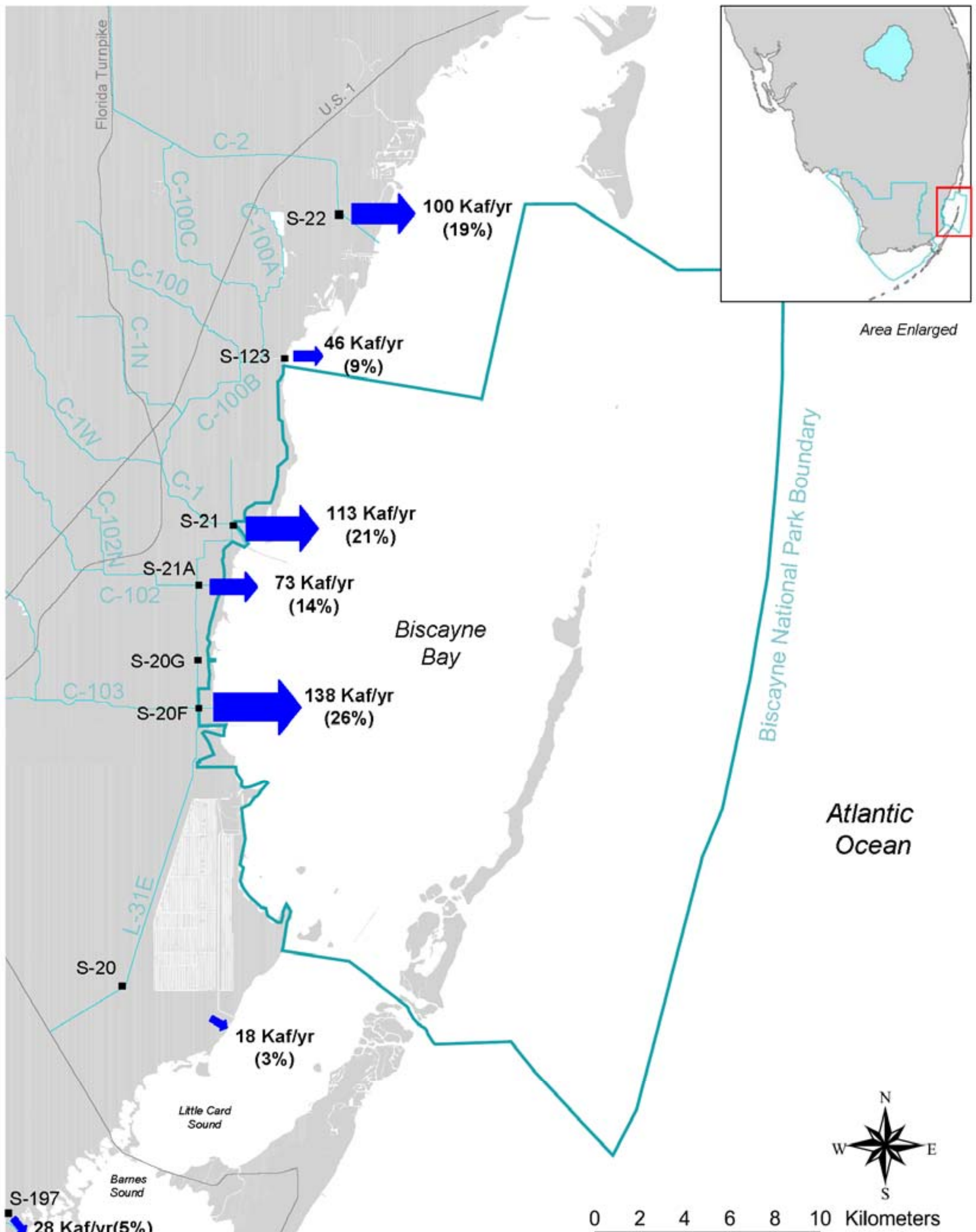

Figure 4. Location and the annual average (percent of total) of canal discharges to southern Biscayne Bay.

