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Quantifying Submarine Groundwater Discharge To Indian River Lagoon, Florida

Figure 1. Sampling for submarine groundwater discharge in Indian River Lagoon.

The discharge of submarine ground water has recently been shown to be an important process in many environmentally fragile coastal ecosystems. However, groundwater discharge into coastal bottom water is still an often-overlooked component of many hydrologic and oceanic models. The exchange of interstitial water across the sediment/water interface may introduce anthropogenic pollutants, may be an important part of coastal nutrient cycles, and may cause excess nutrient loading, thereby potentially degrading the coastal water quality. Here we report on Year-1 results from a co-operative (USGS-UF-LSU) project that is investigating the role of submarine groundwater discharge into Indian River Lagoon, Florida.

Introduction

The Indian River Lagoon system (Fig. 1) extends over 250 km along the east-central coast of Florida and consists of three inter-connected lagoonal basins: Mosquito, Banana River, and Indian River lagoons. Exchange of lagoon water with the Atlantic Ocean is limited to four tidal inlets (Sebastian, Ft. Pierce, St. Lucie and Jupiter) that occur in the southern reaches of Indian River lagoon. The following processes control the salinity of lagoon water: precipitation, the exchange of water through these inlets, wind, tidal forcing, evaporation, surface runoff and potential submarine groundwater discharge. In this system, the intensity and duration of wind have the most pronounced affect on lagoon water levels. The overall objective of this project was to determine the rate and potential ecological significance of submarine groundwater discharge to Indian River Lagoon (Fig. 2).

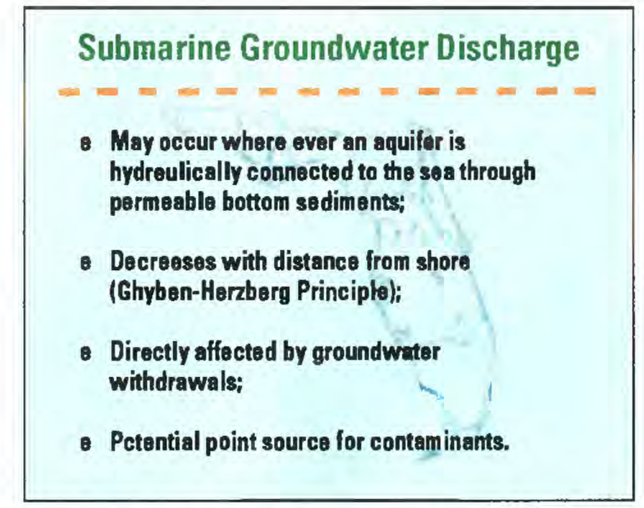

Figure 2. Parameters of submarine groundwater discharge.

The study area during the first year of the project included the northern most 10 km of the Indian River Lagoon (~48 km^2). Of the 28 sampling stations, 22 were arranged in shore-perpendicular transects; the remaining six stations were distributed within the lagoon center (Fig. 3). At each station, lagoon and interstitial water samples were collected, and groundwater seepage rates were measured using conventional seepage meters. Interstitial water samples were obtained from four stations using custom-built multi-samplers. Six groundwater samples were collected from wells surrounding the lagoon. Two additional samples were collected from tributaries to the lagoon including Turnbull Creek and Haulover Canal. Sampling of the seepage stations, groundwater wells, and tributaries occurred in May 1999, to coincide with the end of the normal dry season, and in August 1999, during the normal rainy season. A third trip in December 1999 was used only to sample interstitial water.

