



Groundwater Discharge as an Important Land-Sea Pathway in Southeast Asia

Final report for APN project 2004-16NSY-Taniguchi

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ABSTRACT

We hypothesize that many water quality and associated problems influencing coastal environments around the world today are related to past and on-going contamination of terrestrial groundwaters because those groundwaters are now seeping out along many shorelines. For example, chronic inputs of fertilizers and sewage on land over several decades has resulted in higher groundwater nitrogen which, because of slow yet persistent discharge along the coast, eventually results in coastal marine eutrophication. Such inputs may thus contribute to the increased occurrences of coastal hypoxia, nuisance algal blooms, and associated ecosystem consequences. As the main research component of this APN project, we have initiated direct measurements of groundwater discharge into Manila Bay, The Philippines by a variety of methods. These studies, which engaged scientists from several APN countries, will form a base for more extensive research throughout the Southeast Asian region.

Three lines of seepage meters were installed in transects along the coast at Mariveles, Bataan Province, Philippines during the period 8-10 January 2005. The seepage rates along the northern most line showed the highest submarine groundwater discharge (SGD) at rates of 7.1-10.9 cm day⁻¹. Additional methodologies employed during our fieldwork included automatic seepage meters, resistivity measurements, and use of natural radon as a groundwater tracer.

Another outcome of this project concerned the organization of a regional workshop concerning groundwater discharge into Southeast Asian seas as well as the resulting coastal management implications. The workshop, held in Thailand, was attended by 30 participants from 8 different APN countries. This report provides the results from the fieldwork in Part I and a summary of the workshop's conclusions in Part II.

Part I

Fieldwork on Groundwater Discharge into Manila Bay, The Philippines

INTRODUCTION

The direct discharge of groundwater into the coastal zone, called “submarine groundwater discharge” (SGD) is now recognized as a significant, but poorly quantified, pathway between land and sea. As such, SGD acts as a source of nutrients and other dissolved species, including contaminants, to coastal waters and ecosystems. While the overall flow of fresh groundwater into the ocean is likely no more than about 6% of the river flow on a global basis, it has been estimated that the total dissolved salt contributed by SGD may be as much as 50% of that contributed by rivers (Zektser, 2000).

We proposed to use this APN project to begin the task of assessing the importance of groundwater discharges in selected coastal zone areas of SE Asia. Realistically, this is a huge endeavor, much more ambitious than can be accomplished by one small research team in a one-year period. We see this as an opportunity, however, to introduce this type of research to the coastal scientific and planning communities in the region who can then proceed on a larger scale in a systematic fashion over the long term.

Specific examples of the ecological impact of groundwater flow into coastal zones have been given by Valiela et al. (1978, 1990, 1992, 2002), who showed that groundwater inputs of nitrogen are critical to the overall nutrient economy of salt marshes. Corbett et al. (1999, 2000) estimated that groundwater nutrient inputs are approximately equal to nutrient inputs via surface freshwater runoff in eastern Florida Bay. Bokuniewicz (1980) and Bokuniewicz and Pavlik (1990) showed that subsurface discharge accounts for greater than 20% of the freshwater input into the Great South Bay, New York. Follow-up studies by Capone and Bautista (1985) and Capone and Slater (1990) showed that groundwater is a significant source (~50%) of nitrate to the bay. Lapointe et al. (1990) found significant groundwater inputs of nitrogen and dissolved organic phosphorus to canals and surface waters in the Florida Keys and suggested this may be a key factor for initiating the phytoplankton blooms observed in that area. Nitrogen-rich groundwater is also suspected of nourishing *Cladophora* algal mats in Harrington Sound, Bermuda (Lapointe and O'Connell, 1989). In the cases cited above, shallow groundwaters were enriched in nitrogen because of contamination from septic systems. In some pristine coral reef environments, groundwater inputs were shown to contribute significantly to reef nitrogen budgets in Discovery Bay, Jamaica (D'Elia et al., 1981) and Ishigaki Island, Japan (Umezawa et al., 2002). Groundwater was also shown to be a significant component of terrestrial nutrient and freshwater loading to Tomales Bay, California (Oberdorfer et al., 1990). Johannes (1980), investigating coastal waters off Western Australia, stated that “it is ... clear that submarine groundwater discharge is widespread and, in some areas, of greater ecological significance than surface runoff.”

Manila Bay is one of the areas heavily affected by harmful algal blooms in the Philippines. *Pyrodinium bahamense* var. *compressum* (PBC) blooms have been occurring almost annually in Manila Bay since 1988 but have ceased since 1999. The blooms have been previously attributed to eutrophication. However, the occurrence of PBC blooms in Malampaya Sound (Palawan), which has relatively clean waters, has weakened this hypothesis. Furthermore, the blooms in Manila Bay are typically initiated along the western coast of the bay off the southeast coast of Bataan where the water, relative to the head of the bay, is relatively clean. Thus, some other mechanism other than surface loading of nutrients must trigger these outbreaks. The steep gradients and abundance of artesian wells along the southeast coast of Bataan indicate possible high levels of SGD and inspired the site selection for this study.

CHARACTERISTICS OF MANILA BAY/BATAAN PENINSULA

Manila Bay is a semi-enclosed bay located on the southwestern part of Luzon Island between 14°15' - 14°50' N and 120°30' - 121°00' E (**Fig. 1**). It has a surface area of 1800 km² with a coastline of approximately 190 km. It has an average depth of 25 m and is approximately 52 km long, with widths varying from 19 km at its mouth to 56 km inside the bay. The mouth is divided into a South Channel and a North Channel by Corregidor Island and the Caballo Islands, which reduce the net width of the entrance to only about 10 km. Slightly less than 4 km wide, the North Channel has a maximum depth of 71 m, whereas the South Channel, somewhat less than 6 km wide, is no more than 47 m deep. The deepest parts of both channels are adjacent to the intervening islands. Tides along the coast of the Manila Bay are diurnal and within the microtidal range. The estimated mean tidal range for Port Lamao, Bataan is 1.09 m.

The study area selected for this project lies along the southeastern coast of the Bataan Peninsula. It is part of a small, elongate drainage basin that contains the east-southeast-flowing Lucanin River and has an area of roughly 1,120 ha. The topography of the basin is rolling, mostly 5% slopes but some as much as 14%, with a relatively very narrow, flat coastal area. The highest elevation in the basin is about 330 m.

Bataan has two pronounced seasons - a dry season (November to April) and a wet season (May to October). The average annual rainfall in Limay, about 11 km north of the study area, is 3,000 mm y⁻¹. In Balanga, about 25 km north of the study area, the mean monthly temperature varies from 25.5°C to 29.0°C with an average annual temperature of 27.1°C. The coolest months are from December to February while the warmest months are April and May.

The upper slopes of the mountain range in Limay and Mariveles are made of Pliocene-Quaternary non-active cones (pyroxene andesite) and dacitic and andesitic plugs. Most of the middle and lower slopes are Pliocene-Quaternary semi-consolidated pyroclastic rocks and/or coarse volcanic debris. Quaternary sediments underlie the lower reaches of some of the larger rivers and very narrow coastal strips.

A general land use map was obtained from the Mariveles Municipal Planning and Development Office (**Fig. 2**). Almost one-third of the Lucanin River basin consists of built-up areas. The agricultural area accounts for about 30%. Mixed fruit tree, coconut and irrigated rice paddy are the major agricultural crops in the area. A large portion of the industrial area in northeastern Mariveles is occupied by the industrial park of the Philippine National Oil Co. Petrochemical Development Corp. in The major development in the area is the Batangas Dos where petrochemical processing (polypropylene, polyethylene and polyvinyl chloride) plants occupy a 280 ha area. The upper parts of the drainage basins in Mariveles and Limay are covered with forest. The forest cover of the Lucanin River basin is roughly 15%.

The aquifers in the eastern part of the Bataan Peninsula are associated with Pliocene to Quaternary sand- to gravel-sized volcanoclastic sediments derived from the nearby inactive volcanoes. Confining layers, mainly composed of fine (clay- to silt-sized) ash, form discontinuous layers at different levels in the lower slopes (**Fig. 3**). The area directly north of the study area is underlain by a thick (about 18 m) fine ash layer that extends laterally for at least 1½ km. Low electrical resistivity zones at and near the surface also suggest the presence of this layer. However, this clay layer does not extend south to the study site. The well nearest to the

study site, DRU-10, indicates the presence of two confining layers, each about 3 m thick, between depths of 21 and 34 m below ground level. It is believed that these closely spaced confining layers extend to the study area because the free-flowing wells in Lucanin are about 50 m deep. The base of the unconfined aquifer is projected to extend at least several meters below surface in the survey area.

Transmissivity values derived from constant discharge pumping tests of the partially confined aquifers range commonly from 270 to 730 m² day⁻¹. The hydraulic conductivity values are rather low, usually within the range of 2.2 to 5.1 m day⁻¹. The low hydraulic conductivities can be explained by the very poor sorting of the sediments due to the presence of subordinate amounts of clay. Based on well logs, the materials of the unconfined aquifers in the study area are inferred to be the same as the confined aquifers north of the study area.

EXPERIMENTAL METHODS

Automated Seepage Meters and Resistivity Measurements

Automated seepage meters have been developed over the past decade using a variety of approaches including heat pulse methods (Taniguchi and Fukuo, 1993, 1996; Krupa et al., 1998), ultrasonic measurements (Paulsen et al., 2001), electromagnetic methods (Rosenberry and Morin, 2004) and continuous heat flow measurements (Taniguchi and Iwakawa, 2001, Taniguchi et al., 2003). Four continuous heat – type automated seepage meters were located at 200, 250, 300, and 350 m distance offshore from the coast along a central transect line in the study area (**Fig. 4**). The continuous heat-type automated seepage meter is based on the effect of heat convection due to water flow by measuring the temperature gradient of the water flowing between the downstream and upstream positions in a flow tube with a diameter of 1.3 cm. The principle of this automated seepage meter is described in detail by Taniguchi and Iwakawa (2001) and Taniguchi et al. (2003).

The average depths of the seawater at the seepage meter locations were 0.9, 1.2, 1.5, and 1.8 m at locations A, B, C, and D, respectively. The area of the chamber of these seepage meters is 0.255 m². Measurements of SGD using these automated seepage meters were performed every ten minutes from January 8 to 11, 2005. The tidal (sea) levels were also recorded every 10 min at station D using a pressure transducer. Conductivities and temperatures of waters within the chambers were measured continuously by Conductivity-Temperature-Depth (CTD) sensors (DIK 603A CTD, Daiki Rika Kogyo, Co., Ltd.) which were installed inside each of the chambers of the four seepage meters.

Resistivity under the seabed and land surface at a transect line perpendicular to the coast was measured by a Sting R1 IP/Swift AGI instrument. The number of probes used was 14, and the length of the transect line was 130 m (the interval length between each probe was 10m). The Wenner method and RES2DINV ver. 3.50 Geotomo Software was used for the analyses of the resistivity.

Manual Seepage Meters

The assessment of SGD in the Manila Bay using manual seepage meters (MSM) was conducted during three days from 8th to 10th of January 2005. There were 12 MSM (**Fig. 5**) in use, which were placed in the seabed along three transects (lines) perpendicular to the shoreline (**Fig. 4**). Seepage meters N1 (N = north), C1 (C = central), and S1 (S = south), which belong to

the first row, were placed at the distance of 200 meters from the coast. The second row of the seepage meters N2, C2 and S2, which were placed at an average depth of about 2 meters, at 270 meters from the coast line. The third row of MSM (N3, C3 and S3) were placed at the average depth of 2.5-3.0 meters of the distance of 340 meters from the coastline. The fourth row of MSM (N4, C4 and S4) were placed at the average depth of 4 meters at the distance of 410 meters from the shore.

Radon Measurements

An advantage of geochemical tracers such as natural radon and radium isotopes is that the coastal water column integrates the tracers coming into the system via various groundwater pathways. Smaller-scale variations, which are not of regional interest, are smoothed out. Thus, the tracer approach is a reasonable way to deal with the large spatial heterogeneity problems that are invariably associated with groundwater discharges. Several studies have now shown that radon is an excellent tracer of groundwater discharge (Burnett et al., 1996; Cable et al., 1996; Corbett et al., 1999, 2000; Hussain et al., 1999; Kim and Hwang, 2002; Burnett and Dulaiova, 2003; Garrison et al., 2003; Abraham et al., 2003). Radon works as a tracer because it is greatly enriched in groundwater relative to ocean water, behaves conservatively in seawater, and is relatively easy to measure.

Our automated radon system (Burnett et al., 2001) analyses ^{222}Rn from a constant stream of near-surface water (driven by a submersible pump) passing through an air-water exchanger that distributes radon from a running flow of water to a closed air loop. The air stream is fed to a commercial radon-in-air monitor (Durrige RAD-7) that determines the concentration of ^{222}Rn by collection and measurement of the α -emitting daughters, ^{214}Po and ^{218}Po . Since the distribution of radon at equilibrium between the air and water phases is governed by a well-known temperature dependence, the radon concentration in the water is easily calculated.