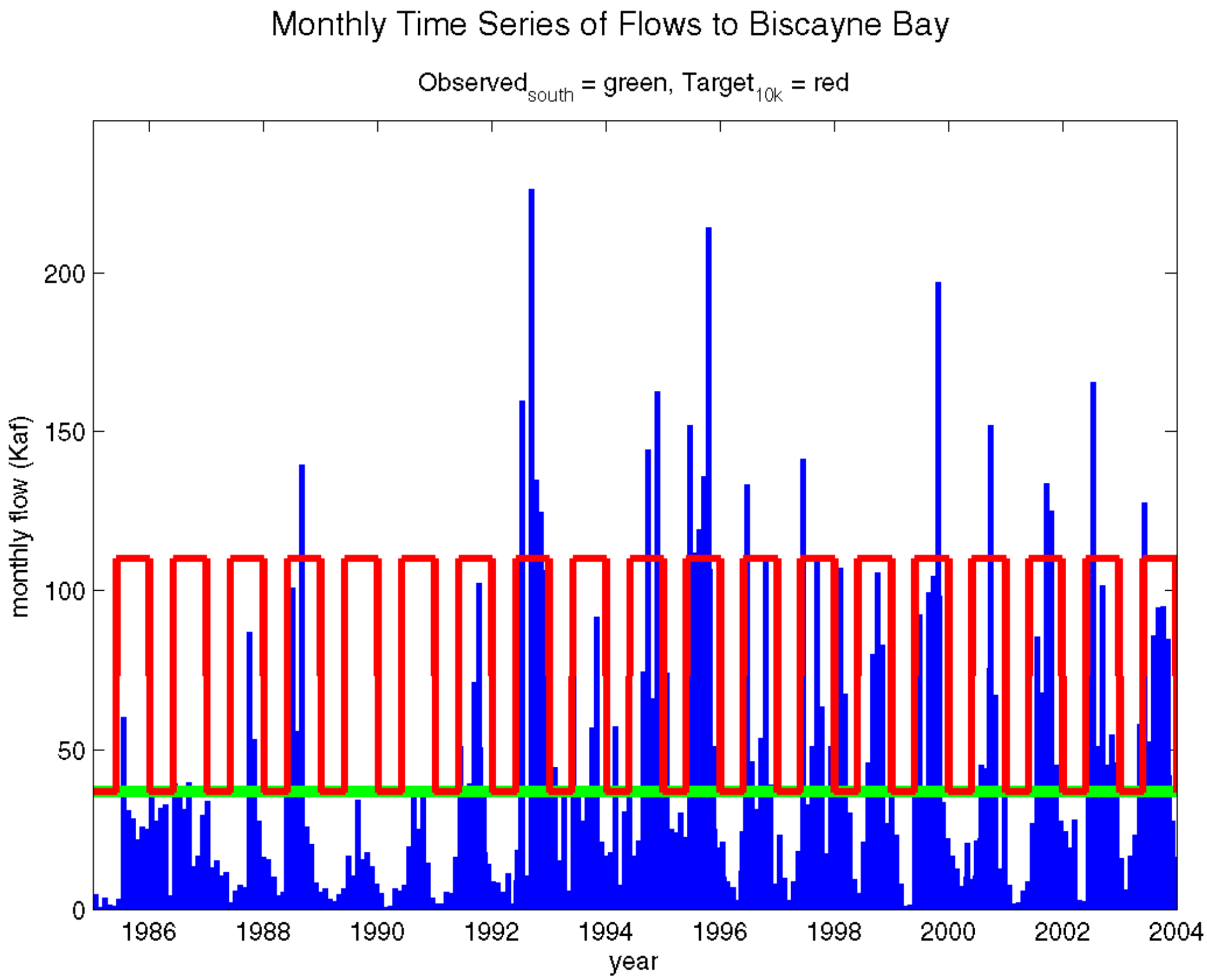

Figure 5: The monthly flows to Biscayne National Park from 1985-2004. The blue are observed flows in K acre-ft/month, while the red are the flows required to meet salinity and ecological targets. The time series shows that target flows are met only 8% of the time in the wet season, and 4% of the time in the dry season. The green line represents a minimum flow that would be required to just barely maintain estuarine conditions throughout the year.