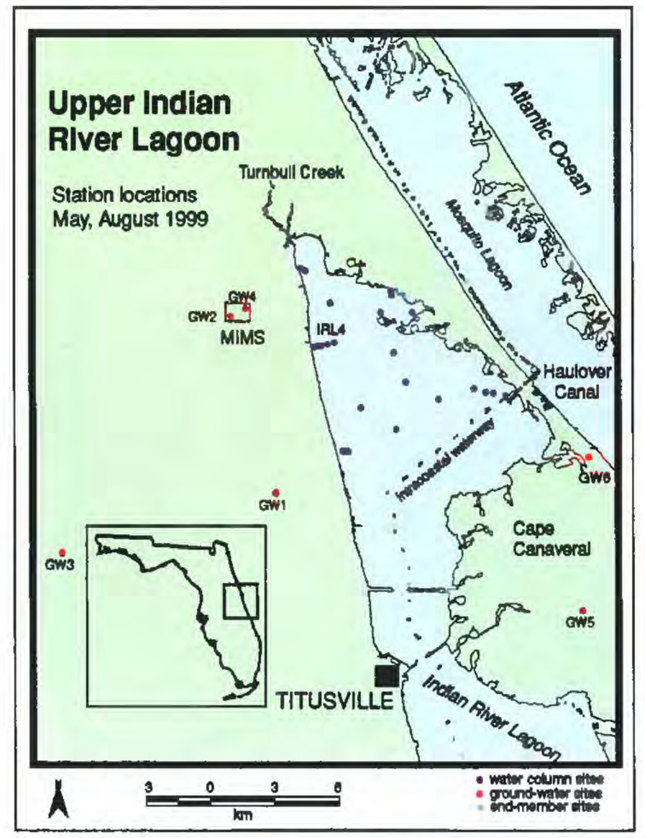

Figure 3. Site location map for upper Indian River Lagoon, Florida.

Hydrogeology

The hydrogeology along the northeastern coast of Florida can be broadly divided into two aquifer systems – the Surficial and the Floridan aquifer system (Fig. 4). Sand, silt and clays of the

Each submarine groundwater discharge technique has individual strengths and weaknesses. Seepage meters provide a direct measurement of localized flow. They can also easily provide 'clean' seep water samples. However, seep meters may be susceptible to possible artifacts caused by interaction of tides and waves, although such limitations have not been thoroughly tested. The radioisotopes are less difficult to sample in the field than using seepage meters, but their measurement requires sophisticated laboratory equipment that is not widely available. One important characteristic of the radioisotope techniques is that they provide an integrated value of seepage rates across the entire lagoon. They are thus complementary to the seepage meter technique.

Chloride concentrations indicate that only a minor component (1 - 5%) of seep water originates from meteoric ground water. This implies that 95 – 99% of the interstitial water has to be recycled lagoon seawater. The isotopic concentration of strontium ($^{87}Sr/^{86}Sr$) was nearly identical in the seep water and lagoon water, yet was measurably lower than that in modern seawater. The $^{87}Sr/^{86}Sr$ ratios were also systematically lower during the rainy season, reflecting the greater influx of seep water into lagoon water and short groundwater residence times. Nutrient concentrations were 3 – 5 times elevated in the seep water over the lagoon water, and suggest that sediment/water interface exchange processes, such as submarine groundwater discharge, are critical components of coastal nutrient budgets (Johannes, 1980; Krest et al., 2000).

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System	Series	Stratigraphic Unit	Hydrogeologic Unit	thickness (m)	Lithology	Hydrologic properties
Quarter-nary	Holocene to Upper Miocene	Undifferentiated surficial deposits	Surficial aquifer system	6-36	Discontinuous sands, clays, shell, and limestone	Sands, shell, limestone and coquina deposits provide local groundwater source
Tertiary	Miocene	Hawthorn Formation	Intermediate confining unit	30-150	Interbedded phosphatic sands, clays, limestone and dolomite	Limited-permeability clays
	Eocene	Upper: Ocala Limestone	Floridan aquifer system: Upper Floridan aquifer	30-100	Massive fossiliferous chalky to granular marine limestone	Principal source of ground-water
		Middle: Avon Park	Middle semi-confining unit	210-335	Alternating beds of granular and chalky limestone, dense dolomites	Low-permeability limestone and dolomite
			Lower Floridan aquifer: Upper zone			Principal source of ground-water
		Lower: Oldsmar Formation	Semiconfining unit	90-150		Low-permeability limestone and dolomite
			Fernandina permeable zone			High permeability, salinity increases with depth
	Paleocene	Cedar Keys Formation	Sub-Floridan confining unit	about 150	Uppermost appearance of evaporites, dense limestones	Contains high salinity water, low permeability

Figure 4. Hydrostratigraphy of northeastern Florida (adapted from Spechler, 1994).

corresponds to the Ocala Limestone and in some parts, the Avon Park Formation (Fig. 4). The Ocala Limestone is characterized by high permeabilities that can be enhanced along bedding planes, fractures and conduits.