Individual radon measurements from samples collected from seepage meters and a groundwater well on land were performed using an attachment to the RAD-7 analyzer called a "RAD-H₂O." This device allows one to sparg a 250-mL sample with air, which is then dried and measured for radon by the RAD-7.

The main principle of using continuous radon measurements to decipher rates of groundwater seepage is that if we can monitor the inventory of ^{222}Rn over time, making allowances for losses due to atmospheric evasion and mixing with lower concentration waters offshore, any changes observed can be converted to benthic fluxes required to maintain the observed radon inventories (**Fig. 6**). Although changing radon inventories in coastal waters could be in response to a number of other processes (sediment resuspension, long-shore currents, etc.), we feel that the advective transport of groundwater (Rn-rich pore water) through permeable sediment is usually the dominate process. Thus, if one can measure or estimate the radon concentration in the advecting fluids, we can convert the ^{222}Rn fluxes obtained in the mass balance to water fluxes by dividing the radon fluxes by the radon concentration of the groundwater.

Nutrient Analyses

Water samples from seepage meters and ambient seawater samples were immediately filtered and analyzed for dissolved phosphate, ammonium, and nitrate (nitrate + nitrite) in the laboratory on site following recommended procedures (Strickland

and Parsons, 1972). Aliquots of all water samples were kept frozen and taken back to Chulalongkorn University, Thailand for the analysis of total dissolved N and P and silicate. Dissolved organic N and P were obtained by difference between the total and inorganic nutrient concentrations.

RESULTS AND DISCUSSION

Estimation of Flow via Dupuit Calculation

The quantity of seepage flow in the unconfined aquifer in the lower slopes of the Lucanin River basin can be roughly estimated using the Dupuit equation. The assumption for the use of the Dupuit equation is that equipotential lines are vertical and flow lines are horizontal. Such conditions can be met if the area where data are taken is not too close to the coast. Hydraulic head measurements were taken roughly 150 m from the shoreline.

The discharge per unit width of the unconfined aquifer, q' is:

$$q' = K/2 ((h_1^2 - h_2^2)/L)$$

where, K = hydraulic conductivity (estimated at 3.63 m day^{-1})

h_1 = hydraulic head at point 1 (2.12 m)

h_2 = hydraulic head at point 2 (1.77)

L = horizontal distance between the two points (27 m)

Using the assumed values, we calculate that the estimated discharge per unit width, q' is:

$$q' = 0.0915 \text{ m}^2 \text{ day}^{-1}.$$

General Strategy Concerning Experimental Assessment of SGD

The geochemical tracers that have been used for assessment of SGD, radon and radium isotopes do not provide information on the extent of fresh versus saline components. Radon should provide total flow, as both fresh and saline water will pick up radon during transit through a coastal aquifer. Radium should be more representative of the saline flow as radium adsorbs to particles in fresh water and is released into saline water due to ion exchange processes. So in principle, one could evaluate SGD using both radioisotopes with the expectation that the radon would provide a higher (fresh + saline) result while the radium isotopes would provide just the saline flow. The difference would thus be the freshwater input. Unfortunately, in systems where seawater recirculation dominates, the two values would be very close and the resulting uncertainty in the freshwater estimate by difference very large.

One can, of course, use direct measurement via seepage meters and use continuous conductivity measurements to evaluate the extent of the fresh versus saline water flow. The difficulty with this approach is that a seepage flux chamber only sees a very small area of the seabed and groundwater discharges tend to be very patchy. Thus, the best overall experimental approach may be to use a combination of approaches in order to provide the most unambiguous data set. That is the line of attack taken in this investigation.

Freshwater-Seawater Interface Observations

The cross-sectional results of resistivity measurements along the transect lines which are parallel to the coast at the lowest tide and at the mid-tide on Jan. 8, 2005 are shown in **Fig. 7**. Fresher pore waters (red color) under the seabed were found during the low tide at the N line.

Temporal changes in resistivity from low tide to high tide on Jan 9, 2005 are shown in **Fig. 8**. These observations show that the freshwater-saltwater interface moves toward land during the rising tide, and moves offshore during the falling tide. Thus the relative amounts of fresh versus saltwater that seep through the sediment at any one location is likely to vary in response to this moving interface.

Seepage Meter Results

SGD along the near shore portion of the N line had the highest seepage rate (**Fig. 9**) while the S line showed a higher rate in the station farthest away from shore. Temporal changes in seepage rate, tide and electric conductivity of SGD are shown in **Fig. 10** for two of the automatic meters. Diurnal variations of SGD were found which matches the tidal period in this area. The SGD rates increased with decreasing tidal level as has been observed in several other areas. The conductivity of the SGD was observed to decrease with increasing SGD flow during low tide, which implies that the freshwater component of SGD also increases during low tide. Because of the high variability in time and space of the seepage rates encountered in this study, we suggest that in order to properly evaluate SGD in Manila Bay, longer term monitoring is required.

Radon Measurements

We first used radon and conductivity in a qualitative manner at the study site by running a multi-detector radon analysis system (Dulaiova et al., 2005) together with a temperature-conductivity probe while underway at slow speed ($\sim 5\text{-}6 \text{ km hr}^{-1}$) from a small fishing boat (the “Sweet Caroline”). This survey was conducted initially along about 25 km of coastline north and south of our base and then about 7 km directly offshore. The alongshore survey was run as close to the coastline as possible but this was often hampered by shallow waters. In general, we were greater than $\sim 0.5 \text{ km}$ offshore. The results (**Fig. 11**) showed generally low radon concentrations ($< 1.0 \text{ dpm L}^{-1}$) with an area about 10 km north of the base showing the highest radon ($\sim 2 \text{ dpm L}^{-1}$). The offshore transit showed a rapid drop off in radon to levels below 0.5 dpm L^{-1} . The low concentrations are thought to be an effect of the influence of South China Sea water (low in radon) that enters Manila Bay and travels along the western shore during winter months.

Samples for radon analysis were collected from two seepage meters and one groundwater production well onshore. The well was artesian and was developed into the main confined aquifer, about 40 m below the surface in this area. The salinities of the waters in the two seepage meters indicated a mixture of fresh water with seawater. The sample with the lower salinity also showed the highest radon and a plot of radon versus salinity shows that the seepage meter measurements extrapolate back to a radon activity at zero salinity that is essentially the same as the groundwater well (**Fig. 12**). This may indicate that there is freshwater leakage from the underlying confined aquifer in spite of the presence of confining layers as mentioned earlier.

During the last few days of the fieldwork (Jan. 9-11), we anchored the boat about 500 m off the base in about 2.5 m water depth. The multi-detector radon system was set for an integration time of 20 minutes and run continuously for approximately 36 hours to develop a time-series record at one location. The results (**Fig. 13**) showed an increasing trend the first day with a peak in the radon concentration just at the low tide point. There was then another systematic increase with the 2nd peak at an even higher concentration and occurring a few hours after the high tide early on Jan. 11th. Applying the radon mass balance model with the appropriate corrections for atmospheric and mixing losses and an estimated radon groundwater concentration of 240 dpm L^{-1} (**Fig. 12**), we calculate a range in the total fluid advection from 0-

17 cm day⁻¹ with a mean and standard deviation of 3.9 ±4.9 cm day⁻¹. Note that the standard deviation reported here is not an estimate of uncertainty but a reflection of the actual variation of advection in this non steady-state system. The radon results thus support those from the seepage meter measurements that suggest the SGD in this area of Manila Bay is not a constant flow but displays tidal cycle scale variations.

When the radon concentrations from the time-series are plotted together with conductivity readings measured outside a nearby seepage meter (**Fig. 14**), it is clear that there is distinct freshening of the water at precisely the same time as the maximum in the radon early on Jan. 10th and very close to the maximum early the next day. Thus, there is no doubt that a freshwater component, most likely from groundwater seepage, is the source for the excess radon observed at this site.

Estimated SGD Nutrient Fluxes

In general, nutrient concentrations of seepage waters were significantly higher than that of near-shore seawater, except nitrate that was higher in seawater than in the seepage meter waters (**Fig. 15**). The ranges and mean concentrations of the nutrients measured both in seepage water and ambient seawater are shown in **Table 1**.

Table 1. Ranges and means of nutrient concentrations in seepage waters and near-shore seawater.

Seepage water	NH ₄ (μM)	NO ₃ (μM)	DON (μM)	PO ₄ (μM)	DOP (μM)	SiO ₂ (μM)
Range	15.3-133	0.4-1.6	10.4-291	0.3-3.8	0.0-34.6	65.1-112
Mean ± s.d.	59.3±36.7	0.6±0.3	105±75.4	1.8±1.0	2.6±8.6	84.7±15.6
Seawater						
Range	1.1-6.1	0.6-1.6	0.5-23.4	0.3-0.9	0.1-4.4	18.1-49.5
Mean ± s.d.	2.6±1.5	1.0±0.4	11.1±8.9	0.5±0.2	1.5±1.7	29.7±9.9

Based on the average seepage fluxes measured in this study, we estimated an average integrated seepage (8.6 L m⁻¹ min⁻¹ or 12.4 m³ m⁻¹ day⁻¹), which is the estimated total seepage flow per unit width of shoreline. Integrating seepage measurements in this manner assumes that the entire width of the seepage face has been sampled by the meters. Since there was still some seepage detected in the meter farthest from shore, our estimate may be a minimum value. The integrated water flux is a total flow (fresh + salt water) and is useful for comparing biogeochemical inputs by groundwater flow to inputs via river flow. By multiplying the average nutrient concentrations in the seepage water (**Table 1**) by the average integrated flow rate (and making appropriate unit conversions), we can calculate the nutrient flux per unit width of shoreline (**Table 2**).

Table 2. Estimates of nutrient fluxes via SGD into Manila Bay

	NH ₄	NO ₃	DON	PO ₄	DOP	SiO ₂
Fluxes (moles m ⁻¹ day ⁻¹)	0.73	0.0078	1.3	0.022	0.032	1.0

In order to make a comparison to river fluxes, we first estimate the total riverine nutrient fluxes of dissolved inorganic nitrogen (DIN = NH₄+NO₃) and inorganic phosphate based on

literature values. Manila Bay is reported to receive $24 \times 10^9 \text{ m}^3 \text{ yr}^{-1}$ of runoff from approximately 17,000 km^2 of watershed comprising 26 catchment areas (EMB-DENR/UNEP 1991; EMB 1992). The two major areas contributing fresh water to the bay are the basins of the Pampanga and Pasig rivers, which respectively contribute about 49% and 21% of the total runoff. Other, smaller river systems contribute (26%) and the balance of 4% comes from the net precipitation over the bay (EMB 1992). The 9,000- km^2 catchment area of the Pampanga River Basin is the largest, and includes the Angat River and other river systems in the provinces of Pampanga, Bulacan, and Nueva Ecija. The Pasig River Basin has a watershed area of 3,900 km^2 and includes the Marikina and Laguna de Bay catchment areas. The average river discharge from the Pampanga River Basin into Manila Bay is $391 \text{ m}^3 \text{ s}^{-1}$ and the Pasig River has an average flow of $170 \text{ m}^3 \text{ s}^{-1}$.

Based on the literature values for river discharge cited above and average nutrient concentrations for nutrients in rivers flowing into Manila Bay from a study by EMB-DENR/UNEP (1991), we have calculated riverine DON and PO_4 fluxes and made a comparison to our estimated fluxes via SGD by calculating an “equivalent shoreline” length (**Table 3**). This estimate represents the length of shoreline in Manila Bay that would produce the same DIN and PO_4 flux as the two most important rivers that drain into the bay. This assumes, of course, that the measurements made at the study site off Bataan are characteristic of all of Manila Bay. While we have no way of evaluating this assumption at this time, we feel that this rough calculation is still useful for illustrating the potential importance of subsurface discharges. The calculated shoreline lengths for equivalent inputs of DIN via SGD are 450 and 200 km for the Pampanga and Pasig rivers, respectively. These estimates are on the same order as the total shoreline length of Manila Bay (~190 km). This implies that SGD may be as important a source of inorganic nitrogen as each of the two main river systems that discharge into Manila Bay. The equivalent shoreline lengths for PO_4 are an order of magnitude longer than the DIN lengths implying that SGD is less important here as a source of inorganic phosphate.

Table 3. Estimates of river and SGD fluxes for DIN and PO₄. A comparison is based on the ratio of the river-to-SGD derived fluxes. The “equivalent shoreline” represents a length of Manila Bay shoreline required to produce the same flux as the river input.