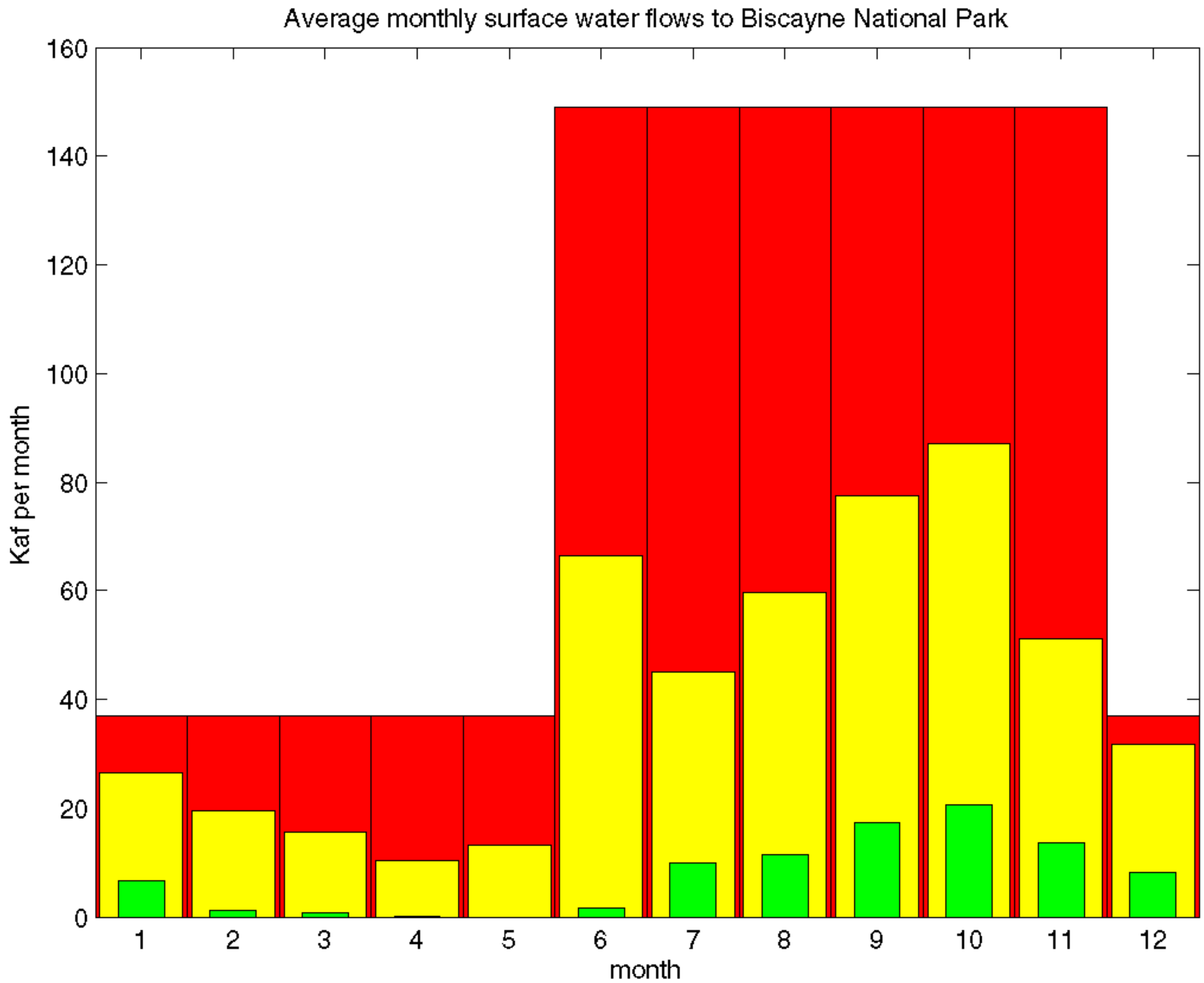

Figure 6: The average monthly flows into Biscayne National Park waters (yellow), the target flows required to meet ecosystem goals (red), the average monthly flows during dry periods (green; for the lower quartile of flows).