Significant variations in ground-water levels occur seasonally (Fig. 5). Superimposed on such seasonal variations is a long-term decrease in the potentiometric surface that is largely attributed to increased groundwater withdrawals (Fig. 6). Nonetheless, recent potentiometric surface maps of the Upper Floridan aquifer indicate elevations that are above sea level for the entire length

Intermediate confining unit, which constitutes most of the Hawthorn Formation, separates these two aquifer systems (Leve, 1970; Spechler, 1994). The Surficial aquifer system consists of Miocene to Holocene interbedded sand, shell, silt, clay and dolomitic limestone strata. The Surficial aquifer system is mostly unconfined, although the hydrogeology can be very heterogeneous. Four clastic, highly regional surficial aquifers border the Indian River Lagoon including Terrace, Atlantic Coastal Ridge, Ten-mile Ridge, and Inter-ridge aquifers. Terrace aquifer occurs on the barrier islands separating Indian River Lagoon from the Atlantic Ocean. The Atlantic Coastal Ridge aquifer occurs in the northwestern region of Indian River Lagoon. This aquifer is composed of the Pleistocene Anastasia Formation, and provides most of the water supply for towns on the western edge of the northern Indian River Lagoon (Mims and Titusville).

The Floridan aquifer system can be further divided into two water-bearing aquifers (Upper and Lower Floridan), separated by less permeable semi-confining units. The Upper Floridan aquifer in the study area