Pampanga River Basin					
	River Conc. μM	River Flux moles day ⁻¹	Seepage Conc. μM	Seepage Flux moles m ⁻¹ day ⁻¹	Equivalent Shoreline km
DIN	10	3.38E+05	59.9	7.43E-01	4.5E+02
PO4	1.7	5.74E+04	1.8	2.23E-02	2.6E+03
	River Discharge = 391 m ³ s ⁻¹				
	Integrated seepage flux = 1.24E+04 L m ⁻¹ day ⁻¹				
Pasig River					
DIN	10	1.47E+05	59.9	7.43E-01	2.0E+02
PO4	1.7	2.50E+04	1.8	2.23E-02	1.1E+03
	River Discharge = 170 m ³ s ⁻¹				
	Integrated seepage flux = 1.24E+04 L m ⁻¹ day ⁻¹				

CONCLUSIONS

Based on a variety of geophysical, hydrological, and oceanographic techniques performed by our team in a coastal area of the Bataan Peninsula, our main findings are as follows:

- (1) Seepage meter and geochemical tracers provide consistent results of estimates of SGD into Manila Bay.
- (2) The waters seeping into Manila Bay along the southeastern shoreline of Bataan are a mixture of fresh and saline waters. The total discharge is highest at low tide and the freshwater component of this flow is also more important at that time.
- (3) The source of the freshwater component may be from the confined aquifer in spite of the presence of confining layers in this area. This could be an effect of ruptures in the confining units providing pathways for the artesian waters.
- (4) The SGD displays high variability in time and space in the area studied. Thus, more precise descriptions should involve longer-term monitoring than was possible in during our study.
- (5) Resistivity profiles show that the saline-freshwater interface moves on a tidal time scale.
- (6) Inorganic nitrogen fluxes via SGD appear to be comparable in magnitude to DIN fluxes from each of the two major rivers that drain into Manila Bay. While these estimates are admittedly very rough, it implies that nitrogen fluxes into Manila Bay may be seriously underestimated if underground inputs are ignored.

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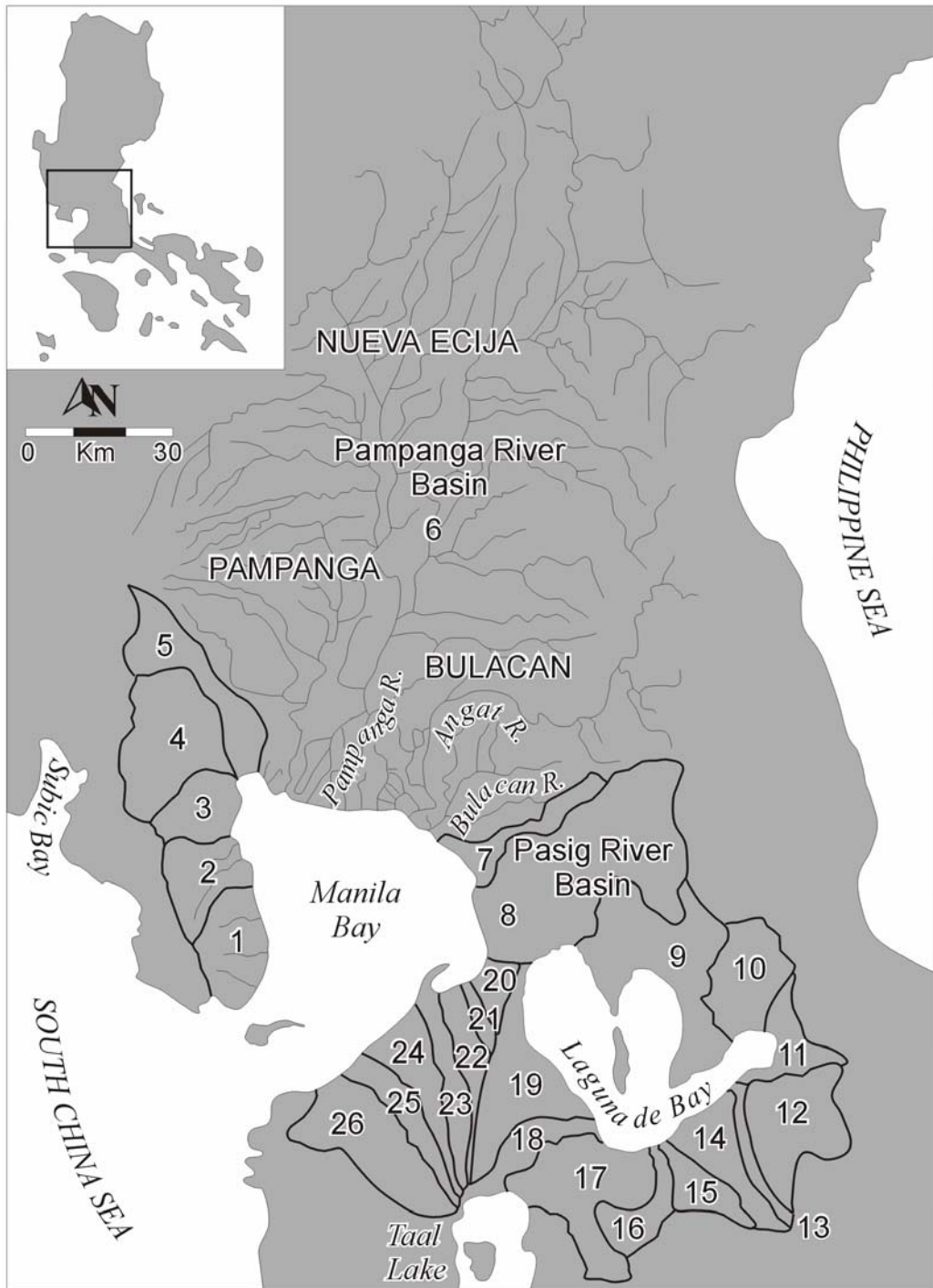


Figure 1 Index map of Manila Bay, The Philippines. The APN fieldwork was performed along the southeast coast of the Bataan Peninsula.

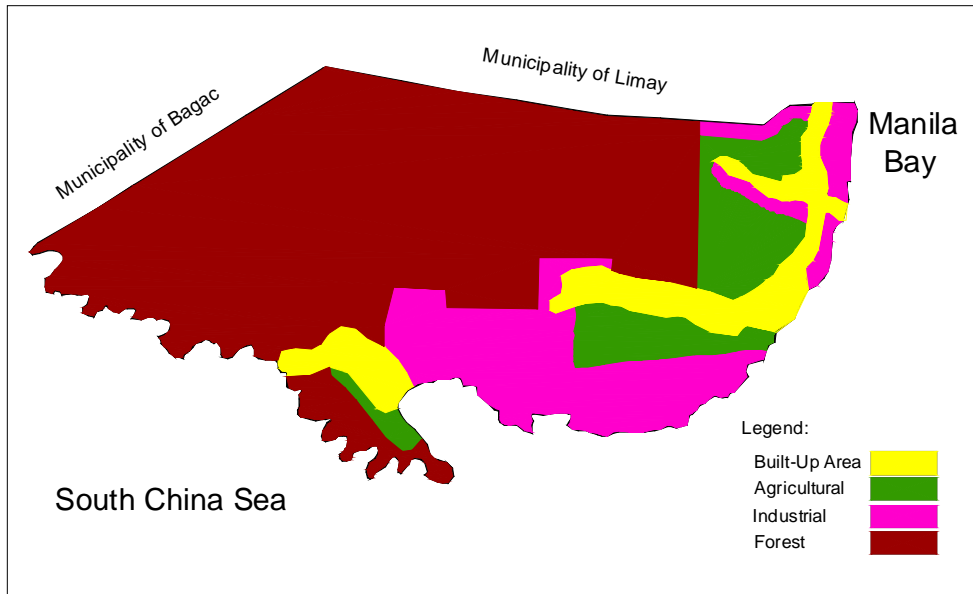


Figure 2. General land use map for the Mariveles region, Bataan, where our field studies were conducted. (Source: Mariveles Municipal Planning and Development Office).

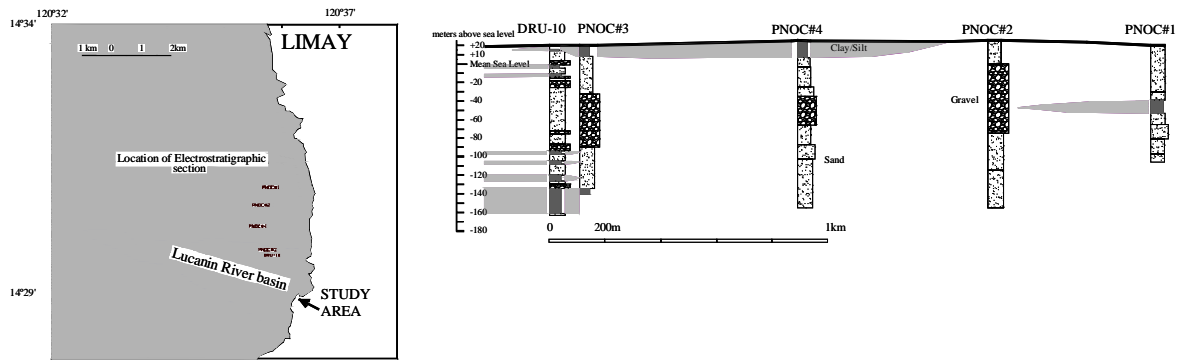


Figure 3. Left: Location of wells and electrical resistivity stations in the vicinity of the study area. Right: Correlation of well logs north of the study area.

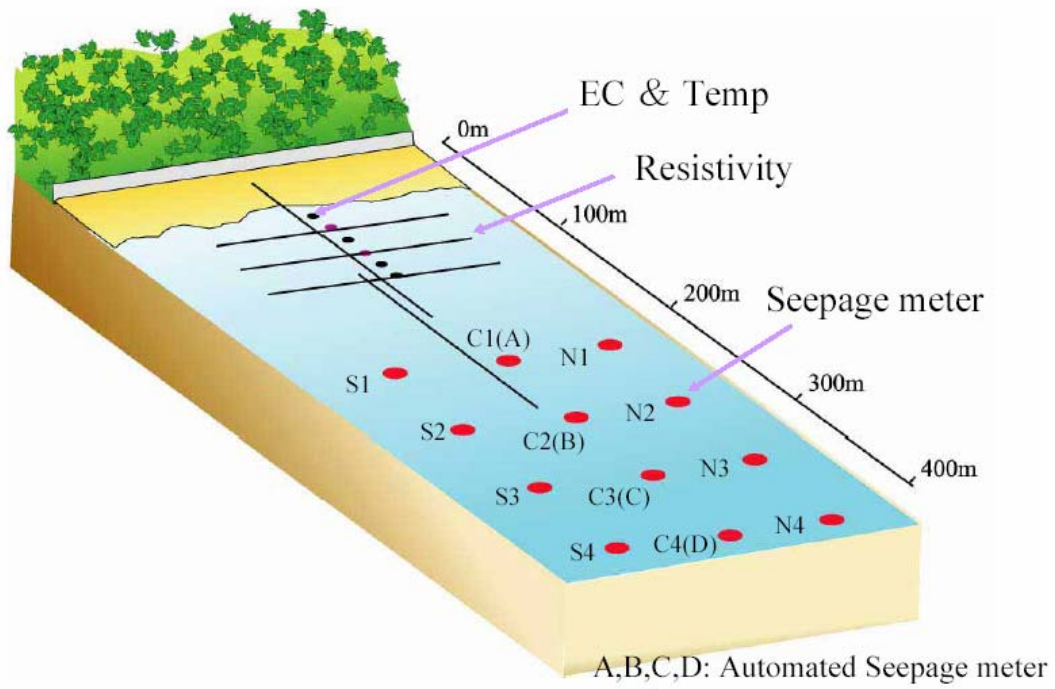


Figure 4. Schematic diagram showing locations of seepage meters (circles) and resistivity measurements (line segments).



Figure 5 Manual seepage meters prepared at NIGS-UP (National Institute of Geological Sciences, University of The Philippines) specifically for this study.