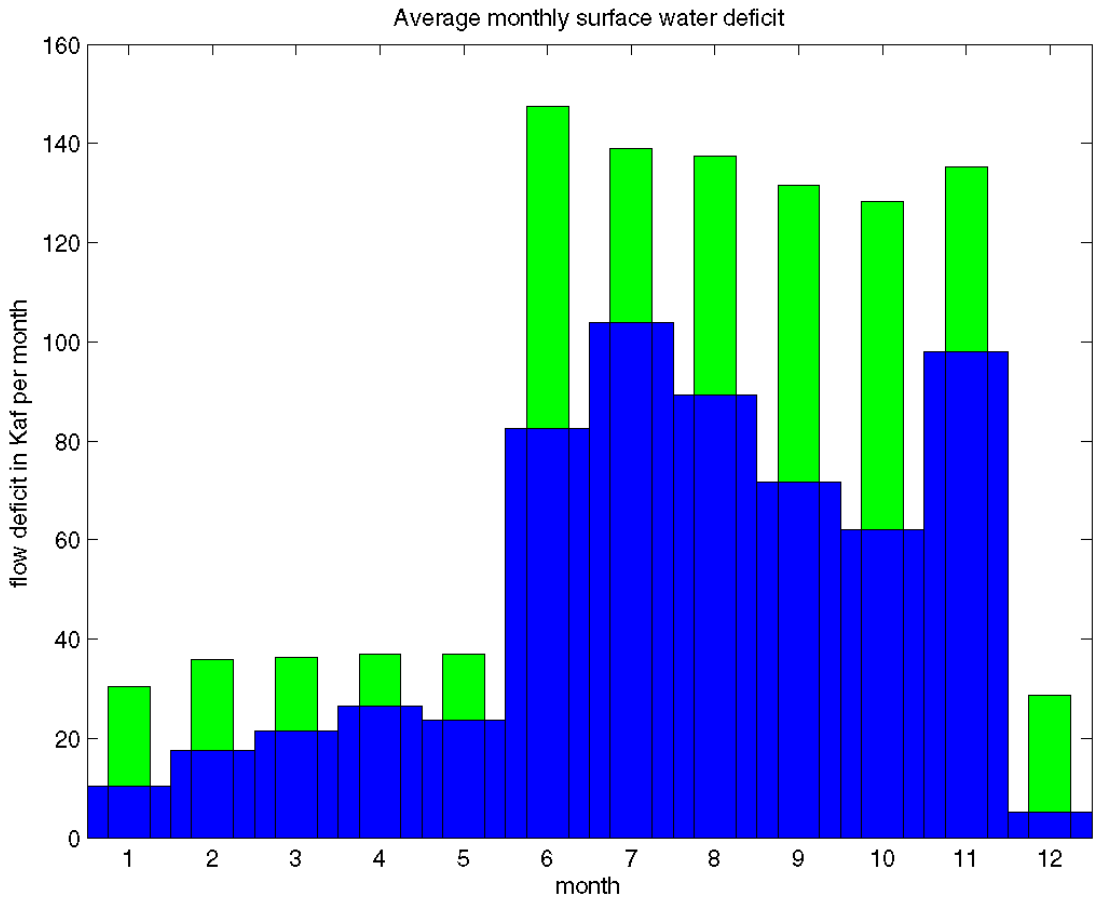

Figure 7. The average monthly flow deficit (target minus actual) for Biscayne National Park is depicted in blue; the deficit for the driest 25% of the record is shown in green.