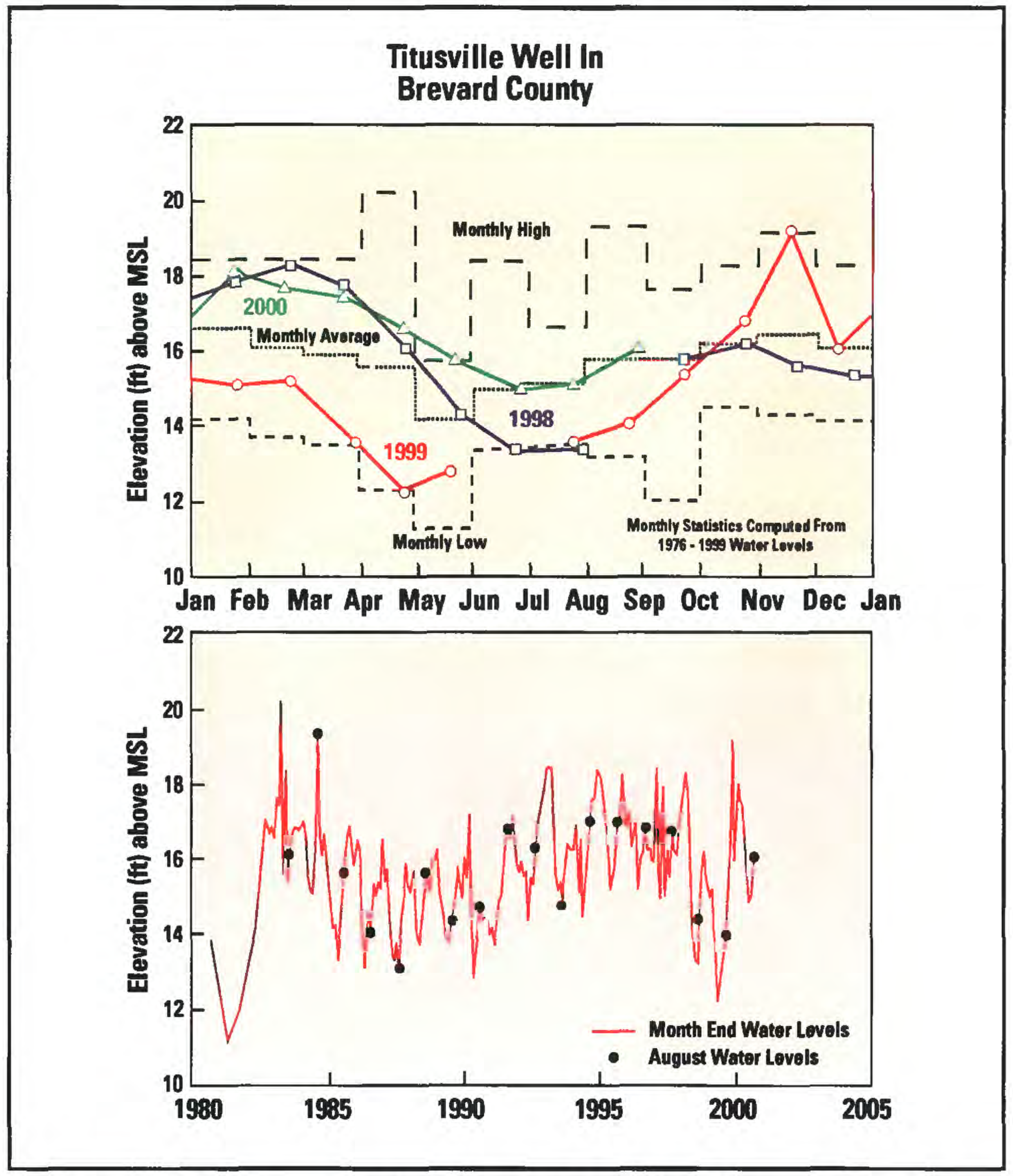

Figure 5. Hydrograph of a Titusville well (adapted from St. John's River Water Management District, 2000).

of Indian River Lagoon. Such potentiometric surface elevations increase from north to south, where the Hawthorn Formation increases in thickness. The elevated potentiometric surface of the Upper Floridan, combined with the general lack of a confining unit in the vicinity of the study area makes much of upper Indian River Lagoon a potential zone of submarine groundwater discharge.

Geochemistry

To derive estimates of ground-water seepage into Indian River lagoon, the following suite of tracers, chemical constituents and sampling devices were measured or utilized: nutrients, Cl^-, conductivity, pH, temperature, dissolved oxygen, $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $^{223,224,226}Ra$, ^{222}Rn, seep meters, multi-samplers, and benthic flux chambers (Martin et al., 2000). Seepage rates were spatially and temporally heterogeneous, yet similar to rates previously measured in Indian River Lagoon using identical techniques. The seepage rates ranged from 3 - 100 ml m^{-2} min^{-1} during May (dry season) to 22 - 144 ml m^{-2} min^{-1} during August (rainy season). The average value for all meters increased from 40 to 63 ml m^{-2} min^{-1} from the dry to the rainy season, implying that there may be a connection between rainfall and increased seepage rates. The heterogeneous nature of these rates is likely caused by fluctuations in sediment permeabilities and other geologic characteristics.

Radon-222 and Ra isotopes have previously provided regionally integrated estimates of seepage flux in varied coastal environments (Cable et al., 1996; Moore, 1999; Swarzenski et al., in press). Benthic fluxes of Ra to the Indian River Lagoon were calculated using three independent methods that rely on the activities of short-lived Ra isotopes: 1) lagoon