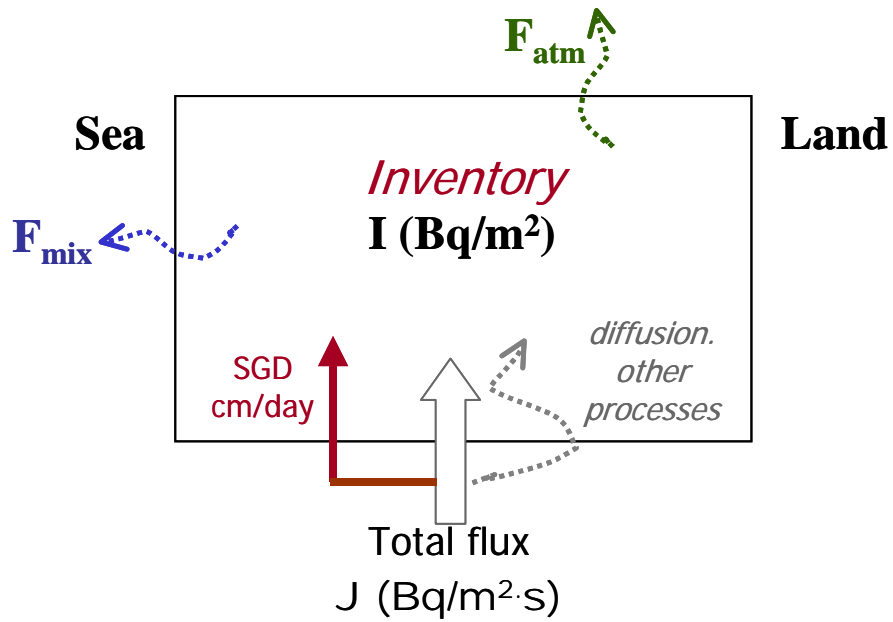


Figure 6. Conceptual model illustrating use of continuous radon measurements for estimating submarine groundwater discharge in a coastal zone via a mass balance approach. The inventory refers to the total amount of excess ^{222}Rn per unit area. Decay is not considered because the fluxes are evaluated on a very short time scale (usually <1 hour) relative to the half-life of ^{222}Rn .

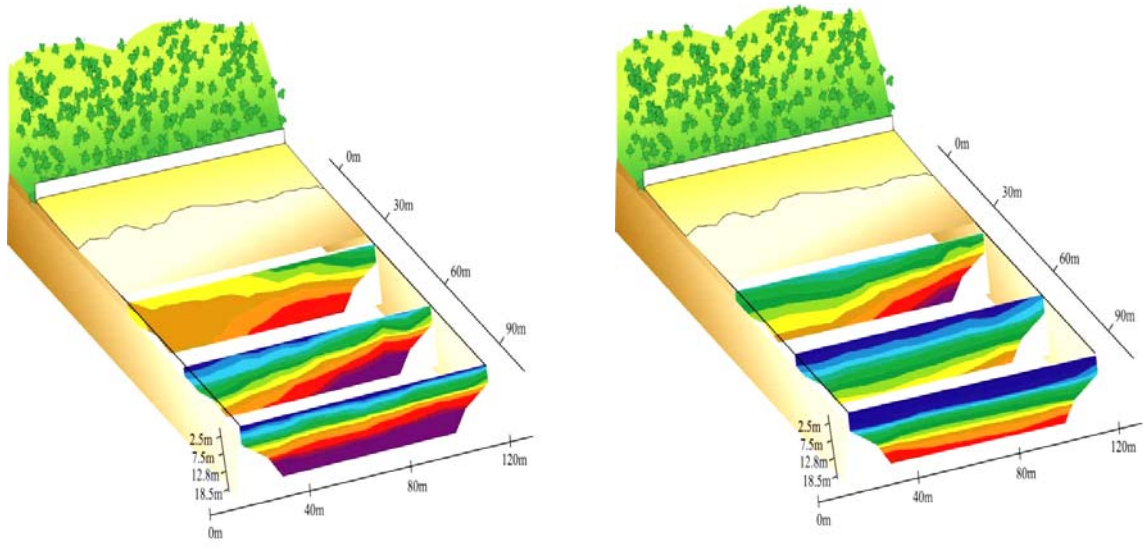


Figure 7. Resistivity at low tide (left) and during middle tide (right). Warm colors (as red) are fresh and cool colors (blue) saline.

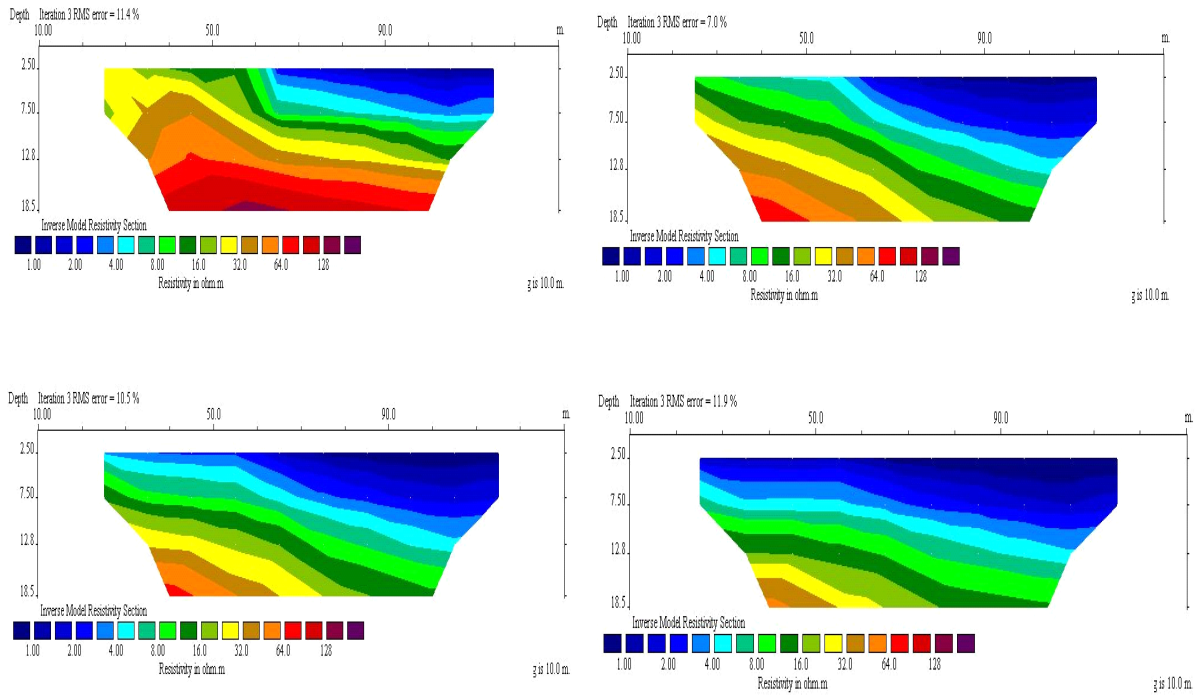


Figure 8 Temporal changes in resistivity from low tide (top left; 06:00, Jan 9, 2005) to high tide (bottom right; 18:00, Jan 9, 2005)

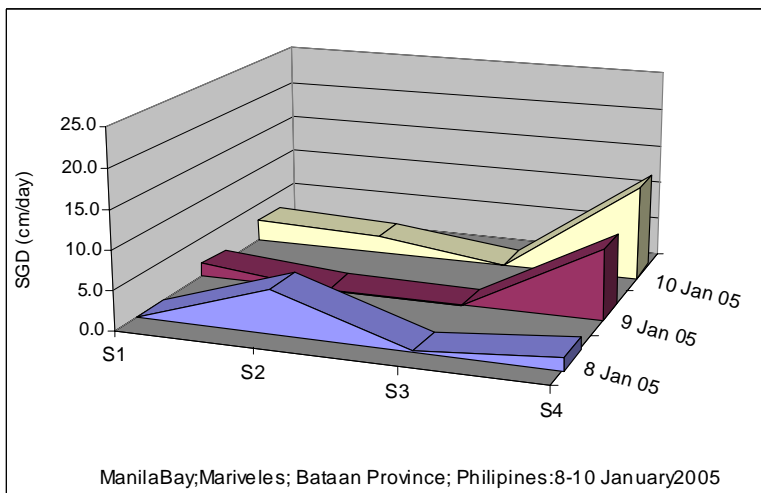
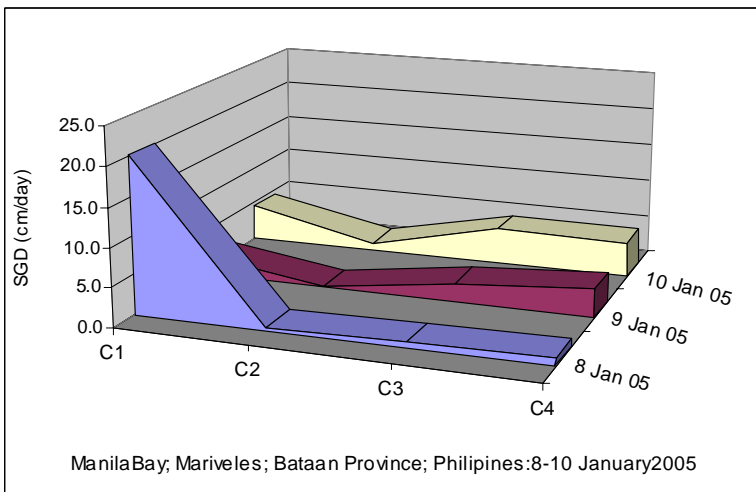
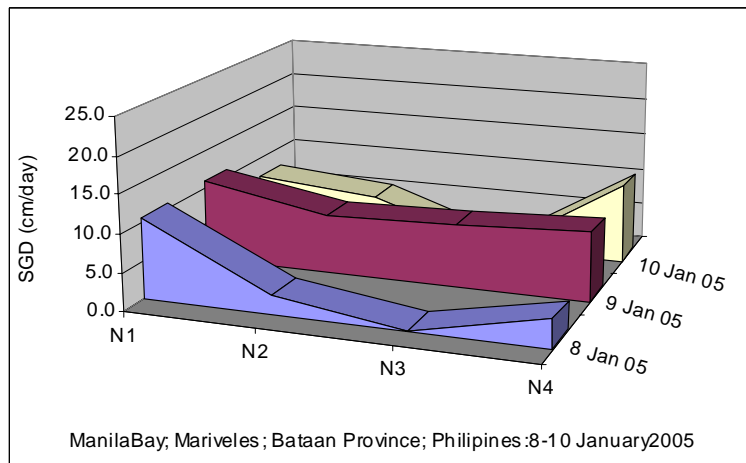


Figure 9 Seepage rate summaries for north (top), central, and southern (bottom) transect lines established off the Bataan Peninsula, 8-10 January 2005.

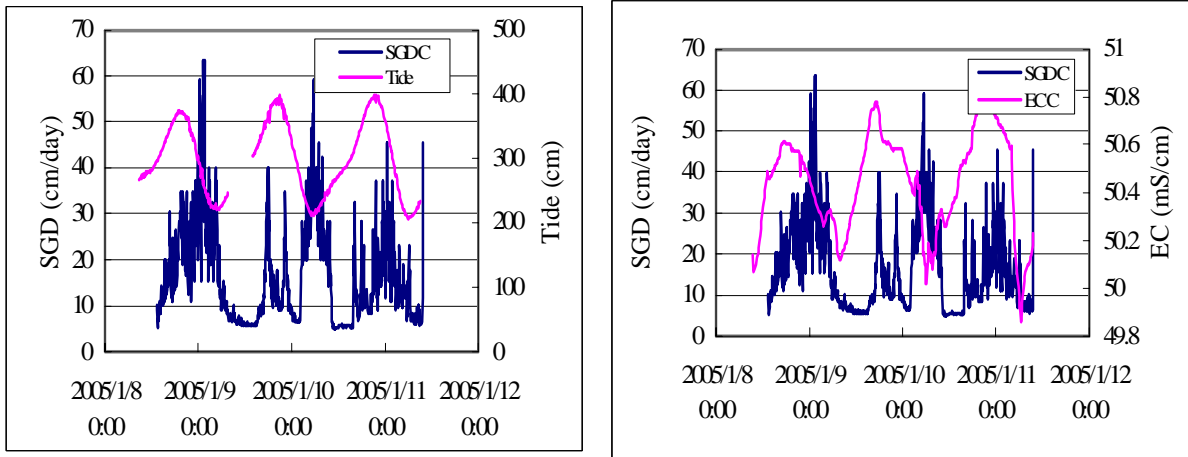


Figure 10. Temporal changes of SGD, water level, and electric conductivity of SGD at location C based on measurements from an automatic seepage meter.

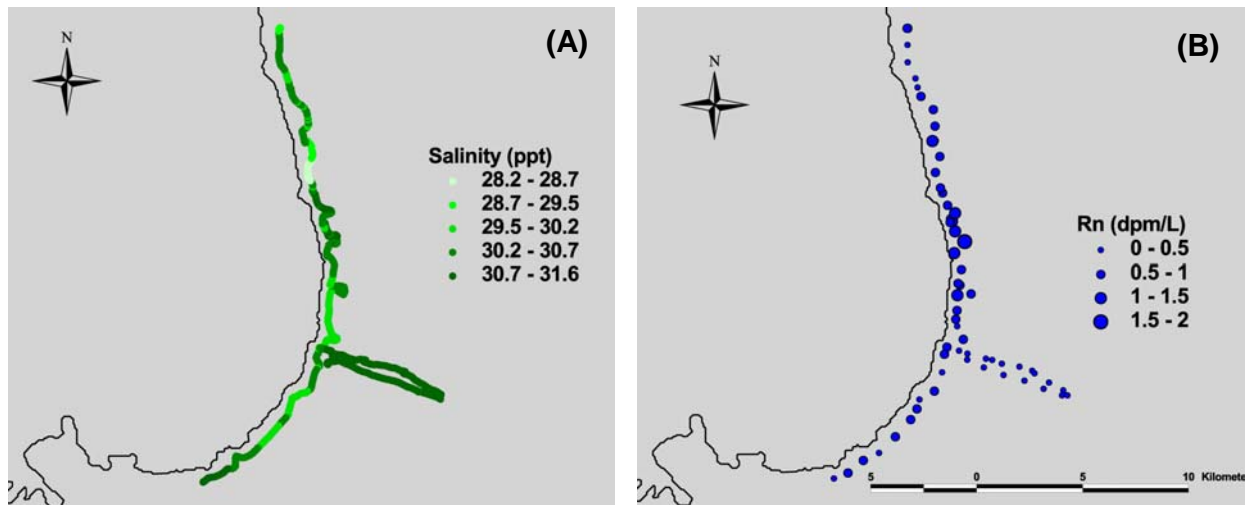


Figure 11 Distribution of (A) salinity (psu) and (B) Rn-222 (dpm L^{-1}) in surface waters along the coast of the Bataan Peninsula and along a shore normal transit out into Manila Bay.