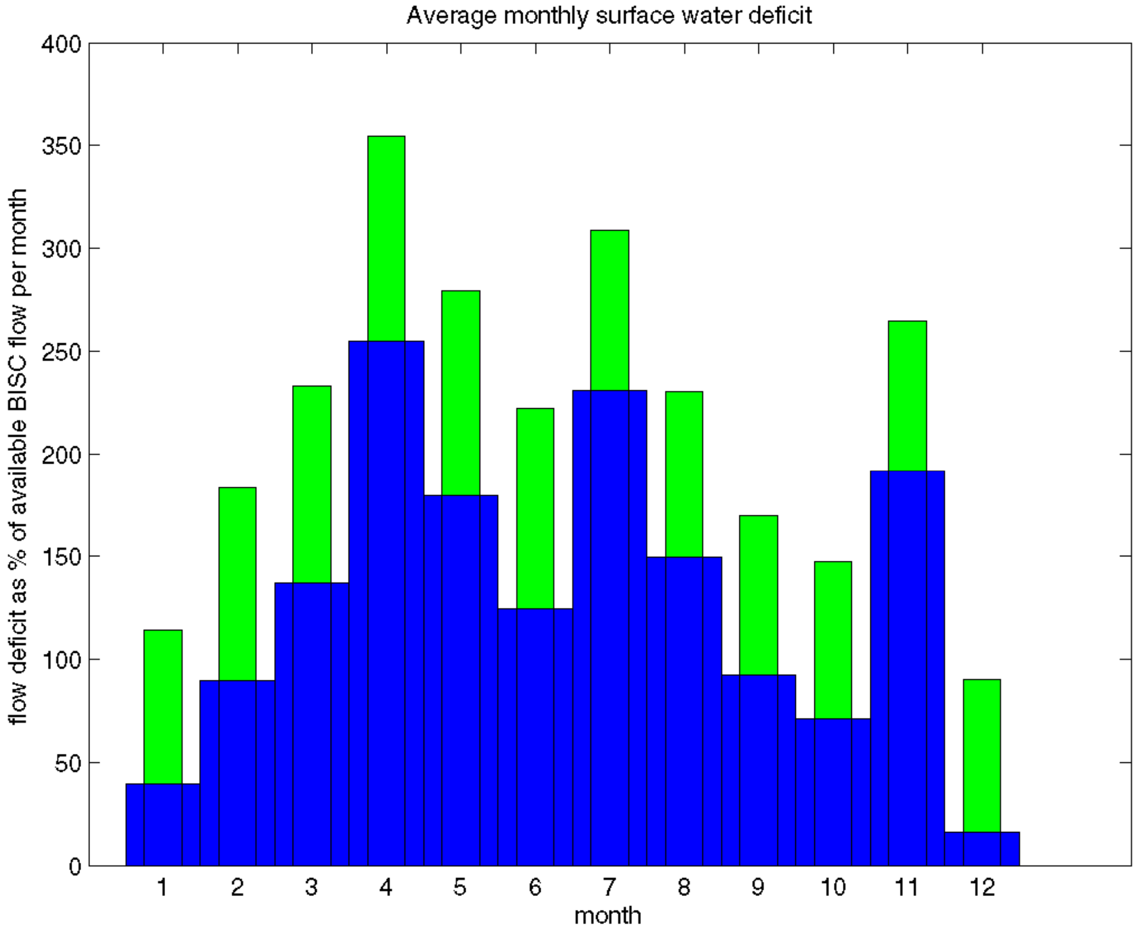

Figure 8. The average monthly flow deficit (target minus actual) for Biscayne National Park expressed as a percentage of the average flows available for each month for all conditions (blue) and the driest 25% of the period of record (green).