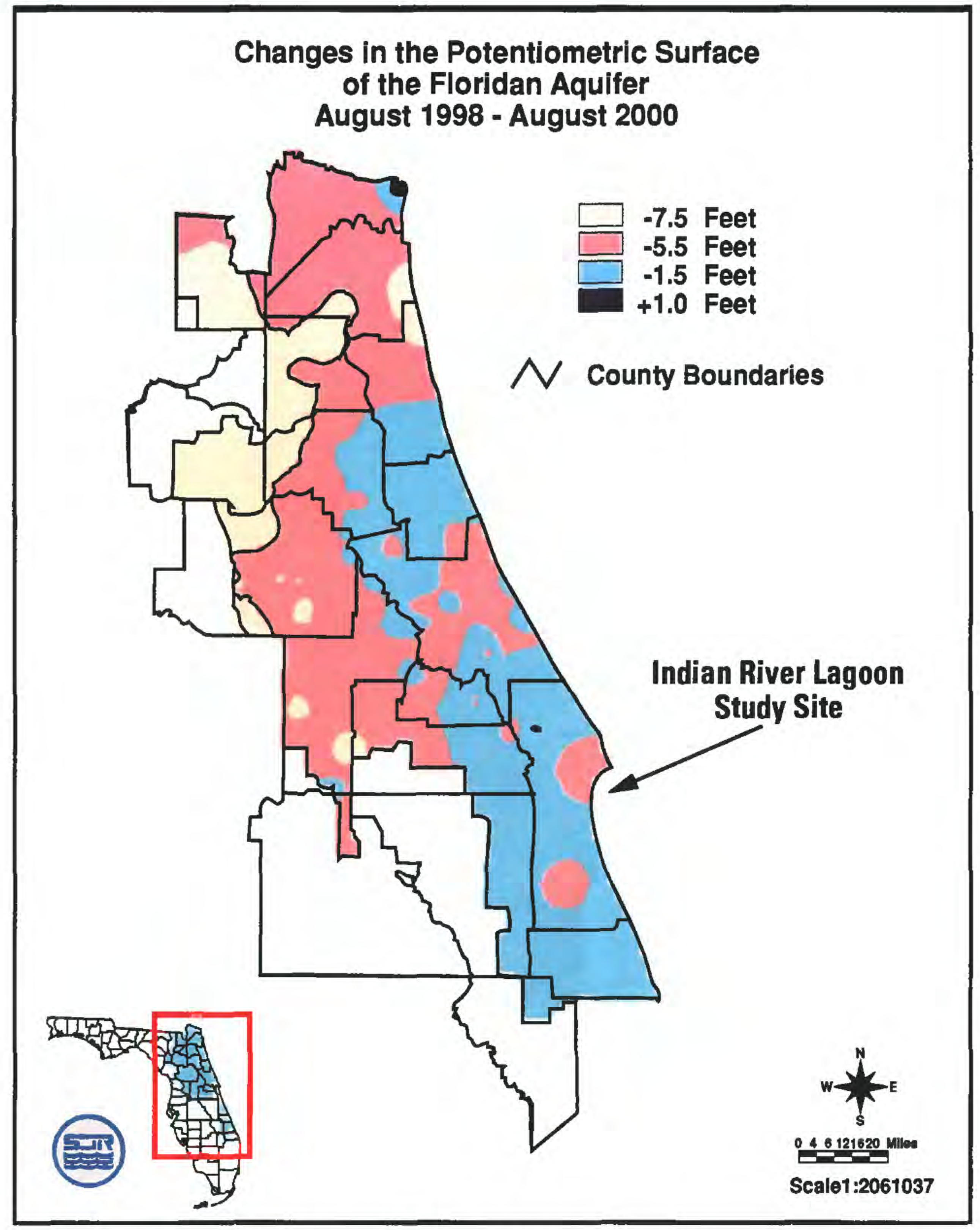

Figure 6. Potentiometric change map (adapted from St. John's River Water Management District, 2000).

budget, 2) benthic flux chambers and 3) pore-water modeling. The first two methods yield direct measurements of flux across the sediment/water interface, whereas the third technique generates an indirect flux estimate on the basis of pore-water Ra profiles. Calculations of the benthic flux of Ra range up to almost 500 dpm m^{-2} day^{-1}. Using ^{226}Ra pore-water activities, a maximum upward subsurface water flow of about 5 - 17 cm day^{-1} is required to sustain these fluxes. These values are similar to the values measured directly with the seepage meters.

By using ^{222}Rn and ^{226}Ra as mass balance tracers of seepage flux to the northern Indian River Lagoon, it is possible to obtain measurements of seepage that are independent of the short-lived Ra isotopes. Assumptions required for this mass balance approach are that negligible effects were observed from surface water exchange to the lagoon, tides, and diffusion from the sediments. Analogous to the short-lived Ra isotopes, seepage fluxes measured on the basis of excess ^{226}Ra activities are similar in magnitude to those estimated using seepage meters.