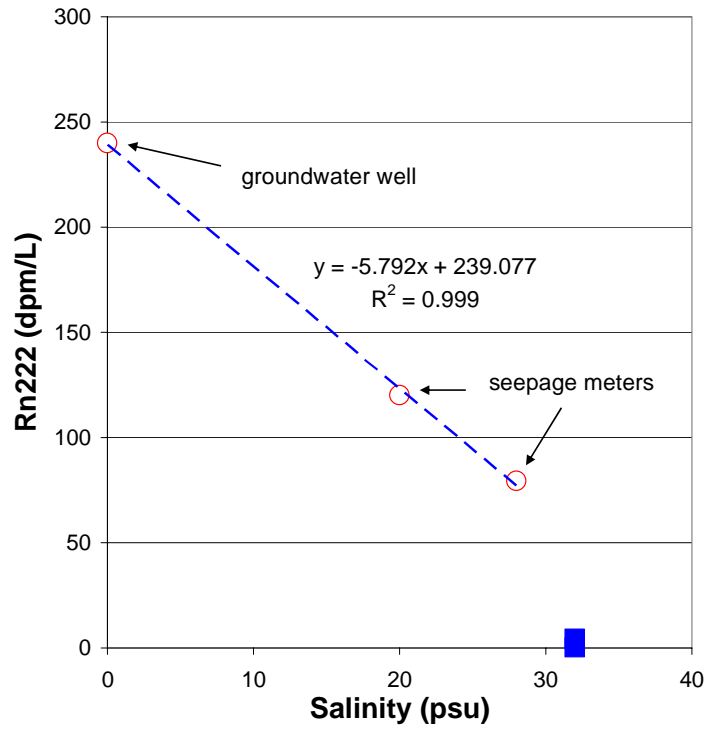


Figure 12 Radon-222 versus salinity in two seepage meters and one groundwater well (open circles). The solid square represents the range in measurements made in the overlying water column.

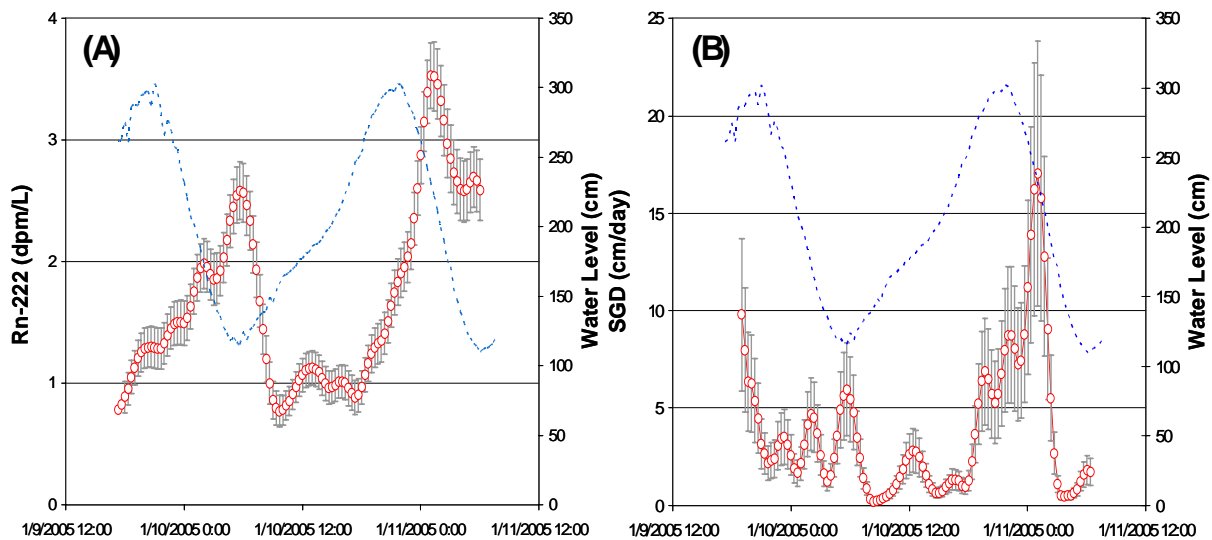


Figure 13. Time-series results showing (A) radon concentrations (open circles) and water level variations (dashed line); and (B) estimated SGD rates in cm day^{-1} (open circles) again with the water level record. Uncertainties in the radon concentrations are 1σ and are based solely on counting statistics. The uncertainties in the SGD rates include error estimates associated with measuring the inventories, assessing atmospheric evasion, and estimating mixing losses.

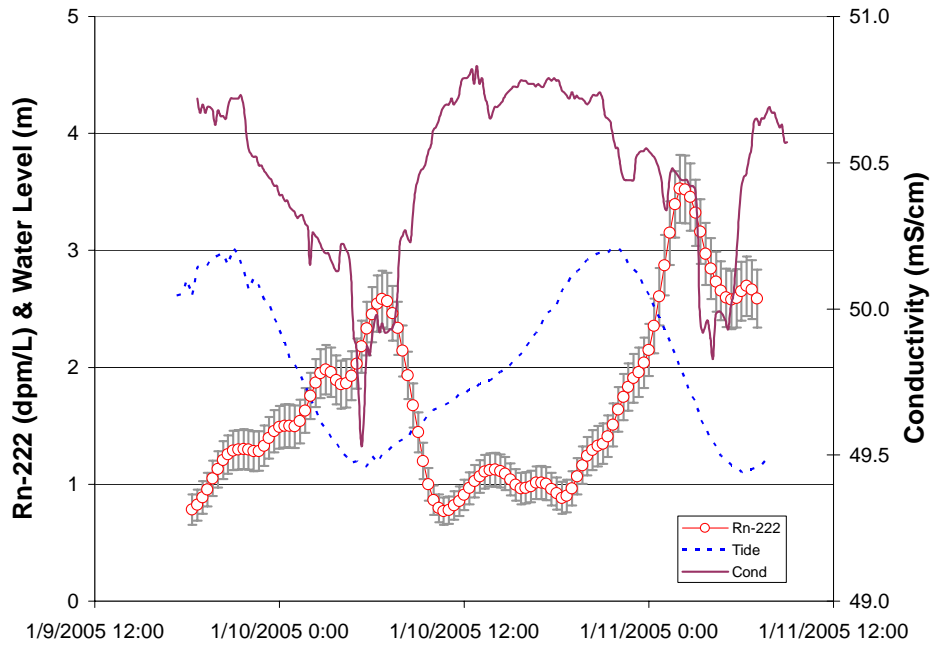


Figure 14 Radon concentrations (open circles), conductivity (solid line), and water level (dashed line) variations over an approximately 36-hour period during Jan. 9-11, 2005 at a station ~500 m off the base.

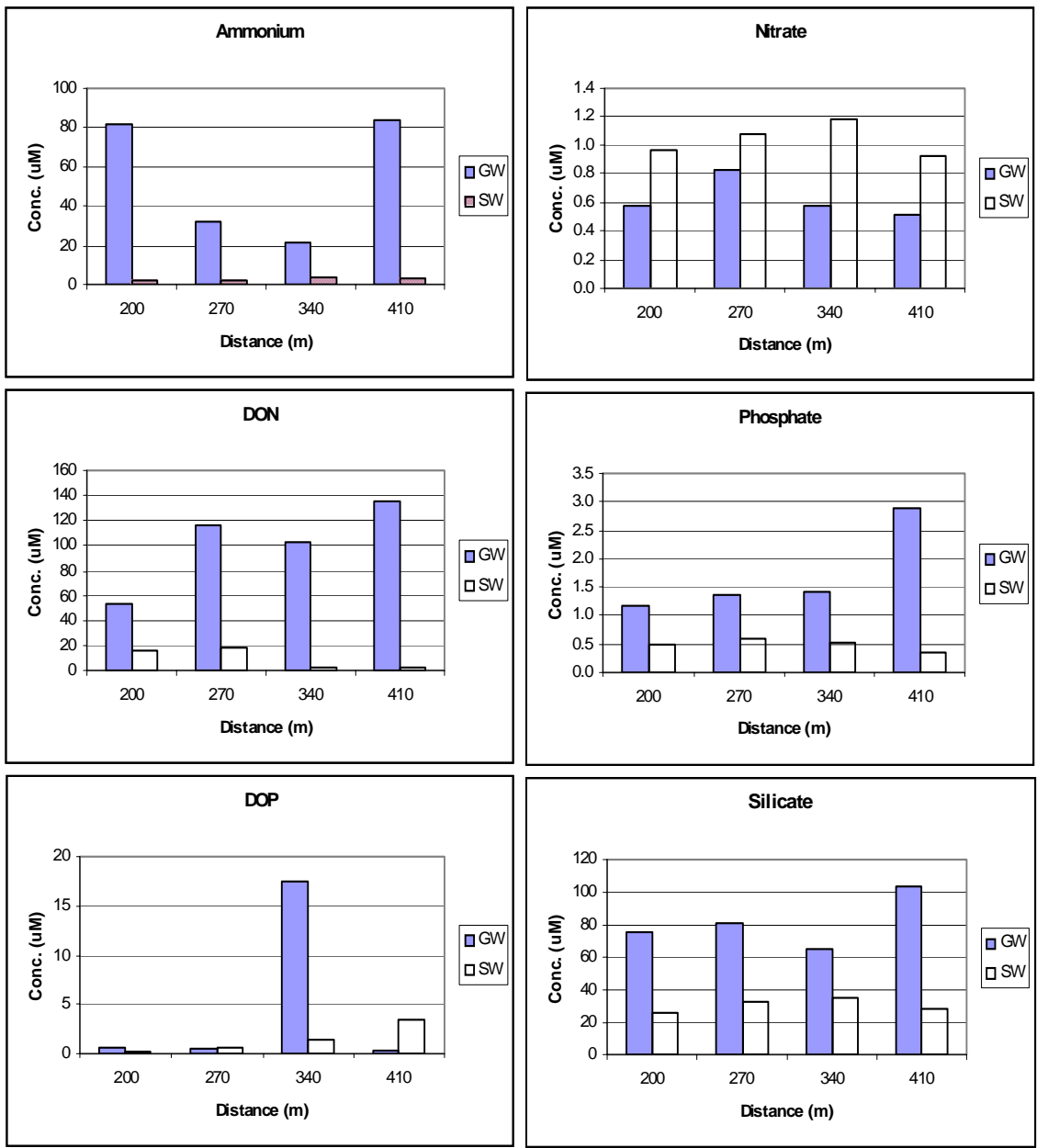


Figure 15. Variation of nutrient species in groundwater (GW) and near-shore seawater (SW) along the transect line with increasing distance from shore.

Part II

**APN Workshop on
“Groundwater Discharge as
an Important Land-Sea
Pathway in Southeast Asia”
at Sichang Island, Thailand
on 8-10 February, 2005**

APN Workshop Summary

The APN workshop was held between 8 - 10 February 2005 at Sichang Island, Thailand. Participants include scientists from Cambodia, Indonesia, Japan, Korea, Malaysia, Myanmar, Philippines, Russia, Twaiwan, Thailand, USA, and Vietnam. In the morning session of February 8, M. Taniguchi (Japan), W. Burnett (USA), and H. Bokuniewicz (USA) introduced the characteristics, methods, and management implications of submarine groundwater discharge (SGD). In the afternoon session, case studies of SGD from Florida Gulf of Mexico coast, Florida Keys, Biscayne Bay, Suruga Bay, Osaka Bay, Shiranui Bay, and Inland Asian seas were presented by W. Burnett (USA), M. Taniguchi (Japan), and E. Kontar (Russia). In the second day, the research results and potential SGD study sites in Asian countries including Korea, Taiwan, Philippines, and Thailand, Cambodia, Malaysia, Indonesia, Vietnam, Myanmar were presented.