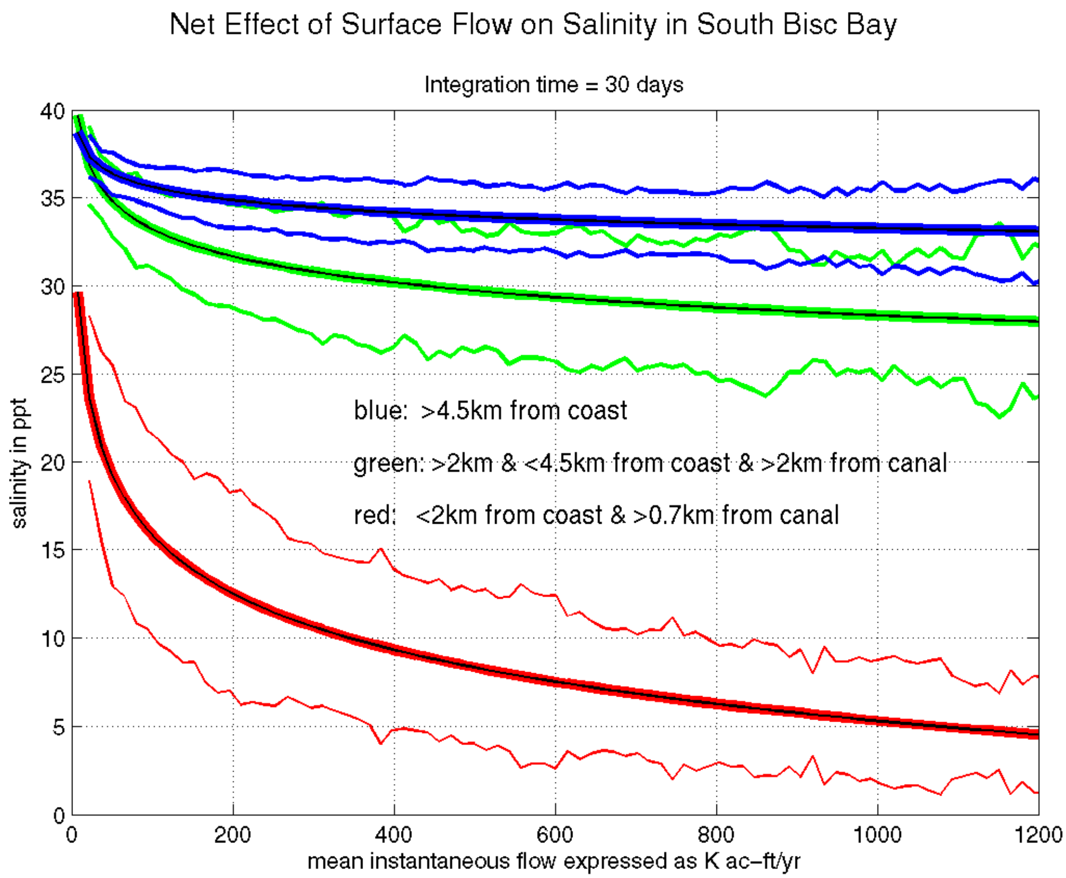

Figure 9. Observed south Biscayne Bay salinity data integrated over 30 days and grouped according to their distance from the coastline vs. flow rates expressed as K acre-ft/yr. the thick red curve denotes the area away from canal mouths but within 2 km from the western shoreline (encompassing approximately 6400 acres), the green line denotes the area from 2 km to 5 km from shore, and the blue line denotes >5km from shore. The thin lines denote an envelope of +/-1 standard deviation of the residuals from the fitted curve.

LITERATURE CITED

Alleman, R. 2003. Historic salinity contours. PowerPoint presentation to Regional Evaluation Team Southern Estuarine Team on May 21 2003. South Florida Water Management District, West Palm Beach, Florida.

Alleman, R. and D. M. Parrish. 2005. Hindcasting salinity in Biscayne Bay. Pp. 201-202. In: Proceedings of the Florida Bay and Adjacent Marine Systems Science Conference. University of Florida, IFAS. December 11-14, 2005. Duck Key, FL.

Biscayne National Park. 2006. Salinity sampling in Biscayne Bay. Annual Report. A report to the U.S. Army Corps of Engineers for the Monitoring and Assessment Plan of the Comprehensive Everglades Restoration Plan for RECOVER Assessment Team, Southeast Estuary Subteam. Homestead, FL.

Brown, G.L., R. McAdory, G.H. Nail, M. S. Sarruff, C. Berger, and M.A. Granat, 2003. Development of Two-Dimensional Numerical Model of Hydrodynamics and Salinity for Biscayne Bay, Florida. US Army Corps of Engineers Coastal and Hydraulic Laboratory Report ERDC/CHL TR-3-10. 173 pp.

Downer, C., J. Klochak, and T. Mullins. 2005. Biscayne Bay Coastal Wetlands Alternative P Specifications. Prepared for Comprehensive Everglades Restoration Program, Biscayne Bay Coastal Wetlands Project Delivery team.

Department of the Interior 2006. Ecological Performance Measures for Western Biscayne National Park. Discussion paper prepared by the office of the Director of Everglades Restoration Initiatives, Office of the Secretary, Florida International University, Miami FL.

Kearns, E.J., A. Renshaw, and S. Bellmund, 2008. Environmental Impacts of the Annual Agricultural Drawdown in Southern Miami Dade County. Joint Assembly of the American Geophysical Union, Ft. Lauderdale, FL.

Kohout, F. A. and Kolipinski, M. C. 1967, Biological zonation related to groundwater discharge along the shore of Biscayne Bay, Miami, Florida; In: G. H. Lauff (Ed.). Estuaries: American Association for the Advancement of Science, Publication no. 83: 488-499.

Langevin, C. D. 2001. Simulation of Ground-Water Discharge to Biscayne Bay, Southeastern Florida. U.S.G.S. Water-Resources Report 00-425, 127pp.

Lee, T. and C. G. H. Rooth. 1976. Circulation and Exchange Processes in Southeast Florida's Coastal Lagoons. Biscayne Bay Symposium, University of Miami Sea Grant Report No. 5. Rosenstiel School of Marine and Atmospheric Science, Miami, FL.

Meeder, J. F., P. W. Harlem, and A. Renshaw. 2002. Restoration of the Black Creek Coastal Wetlands and adjacent nearshore estuarine zone of Biscayne Bay. Report to the South Florida Water Management District, West Palm Beach, Florida. Southeast Environmental Research Program, Florida International University.

SFNRC Technical Report 2006 (1). Ecological and Hydrologic Targets for Western Biscayne National Park. South Florida Natural Resources Center, Everglades National Park, Homestead, FL. SFNRC Technical Series 2006:1: 25 pp.

Sonenshein, R. S. 1995. Delineation of Saltwater Intrusion in the Biscayne Aquifer, Eastern Dade County, Florida. USGS Water-Resources Investigations Report, 96-4285.

Wang, J.D., E. Daddio, M.D. Horwitz, 1978. Canal Discharges into South Biscayne Bay. Report to the Department of Environmental Resources Management, Metropolitan Dade County. 57 pp.

Wang, J. D., J. Luo, and J. S. Ault. 2003. Flows, salinity, and some implications for larval transport in south Biscayne Bay, Florida, Bulletin of Marine Science 72: 311-329.

Wingard, G. L., T. M. Cronin, C. W. Holmes, D. A. Willard, G. Dwyer, S. E. Ishman, W. Orem, C.P. Williams, J. Albietz, C. E. Bernhardt, C. A. Budet, B. Landacre, T. Lerch, M. Marot, and R. E. Ortiz. 2004. Ecosystem history of southern and central Biscayne Bay: Summary report on sediment core analyses – Year Two. Open File Report 2004-1312. U.S. Geological Survey.

APPENDIX A: ADVECTION VERSUS DIFFUSION

A one-dimensional flow of water and salt in the x direction can be expressed in a steady-state, vertically-mixed form as:

$$D(US)/dz = d/dx\ (A\ dS/dx)$$

where S is the salt content, U is the horizontal velocity, and A is the horizontal turbulent diffusion coefficient. If one assumes that U is independent of the distance x from the coast (which is a very reasonable assumption for a flow distributed all along a coastline, and an unreasonable assumption for a point source flow), and that A is likewise independent of x (a poor but pragmatic choice) then:

$$U\ dS/dx = A\ d^2S/dx^2$$

Given the assumptions, the analytical solution is exponential. The importance of this solution is that, in the absence of other transient forcing, a steady flow offshore gives a persistent exponential gradient located near the coast. As the speed of the flow increases, this gradient will move farther offshore and will become sharper (larger magnitude). As the mixing becomes more intense or efficient (i.e., the magnitude of A increases) the gradient will move closer to shore and the gradient's magnitude will decrease. The ratio of A/U is the length, or e-folding scale, and, as such, is a good estimate of the width of the offshore gradient region. While the velocity U along a coastline can be determined by metering out a known volume of water at a known rate along a length of shoreline, the horizontal turbulent diffusion coefficient A is not as simple and is often several orders of magnitude greater than equivalent molecular diffusivities. It is a function of the flow and resulting friction in the area and, as such, will be dependent on the tides, winds, and topography, and can vary by several orders of magnitude.