The agenda of APN workshop and abstracts of each presentation are attached.

The future studies of each participated country were discussed and summarized as below.

Taiwan (C. Wang)

- will conduct further investigation & study to the SGD in Taiwan.
- will explore the impact of human activities on the water resources in Taiwan (for metropolitan & rural areas)
- will participate the future meetings, workshops, & will provide stable isotope training courses to scientists of southeastern countries.

Japan (M. Taniguchi)

- Research Institute for Humanity Nature (Japan) will have a project on subsurface environments including submarine groundwater discharge in Asian countries such as Thailand, Philippines, Indonesia and Taiwan. Capacity building in Southeast Asia is very important, and JICA may play a role of transfer the techniques for evaluations of the SGD.
- Other activities on SGD in Japan are going on with the funds of JSPS etc, then we may be able to invite Southeast Asian scientists for joint works or teaching. Collaborations with APN, SEA-START, GWSP (Global water System Project)-Asia and other regional research frameworks are extremely important for the future works, as well as international research agencies such as UNESCO, LOICZ/IGBP, etc.

Korea (G. Kim)

- will add more SGD data from the various areas of the Korean coastal zone
- will determine the SGD associated flux of more chemical species such as organic pollutants, radionuclides, trace elements, organic carbon, and pesticides.

Russia (E. Kontar)

- will apply to international funding organization from the consortium made during this APN project for another project related to the groundwater – seawater interactions in the coastal zone.

- Possible title of the new proposal: influence of tsunami waves of the coastal aquifers: risk assessment, post event studies
- Possible funding organization: IOC/UNESCO and IHP/UNESCO

Thailand (Sompop Rungsupa)

- will standardize and improve manual seepage meters
- will set permanent line at Sichang Island for long-term monitoring of SGD and associated chemical transport in comparison with results from groundwater well nearby.
- will conduct SGD at another site in Chonburi Province the East Coast of the upper Gulf of Thailand.

Thailand (Penjai Sompongchaiyakul/Sopit Piromlert)

- Proper plan to study fluxes and quality of SGD to the coastal sea of this area is on processing
- Analysis of water quality in term of carbon, nutrients, trace metals, stable isotopes and others will be carried on and calculation of their fluxes will be done.
- will study amount of groundwater discharge from urbanization that contaminate the coastal sea by means of groundwater and chemical mathematical model and isotope in southern Thailand.

Thailand (Gullaya Wattayakorn)

- will investigate SGD and the associated nutrients in other sites along the coastline of the Gulf of Thailand, using manual seepage measurements and tracers (in cooperation with Drs Wang and Burnett).
- Typological approach may be employed to classify the coastal types of Thailand. This will help in shortening the time need for field investigation. Coastal areas with high density of human impacts will be compared with the less impacted areas.

Indonesia (Robert Delinom)

- will give some information to some hydro-geologists in Indonesia about SGD.
- will make a presentation in Eco-hydrology workshop in August 2005, in Bali concerning the APN-SGD Program. Hosted by UNESCO, IHP, and Indonesian Institute of Sciences (LIPI)
- will make a proposal to Indonesian Government for a SGD research in Jakarta Bay.

Philippines (F. Siringan/J.M. Foranda)

- An echo-seminar will be given during the annual symposium of the Philippine Association of Marine Scientists (PAMS) to be held in October 2005.
- will look for opportunities to dovetail SGD work our research program funded by the local science ministry (Department of Science and Technology) addressing harmful algal blooms. The influence of SGD on coral reef zonation and degradation is also of interest to us.
- A typological approach using water table and aquifer parameters will be adopted to give us an initial picture of SGD variation. Students will be encouraged to work on SGD related topics for their thesis. We will continue and try to expand our collaborative work with foreign researchers.

Myanmar (Thazin Lwin)

- SGD work will be initiated in Myanmar through Ph. D. level graduate student work in the Chemistry Department, Rangoon University in Myanmar.
- Our university has limited experience and research facilities in SGD work thus we need assistance and collaboration with researchers from other countries.

Cambodia (KONG Meng)

- will take long term research project at Krong Preah Sihanouk catchment for groundwater investigation.
- will look for financial and technical support from many sources

APN Workshop

On

**“Groundwater Discharge as Important
Land-Sea Pathway in Southeast Asia”**

*8-10 February 2005
Sichang Island, Thailand*



*Asia-Pacific Network for Global Change Research
Research Institute for Humanity and Nature, Japan
Aquatic Resources Research Institute, Chulalongkorn University, Thailand*

APN Workshop Agenda

Tuesday, February 8:

08:30 AM: travel from Ambassador Hotel to Sri Racha, ferry to Sichang Island

14:00 PM: **Introduction to SGD**

- (1) Characteristics, fluxes, review of studied areas (*Makoto Taniguchi*)
- (2) Isotopic methods for assessment of SGD (*Bill Burnett*)
- (3) Coastal zone management implications of SGD (*Henry Bokuniewicz*)

PM **Case studies**

- (1) Florida – examples from Florida Gulf of Mexico coast, Florida Keys, Biscayne Bay (*Bill Burnett*)
- (2) Japan 1 –examples from Suruga Bay, Osaka Bay and Shiranui Bay (*Makoto Taniguchi*)
- (3) Inland Asian seas (*Evgeny Kontar*)

Wednesday, February 9:

09:00 AM: **SGD Studies in Asia**

- (1) Korea (*Guebuem Kim*)
- (2) Taiwan (*Chung-Ho Wang*)
- (3) Philippines (*Fernando Siringan/Joseph Foronda*)
- (4) Thailand (*Gullaya Wattayakorn*)

14:00 PM: **Coastal Zones in SE Asia & Potential SGD Study Sites**

- (1) Cambodia (*Kong Meng*)
- (2) Malaysia (*Ong Jin Eong*)
- (3) Indonesia (*Robert Delinom*)
- (4) Vietnam (*Cao Thi Thu Trang*)
- (5) Myanmar (*Thazin Lwin*)
- (6) Philippines (*Fernando Siringan*)
- (7) Thailand (*Sompop Rungsupa*)
- (8) Thailand (*Penjai Sompongchaiyakul*)

Thursday, February 10:

09:00 AM: New Projects

- (1) RIHN Project: Human Impact on the Subsurface Environment (Makoto Taniguchi)
- (2) Future plans (all participants)
- (3) Input for preparation of APN Report

14:00 PM: Travel to Bangkok (check into Hotel Ambassador)

18:00 PM Dinner hosted by SEA START

Friday, February 11:

09:00 AM

1. Departure of most participants
2. P.I. meeting and preparation of APN Report: Aquatic Resources Research Institute, Chulalongkorn University
3. Discussion of future proposals: RIHN and others (Bill, Makoto, Gullaya, Fernando, Anond Snidvongs, Evgeny, Somkid, Guebuem, Chung-Ho, Robert, and others)

Departure: PM

Abstracts (in order of presentation)

Characteristics, Fluxes, Review of Studied Areas

Makoto Taniguchi

Research Institute for Humanity and Nature, Japan

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Abstract

Submarine groundwater discharge (SGD) is now recognized as a significant water and dissolved material pathways from land to the ocean. Previous reviews show the lack of SGD data in Asian coasts (Taniguchi *et al.*, 2002). International research organizations such as SCOR/LOICZ, IOC/IHP, IAEA, START and APN funded the researches on SGD recently. Intensive measurements through intercomparisons on SGD with different methodologies (Taniguchi *et al.*, 2003a) have been carried out in Florida, Sicily, Perth, New York, Brazil, Thailand, and Philippines.

Regarding the results from intercomparisons, SGD consists of SFGD (Submarine Fresh Groundwater Discharge) and RSGD (Recirculated Saline Groundwater Discharge). SGD rate changes with time by tidal effects (high-low tide and spring-neap tide), precipitation, and barometric pressure. SGD rate also changes with space by distance from the coast, location within the bay (curvature of the coastline), the distance from the adjacent river, and heterogeneity of the geology (Taniguchi *et al.*, 2003b).

Relationships between SGD and saltwater-freshwater interface, SFGD and RSGD, and phase lag of SGD and tidal changes, have also been evaluated by continuous measurements of conductivity of SGD and resistivity of the aquifer across the coast.

Although the process of temporal changes in SGD has been mostly evaluated in the previous intercomparisons on SGD, more studies on spatial integration of SGD and material transports by SGD are need in the future researches on SGD.

Taniguchi M, Burnett WC, Cable JE, Turner JV (2002): Investigation of submarine groundwater discharge. *Hydrol Process* 16:2115-2129.

Taniguchi, M., W.C. Burnett, J.E. Cable, J.V. Turner (2003a), Assessment methodologies of submarine groundwater discharge. M. Taniguchi, K. Wang, and T. Gamo eds., “*Land and marine hydrogeology*” Elsevier, Amsterdam, 1-23.

Taniguchi, M., W.C. Burnett, C.F. Smith, R.J. Paulsen, D. O’Rourke, S.L. Krupa, and J.L. Christoff (2003b), Spatial and temporal distributions of submarine groundwater discharge rates obtained from various types of seepage meters at a site in the Northeastern Gulf of Mexico. *Biogeochemistry*, 66, 35-53.

Tracing Groundwater Discharge into the Ocean via Continuous Radon-222 Measurements

William C. Burnett

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Abstract

Quantifying groundwater discharge into the ocean is difficult as there is no simple way to gauge the flow. Groundwater discharges are often diffuse with large spatial and temporal variations. Natural tracers are one way to approach this problem. Time-series measurements of natural Rn-222 can be used both to quantify groundwater discharges and examine the dynamics of these inputs. We use a continuous radon monitor to measure radon concentrations in the shallow coastal zone and a mass balance approach to calculate groundwater inputs. The change in radon inventories over time, after making appropriate allowances for inputs and losses during tidal fluctuations and atmospheric evasion, is used to estimate fluxes into and out of the coastal system (**Fig. 1**). Assuming that benthic fluxes of radon are driven mainly by groundwater (pore water) advection, one can convert calculated ^{222}Rn fluxes to water fluxes by dividing by the radon concentration of the advecting fluid.

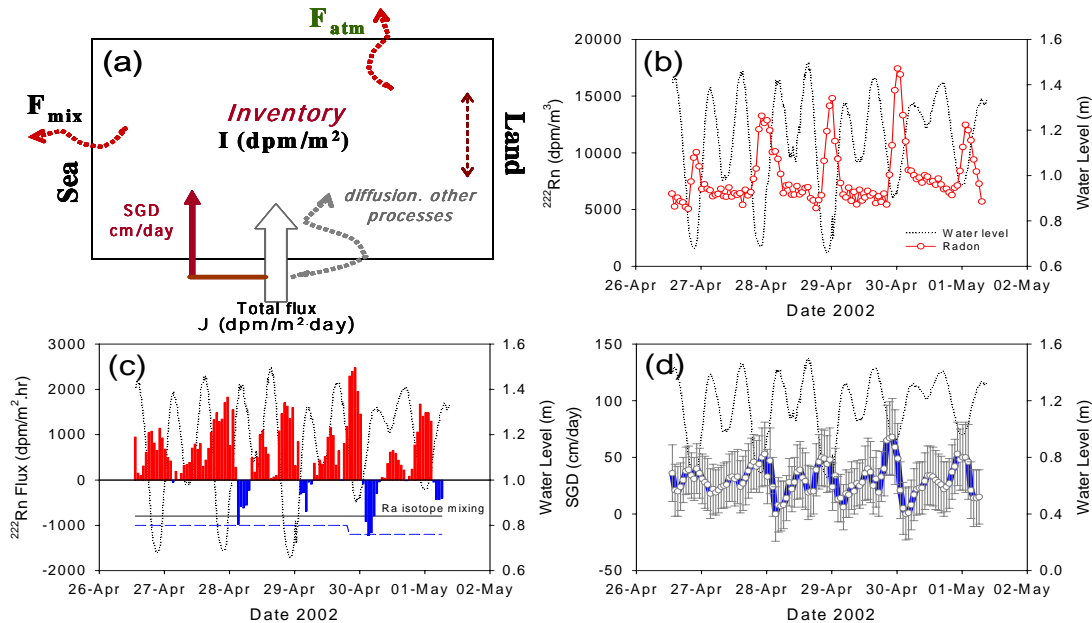


Figure 1. (a) Radon mass balance conceptual model showing how the measured inventory of ^{222}Rn in the water column is a balance between benthic inputs (assumed to be dominated by fluid advection) and outputs via atmospheric evasion and mixing with lower concentration waters offshore. (b) Example of a continuous Rn record from NW Florida together with the tidal record. (c) Calculated net Rn fluxes based on the change in inventory per unit time after correction for tidal variations and atmospheric losses (atmospheric evasion rates based on equations in Macintyre et al., 1995). The horizontal solid and dashed lines represent mixing losses of radon based on Ra isotopes and inspection of Rn fluxes, respectively. (d) Calculated fluid advection rates determined by dividing the radon fluxes by measured pore water ^{222}Rn activities. Estimated uncertainties include errors associated with measuring inventories, estimating atmospheric fluxes, and mixing losses. Detailed descriptions of the radon measurement techniques and modeling have been reported in Burnett et al. (2001a) and Burnett and Dulaiova (2003).