The advection dispersion estimate provided on page 21 is derived from a horizontal diffusivity of A = 1 m^2/s and steady offshore velocity U= 0.001 m/s for 26 km of coastline with an average depth of 1 m. The value of the diffusivity A has been shown by Wang et al. (1978) to vary from 0.5 m^2/s to 5 m^2/s along the western shoreline, producing a theoretical range of net offshore velocities from 0.0005 m/s to 0.005 m/s. These velocities translate to freshwater fluxes of 400 K acre-ft/yr to 4 Maf/yr, respectively – a considerable span of values. However, the diffusivity is highly variable with time and space, including dependencies on wind speed, current speed, water depth, and the distance to the shoreline. Since the shallow areas adjacent to the coastline are not subject to the largest tidal velocities and wind/wave effects, they will likely have effective diffusivities on the lower end of the range in all but the most extreme (storm) events. The 800 K acre-ft/yr target flow estimate was arrived at by a conservative evaluation of these factors and assuming an average diffusivity in the Western Bay Zone of 1 m^2/s.

United States Department of the Interior
National Park Service

Biscayne National Park	Everglades National Park
9700 SW 328 Street	40001 State Road 9336
Homestead, FL 33033	Homestead, FL 33034

In reply refer to: L54

July 2, 2008

Ms. Carol Ann Wehle
Executive Director
South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33406

Dear Ms. Wehle:

The National Park Service received a letter from your agency in April of 2005, requesting technical information relevant to the establishment of reservations for Biscayne Bay. In response to this letter and to more recent ongoing conversations with your agency, the National Park Service has developed the attached document, entitled "Estimates of Flows to meet Salinity Targets for Western Biscayne National Park**".** The present document represents technical work that follows on a previous document, titled "Ecological Targets for Western Biscayne National Park", transmitted to your agency on June 16, 2006. We hope that these technical analyses will be helpful as your agency addresses projects that affect Biscayne National Park resources, including water management operations, Florida State water law processes such as reservations and Minimum Flows and Levels, and the design of the Biscayne Bay Coastal Wetlands project.

The technical analysis in the attached document supports the National Park Service's broad responsibility for the preservation of our nation's natural and cultural resources. In the context of the ecosystem restoration efforts in South Florida, this translates into the responsibility for determining the ecological and underlying physical conditions that represent the restored natural resources of the South Florida Parks.

The attached document represents a joint effort by Biscayne National Park resource management staff and staff at the South Florida Natural Resources Center at Everglades National Park. During the early evolution of this document, valuable comments and input were received from staff at the U.S. Fish and Wildlife Service Office of Ecological Services in Vero Beach.

We anticipate that continuing collaboration with your staff will be beneficial in developing further metrics associated with the hydrologic restoration targets for Biscayne National Park. We are looking forward to continued cooperation in the establishment of restoration targets for our South Florida National Parks, and to working with your agency to provide the needed water for restoration of these nationally important natural areas.

Sincerely,

Mark Lewis, Superintendent
Biscayne National Park

Dan B. Kimball, Superintendent
Everglades National Park

Cc: Kameran Onley, U.S. Department of the Interior
Michael Collins, SFWMD Governing Board Member
Chip Merriam, SFWMD Deputy Executive Director, Water Resources Management
John Mulliken, SFWMD Director, Water Supply
Cecelia Weaver, SFWMD, Director of the Florida Keys Service Center
Beth Carlson Lewis, SFWMD Office of Counsel
Joan Lawrence, U.S. Department of the Interior
Terrence “Rock” Salt, U.S. Department of the Interior
Robert Johnson, U.S. National Park Service
Paul Souza, U.S. Fish and Wildlife Service
Pamela Repp, U.S. Fish and Wildlife Service