Integrating SGD into Coastal Zone Management

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Abstract

Coastal managers must control development especially to prevent depletion of potable water for coastal communities and for coastal dependent industry. Coastal populations also add pollutants to the groundwater from septic systems, agricultural practices, industrial waste, road runoff and a host of other sustained activities. Even if contaminants do not directly affect the potable water supply, their impacts in the coastal ocean can impair other management objectives, such as the sustainability of coastal fisheries, aquaculture or recreation. Submarine groundwater discharge (SGD) provides the links between coastal water use and the coastal ocean.

As a first step, coastal zone managers are faced with deciding if there is a “reason to believe” that SGD may be relevant in their jurisdiction. Measurements of SGD have been made at some hundred sites around the world, but in many other areas, anecdotal or indirect evidence of SGD exists. SGD might be distinguished by color, temperature or salinity fingerprint. The presence of elevated levels of radium or radon methane, hydrogen sulfide, silica or carbon dioxide may be indicative of a groundwater source. Geomorphic indicators of SGD can also be recognized; in Australia, rapid SGD through buried paleochannels create pits, locally referred to as “wonky holes” as far as ten kilometers from shore. A typology based on clustering techniques might be used to relate relevant characteristics of coastal regions where the importance of SGD is unknown, to other regions where SGD has been determined.

SGD can impact the coastal ocean in diverse ways. High nutrient loads carried by SGD, especially from developed coastal land, are known to cause eutrophication in restricted, open waters. Opportunistic macro algae, such as *Cladophora*, *Ulva*, *Enteromorpha*, and *Gracilaria*, are indicators of sewage enrichment that could be provided by SGD. The spread of macroalgal mats can displace eelgrass meadows (*Zostera marina*) and reduce productive habitat as it has in coastal embayments. In shallow embayments on Long Island (New York, USA), intense blooms of “brown tide”, a unicellular microalgae (*Aureococcus anophagefferens*) has devastated the scallop industry. SGD has been implicated in the occurrence of these nuisance algal blooms. During years of high SGD, bay salinities are reduced; blooms of mixed macroalgae and phytoplankton are fueled by dissolved, inorganic nitrogen. When SGD is low, however, salinities are high and production relies on remineralized nitrogen. Both of these conditions favor the “brown tide” organism. In another example, patches of *Marenzelleria viridis*, a polychaete tubeworm, mark lower salinity seeps on the floor and use these seeps as “stepping stones” to spread through more saline environments.

Submarine Groundwater Discharge Studies in Florida

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Abstract

The direct discharge of groundwater into the coastal zone has received increased attention in the last few years as it is now recognized that this process represents an important pathway for material transport. Assessing these material fluxes is difficult, as there is no simple means to gauge the water flux. To meet this challenge, a working group, first established by the Scientific Committee on Oceanic Research (SCOR) and the Land-Ocean Interactions in the Coastal Zone (LOICZ) project of IGBP began conducting a series of groundwater discharge assessment intercomparison experiments. This effort is now continuing with sponsorship from the International Atomic Energy Agency (IAEA) and UNESCO. Each intercomparison is held in a coastal setting with different hydrogeological characteristics (karst, coastal plain, glacial, volcanic). At each site a multi-disciplinary group of investigators make estimates of the magnitude of submarine groundwater discharge based on a variety of techniques including manual and automated seepage meters, natural isotopic tracers, artificial tracers, and hydrogeological modeling. The first such intercomparison was held in northwest Florida on the Gulf of Mexico in August 2000.

The study site is in an undeveloped, pristine region of Florida. The site is characterized by significant, near-shore seepage that is thought to originate from a surficial aquifer system and possibly additional inputs from the main Floridan aquifer. The surficial aquifer, predominately sand with some silt, is approximately 4 m thick. It is separated from the Floridan aquifer system (the Bruce Creek Limestone) by a thin section of the Intracoastal Formation, an argillaceous limestone that acts as a regional confining layer for the Floridan. Hydrogeologic measurements, manual and automated seepage meter readings, and tracer measurements were collected during the experiment.

Estimates of SGD based on manual seepage meters, radon, and radium isotopic measurements are similar (Table 1). The modeling results, however, indicated flows 8-10 times lower, perhaps because the models did not include transient processes such as tidal pumping. Reconciling the hydrological modeling results with the seepage meter and geochemical estimates will be an important aspect of upcoming research. While differences in spatial and temporal scales make such comparisons difficult, coordination of field measurements and modeling efforts is leading to important new insights.

Table 1. Discharge estimates made for a 20,000-m² domain at the Florida intercomparison.

Date 2000	Lee-Type Meters (m ³ /min)	Automatic Seepage Meters (m ³ /min)	Radium Isotopes (m ³ /min)	Continuous Radon Model (m ³ /min)
14 Aug	1.9	1.8	1.5	1.7
15 Aug	1.6			2.0
16 Aug	2.3			2.1
17 Aug	2.5			2.5
18 Aug				<8.9*

*Based on limited measurements (~6 hrs.) made during a period of high seepage (falling tide)

SGD in Japan – Examples from Suruga Bay, Osaka Bay and Shiranui Bay -

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Abstract

Submarine groundwater discharge (SGD) has been studied in several areas in Japan, as in Osaka Bay, Suruga Bay, and Shiranui Bay. Those areas are alluvial coasts, and annual precipitation in Japan is about 1800 mm. The relief of the morphology is generally steep, therefore high SGD is expected. Measurements on SGD have been done using automated seepage meters, piezometers, and resistivity cables.

In Suruga Bay, SGD rates were measured continuously by automated seepage meters to evaluate the process of groundwater discharge to the ocean in the coastal zone. The ratio of terrestrial fresh-SGD to total-SGD was estimated to be at most 9 % by continuous measurements of electrical conductivity of SGD. Semi-diurnal changes of SGD due to tidal effects and an inverse relation between SGD and barometric pressure were observed. Power Spectrum Density (PSD) analyses of SGD, sea level and groundwater level show that SGD near shore correlated to ground water level changes and SGD offshore correlated to sea level changes. SGD rates near the mouth of the Abe River are smaller than those elsewhere, possibly showing the effect of the river on SGD. The ratio of terrestrial groundwater discharge to the total discharge to the ocean was estimated to be 14.7 % using a water balance method (Taniguchi *et al.*, 2005).

Semi-monthly, diurnal and semi-diurnal variations of SGD were found in Osaka bay, Japan, by continuous measurements of SGD using newly developed automated seepage meters. SGD increased sharply from neap to spring tide with semi-monthly period. SGD also changes with diurnal and semi-diurnal periods due to changes in hydraulic gradient between the groundwater and seawater in the coastal zone. SGD variation with semi-monthly period by neap-spring tidal pumping is much larger than those with diurnal and semi-diurnal variations by tidal height changes (Taniguchi, 2002).

Relationships between SGD and the freshwater-saltwater interface are evaluated by continuous measurements of SGD rates, conductivity and temperature of SGD, and resistivity measurements across the coastal aquifer, Shiranui bay, Japan. Our measurements show that the processes of SGD differ between the offshore and near shore environments. SGD in the near shore can be explained mainly by connections of terrestrial groundwater, while offshore SGD rate is controlled mostly by oceanic process such as recirculated saline groundwater discharge.

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Asian Coastal and Inland Seas: GeoRisks and Sustainability

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Abstract

The Maritime GeoRisk project was recently accepted for funding by EU. The project objectives targeted research area directly related to the coastal and inland Asian seas. The general goal of the project – establishing an information point to eventually create a research consortium, which is capable of initiating and implementing a large international research project – meets the general objective of the INCO activities, “to help open up the European Research Area to the rest of the world”. The assessment of the potential of geo-hazards and their risks to populated areas is becoming an important domain of scientific research and mitigation management. Shelf zones are quickly becoming new major areas of industrial technological development owing to growing population in maritime regions and vast natural resources such as fish, oil, and gas available in these areas. Therefore, understanding risks of natural and human-made hazards in these areas contributes to strengthening the scientific and technological basis of a number of industries including oil/gas production and transport. Traditional ways to evaluate the coastal zone risks through analyzing historic data are often not comprehensive enough and may result in lower estimates of the actual risks of these hazards, while a combined approach developed recently at the P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences (SIORAS) provides more accurate evaluations, which may affect significantly human research and industrial activities in maritime areas. The goal of the project is to disseminate information to scientific and industrial communities on combined risks of the coastal zone saltwater intrusion, contaminated submarine groundwater discharge, earthquakes, landslides, and tsunamis to create a consortium for conducting a large-scale international project devoted to investigation of combined geo risks in coastal areas. At the same time, information can be introduced targeting potential risk groups, including local authorities and the general public, to enhance general risk awareness. This goal will be achieved through preparing educational and illustrative material, including CD-ROMs, e-newsletters and brochures, organizing meetings, workshops with and giving presentations to potential partners, planning and conducting official and personal communications devoted to the project and setting up an informative website, which will be continually updated with the newest information. The IAPSO Commission on Groundwater-Seawater Interactions supports the Maritime GeoRisk Project by using its experience in e-publishing and electronic communication networks to assist in the production and dissemination of educational material and in the organisation of events so that eventually a more knowledgeable and a more organized community will lead to a safer environment.

Application of Typologies to the Study of SGD

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Abstracts

Classifications of shoreline characteristics may be useful in extrapolating measurements of SGD made at isolated, specific sites and in placing individual measurements in a global content. Such SGD typologies might be constructed based on geological/geomorphic designations, such as karsts, deltas, coastal plains, etc. Alternatively, a typology could be constructed based on the state variables used to describe groundwater flow such as hydraulic gradient, hydraulic conductivity and aquifer dimensions. Within the LOICZ global database a SGD “cluster” might be desired of relevant parameters such as soil type, precipitation rate, Statistical clustering techniques can be used to identify sections of the world’s coast with similar characteristics relevant to SGD.

Submarine Groundwater Discharge (SGD) to the Coastal Zones of Korea

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Abstract

In order to gauge SGD rates through the coast of Korea, I have measured various geochemical tracers (^{226}Ra , ^{228}Ra , ^{224}Ra , ^{223}Ra , CH_4 , and ^{222}Rn), together with direct seepage measurements, in areas whose geological and environmental settings are different. The study locations include a volcanic island which is composed mainly of high-permeability rocks, a semi-enclosed bay where red-tides occur every year, an estuary where an artificial dam houses water upstream, and the Yellow Sea which is one of the largest continental shelves in the world. All study areas showed considerably large discharge of submarine brackish groundwater, which may rival or even be greater than river-water discharge. I will present the particular importance of SGD for the transport of materials (including nutrients and contaminants) from land to the ocean in these areas. For example, the dinoflagellate red tides occurring off Koheung, Korea, were found to be associated with SGD, which delivers high DIN, and high DIN:DIP ratios. In conclusion, SGD and associated “new” nutrient fluxes may positively impact coastal ecosystems by supplying essential nutrients, but may often negatively impact by contributing to coastal eutrophication and red-tide blooms in some areas of the coastal zone.

Interaction between Groundwater and Seawater off the Pingtung Plain, Taiwan

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Abstract

The aquifers of Pingtung Plain had long been a substantial source for submarine groundwater discharges (SGD) to the adjacent coastal waters. However, due to inadequate over drafting of the groundwaters, seawater has encroached the aquifers through outcrops along the offshore canyon of the Kaoping river at an estimated rate of 400-500 m per year since 1980. The affected groundwater area that has been salinized by seawater intrusion is about 100 km² with a depth down to 300 m. The net loss of freshwater resource due to this groundwater salinization is estimated to exceed 3x10⁹ M³. Detailed hydrographic surveys for water columns off the Pingtung coastal zone, southwestern Taiwan, were preformed using stable isotope compositions, salinity and temperature data to determine the source and mixing of water masses during different seasons from 2001 to 2003. Results show that two layers of relatively depleted oxygen isotope values are found along the Kaoping Canyon in depths ranging from 400~600 m and 1200 m, respectively, in the summer (wet) periods. On the other hand, only the lower one still remained the depleted oxygen isotope nature in the winter (dry) seasons. Those light oxygen isotope signals along with ¹⁴C and tritium data of coastal waters in both summer and winter periods provide encouraging evidences of submarine groundwater discharges from the deep aquifers of the Pingtung Plain. Thus, though seawater intrusion has been found in the upper aquifers of Pingtung coastal zone (0-300 m) for the last two decades, SGD may still prevail in the deeper part of Kaoping Canyon. More analyses are currently carried out in different offshore regions to further the SGD investigation around Taiwan.

Initial Assessment of SGD in Manila Bay, Philippines

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Abstract

Assessment of SGD in the southwest coast of Manila Bay was performed from January 8 to 10, 2005 on a small beach pocket on the flanks of an inactive volcano. Manual and automated seepage meters, continuous radon-in-water monitors, resistivity meters, CTD, and piezometric measurements were employed. Nutrient and salinity measurements were performed on water well, seepage meter, and sea-water samples. Radon activity in the surface waters of Manila Bay are typically below 1 dpm/l with an average of about 0.6 dpm/l. Radon is low possibly due to incursion of South China Sea waters. Water samples from the seepage meters yielded average values for salinity, ammonia, phosphate and nitrate at 27.5 ppt, 54.7 μM , -1.4 μM , and -0.6 μM , respectively; the average values for sea water are 32 ppt, 2.8 μM , 0.5 μM , and 1.3 μM , respectively. SGD flow rate estimates converge at about 20 cm/day; the automated seepage meter measurement yielded the highest value at about 150 cm/day while the manual seepage meter gave the lowest at -1.1 cm/day. The low SGD rates can be attributed to the low transmissivity of the primary unconfined aquifer in the area which is comprised of flat lying interbeds of pyroclastics and clayey coarse-grained lahars.

Submarine Groundwater Discharge (SGD) Studies in Thailand

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Abstract

Submarine groundwater discharge (SGD) was studied at two areas in the Upper Gulf of Thailand in 2004. The study was a joint effort among the research groups at Florida State University (FSU), Research Institute for Humanity and Nature (RIHN), Japan and Chulalongkorn University. We have initiated the first direct measurements of groundwater discharge in the Chao Phraya Estuary and near-shore areas of the upper Gulf of Thailand, just to the east (Sri Racha) and west (Hua Hin) of the estuary. Measurements in the river and near-shore regions included river flux assessments, manual and automatic seepage meter deployments, natural isotopic tracers, and biogeochemical parameters. Manual and automatic seepage meter measurements together with nutrient analyses were used to estimate nutrient fluxes via groundwater discharges.

Our findings show that disseminated seepage of nutrient-rich groundwater into the upper Gulf of Thailand is significant. Amounts of ammonia, phosphate, and silica comparable to that delivered by the Chao Phraya River are introduced to the coastal waters of the upper Gulf via seepage along shoreline lengths on the order of only a few hundred kilometers. This is especially impressive in view of the contaminated nature of the Chao Phraya River.

Reference:

Wattayakorn, G., Burnett, W.C., Taniguchi, M., Sojisuporn, P. and Rungsupa, S. (2004)
Contribution of Carbon and Nutrient Species into SE Asian Waters via Submarine Groundwater Discharge. Final Report Submitted to Southeast Asia Regional Committee for START (SARCS), Taiwan, 34 pp.

Groundwater Characteristics of Krong Preah Sihanouk

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Abstract

In the year 1958, on behalf of the United States Operation Mission (USOM) in Cambodia, groundwater characteristics have been investigated by U.S. Geological Survey (USGS), R. V. Cushman. The main purpose could be for agriculture economic for irrigation was available during dry season from December to May. The result of this program had been collected for all the data needed and carried out for the groundwater used in the future need.

During 1960-1963, 1103 holes were drilled of which 795 of approximately 72 percent productive wells at rates were ranging from 1.1 to 2,967 l/min. The productive wells ranged in depth from 2 to 209.4 m and were 23.2 m deep on the average. The quality of water is recorded in only a few analyses. The dissolved-solids concentrations appear to be generally low so that the water is usable for most purposes without treatment. Some well waters are high in iron and would have to be filtered before use.

The study area is Sea-Port town called Sihanoukville at the South-western part of Cambodia. Elevation feature of the area between 5m along the valley at the flat area and 1000m amsl. at the top of mountainous area. The mean flat area is covered by alluvium about 30m in average. The mountain is formed by middle Jurassic and Lower cretaceous sandstone, conglomerate and siltstone. The main groundwater aquifer is colluviums and alluvium sand and maybe weathered sandstone.

The groundwater head varies from 1.5-15.0 m from the topsoil surface. The borehole depth in average is about 30m depth. The yields are between 1.0-10.0 m³/h. The yield average of ground water capacities is 2.0 m³/h. But some of them were dried and salinities intrusive as at Andong Thmar, Prey Nup hospital.

According to the situation of water needed, water from streams, lakes and groundwater has been always provided the dominant source of water supply in the study area of Krong Preah Sihanouk. Groundwater is the main sources and important for the water supply of that area. Other hand, groundwater is the first priority of the water used and supplied as well as a principal source for industry, irrigation, and domestic and rural needs. So for increasing population, groundwater discharge should be increase. In this case to protect the environmental impact from humanity act the natural resources, groundwater should be carefully exploited otherwise saline water will be intrusive into groundwater or soil set-down.

Nutrient Fluxes from the Sungai Merbok Mangroves Estuary, Malaysia: Getting a Salt Balance

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Abstract

We have worked on the Sungai Merbok Mangrove estuary for a quarter of a century and have collaborated with many of the world's leading non-bluewater physical oceanographers during that time. Yet, to date we have not been able to provide a definitive answer to the question of "outwelling" from our mangrove estuary, let alone make a generalization about outwelling from mangroves. This presentation will discuss some of the main problems, including one of obtaining a salt balance (for which we have not factored in groundwater discharge).

Coastal Groundwater Research in Indonesia: An Overview

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Abstract

As an archipelago country, Indonesia has around 17.000 big and small island. Therefore, the coastal area play an important role in the history of this country since long ago, and most of important cities are located in coastal area, such as Jakarta, Surabaya, Semarang, Medan, Palembang and else. Nowadays, coastal area still is a developing area with degree of movement faster than hinterland area and groundwater exploitation as a potable water is increasing.

Groundwater in coastal area in Indonesia generally is available in enormous amount, and its existence and the technique to exploit it is very much depend on the geological condition in certain area. There two phenomena that influential in decreasing the groundwater quality in coastal area in Indonesia, e.g., salt water intrusion and salt water encroachment. The salt water intrusion is more naturally and slowly process, it can be caused by tide as seen in Biak Island (eastern part of Indonesia, Papua Province). While salt water encroachment is caused by groundwater over production as it happened in some big cities that located in coastal Area, such as Jakarta, Surabaya, Semarang, Medan and some cities along the beach of North Jawa.

The detailed research of coastal groundwater in Indonesia has been done in some area, especially in strategic area, and the most intensive research was executed in the coastal low land area of North Jawa, including the city of Jakarta, Semarang and Surabaya. Thus coastal low land area is built by the inter fingering of Quaternary shallow sea sediment and fluvio-volcanic product of volcano chain in the southern part of the area. Nowadays, this area is changed from rice field area to a dense industrial area. The logic consequence of this substitution is the increment of groundwater exploitation.

The last investigation that had been done is to generate the groundwater model in the coastal area and the first area was chose is the Jakarta basin Area. The geometry basin was established by measuring the groundwater temperature, analyzing hydro-chemical condition, isotope stable content and basin geological condition. From this analysis, it can be concluded that the Tertiary Formation played an important role in ground water flow of Jakarta Area. It is hoped that the similar research will be done in other coastal area cities.

Vietnam: Water Resources in the Relation with Coastal Features

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Abstract

Vietnam's seas include a part of the East Sea, also called the South China Sea. This is part of the Pacific Ocean and borders 9 nations: Vietnam, China, the Philippines, Malaysia, Brunei, Indonesia, Thailand, Cambodia and Singapore. The East Sea connects the Gulf of Tonkin with the Gulf of Thailand and the Andaman, Araphura, Bali and Banda seas. The East Sea is the main gate to Europe, Africa and the Middle-East. It contains five of the ten most important seaways world-wide.

Vietnam coastal zone located in the monsoon tropical area. Mountain terrain and tropical monsoon climate affect sharply to amount and the distribution of aquatic resources. The water resources in Vietnam are potential but there are many problems relating the management of water resources such as pollution, saltwater intrusion, flood, and the degradation of river basins... The rainfall is not steady with seasons, causing flood and lack of water. Annually, the rainfall is about 2.000m, mainly occur in the period from May to November. The surface water is favorable, 75% of which is from Red and Mekong river basins. In dry season, the amount of water is also limited due to insufficient storing. The capacity of groundwater exploitation is low, some areas groundwater is affected by saltwater intrusion.

This paper is the overview of Vietnam' sea include geomorphologic features, current and tide regime, hydro chemical factors and some issues related to water resources in Vietnam.

Discharge and Water Quality Relations of the Ayeyarwady River Basin near Industrial Sites of Myanmar

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Abstract

The water quality of the Ayeyarwady River near three different stations, including a fertilizer plant, an oil refinery plant, and a textile plant was investigated for three seasons. The impacts of human and natural events on these water bodies were assessed by the determinants such as hydrological profiles, physico-chemical parameters, inorganic and metallic constituents, nutrients, organic contaminants, biological characteristics, and possible presence of radioactivity. Based on the unique seasonal trends of the discharge; statistical models such as time series *Box-Jenkins ARIMA model* and *linear regression model* were generated to forecast the future aspects of the water quality of the Ayeyarwady River Basin. The systematic studies have revealed that the water bodies along the stretch of 328 km are more or less in the threshold of pollution stress. Therefore, in order to make use of the water body as a possible water resource, cost-effective and efficient water treatment and monitoring processes are needed. To reduce the present pollution situation, it is essential to establish wastewater treatment and monitoring stations near the point sources.

Keywords: *discharge, Box-Jenkins ARIMA model, Ayeyarwady River Basin, pollution stress, cost-effective and efficient water treatment*

Possible SGD Studies in the Philippines

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Abstract

Previous work such as in Korea and Florida suggest the direct role of SGD in the occurrence of HABs and coral reef degradation. These two issues are major concerns in the Philippines as they directly affect our food resource, economy and health. HABs are known to occur in 18 areas, distributed across the country, and coral reefs are practically all over and are at different stages of degradation. Identification of the role of SGD is thus of great importance for the country. Manila Bay and contiguous coastlines are possible study sites. *Pyrodinium bahemense* var. *compressum* blooms in Manila Bay was first reported in 1988 occurring almost annually until 1999. *Noctiluca scintillans*, which is non-toxic, has taken over since but is practically in high density throughout the year. Several coral reefs outside of Manila Bay but in the adjacent areas have been declared as marine sanctuaries but are threatened by rapid urbanization and industrialization. A typological approach to the study of SGD can also be adopted as the country has variable coastal physiography, geology, climate and land use such as along the coast of Lingayen Gulf.

Submarine Groundwater Discharge, Nutrients and Organic Pollutants Contribution in the Coastal Areas of the Upper Gulf of Thailand

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Abstract

Eutrophication along the east coast of the Upper Gulf of Thailand caused by *Noctiluca scintillans*, the green colour, and *Ceratium furca*, the red colour, was reported to occur more frequently and imposed more serious problems to coastal aquaculture during the last 2 years. The cage cultured sea bass at Sichang Island and Sri Racha Bay were killed in 2004. Increasing volume of wastes discharge from local communities, tourist activities and industries contribute more nutrients and organic wastes to the coastal water and caused more eutrophication. However, groundwater and associated nutrients discharge from the beachface to the coastal areas may also contribute significantly to eutrophication and the ecological structure of the adjacent intertidal and subtidal benthic communities. There is limited information on contribution of nutrients and organic wastes by submarine groundwater discharge (SGD) in this area. Therefore, additional studies on daily and annually SGD rate, direction to the coastal area correlate with other parameter as nutrient flux, organic carbon flux, and some heavy metals flux are required, in order to better understand eutrophication events in this area. Groundwater map as well as water table, flow and direction variation annually will be studied together with the improved technique for manual seepage meter, and especially the calibration of seepage meter. Grain size of sediment, porosity, water content of sediment and nutrient content in the sediment will also be studied in the future. The proposed study areas will at Chonburi province, especially at Bangsaen, Siracha, Sichang Island, LaemChabung, Pattaya and Sattahip which represent local community area, tourist area and industrial area.

Potential SGD Study Sites in Southern Thailand

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Abstract

Southern Thailand is a narrow strip. There is a long range of mountain along the strip. The east-coast basins mainly are fault block basins. The climate of this area is governed by two monsoons, Southwest Monsoon during mid-May to September and Northeast Monsoon during October to February. Rainfall is distributed across the area throughout the year with an average around 2,000-2,500 mm per year. Rainfall during November to December contributes about 80% of the total annual rainfall. Large quantities of carbon and nutrient are discharged to the coastal sea via river transport. This makes many places along the east-coast are important marine nursing ground and aquaculture. Contribution of such discharges from groundwater seepage is not yet been known. From a survey being done on 1st Feb 2005, it was found that in some places groundwater at about 10 cm below sediment-water interface had much lower salinity than seawater above. This indicates high freshwater fluxes from groundwater to the coastal sea in this area. More details study is of interest.

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