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INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
(of UNESCO)

PROGRAMME ON ASSESSMENT AND MANAGEMENT IMPLICATIONS OF SUBMARINE GROUNDWATER DISCHARGE INTO THE COASTAL ZONE

Following IOC Resolution XX-2, a project proposal on Measurement and Management of Submarine Groundwater Discharge has been elaborated in collaboration with the UNESCO's Science Sector programmes, SCOR and LOICZ. The objective of the proposal is to (i) develop, test, and standardize methodologies for assessment of submarine groundwater discharge (SGD) into the coastal zone; and (ii) evaluate the management implications of SGD and provide appropriate training for coastal zone managers via ICAM.

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ASSESSMENT AND MANAGEMENT IMPLICATIONS OF SUBMARINE GROUNDWATER DISCHARGE INTO THE COASTAL ZONE

A Project Proposal to the Intergovernmental Oceanographic Commission (Integrated Coastal Area Management (ICAM) Program)

From

Scientific Committee on Oceanic Research (SCOR)

Land-Ocean Interactions in the Coastal Zone (LOICZ)

Working Group 112

"Magnitude of Submarine Groundwater Discharge and Its Influence on Coastal Oceanographic Processes"

Funding Period: 5 years, beginning Sept. 1, 2000

Request Year-1: $25,000

Subsequent Years: $20,000-$25,000/year

April 1, 2000

Preface

This proposal requests co-sponsorship from the IOC for a 5-year program to: (1) develop, test, and standardize methodologies for assessment of submarine groundwater discharge (SGD) into the coastal zone; and (2) evaluate the management implications of SGD and provide appropriate training for coastal zone managers via ICAM. This proposal is being submitted by a group of scientists, representing the fields of oceanography and hydrology, who have formed a working group to address this important issue. The working group is currently sponsored by the Scientific Committee on Oceanic Research (SCOR) and the Land-Ocean Interactions in the Coastal Zone (LOICZ) Project of IGBP.

A preliminary proposal was submitted to the IOC via the Russian National Oceanographic Committee at the end of 1998, and was acted on at the Twentieth Session of the IOC Assembly (June 29 - July 9, 1999) with support of the delegations of the USA, Japan, Italy, Chili, Greece, Israel, Ukraine and other member-states. This resulted in the adoption of Resolution XX-2 which instructed the Executive Secretary to convene a group of experts to: (1) draft a basic plan for a SGD project in the context of ICAM; (2) to prepare an intercomparison program to resolve existing measurement problems and develop new techniques as appropriate; and (3) to report progress to the thirty-third session of the IOC Executive Council and submit the draft plan and program to the Twenty-First Session of the IOC Assembly.

A group of experts was convened at IOC Headquarters during the period Feb. 2-4, 2000 and a draft plan was formulated. This document represents the outcome of that meeting.

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Abstract

While the major rivers of the world are reasonably well gauged and analyzed, thus allowing comparatively precise estimates of riverine inputs to the ocean, it remains very difficult to evaluate the influence of direct groundwater discharge into the ocean. In spite of the recognition that many land-sea interfaces of the world are characterized by "leaky" continental margins, it is unclear how important groundwater-derived springs and seeps are in terms of overall marine geochemical budgets.

The principal reason that groundwater estimates have not attained the precision base that is typically achieved of other oceanic inputs is that the direct discharge of groundwater into the coastal zone is inherently very difficult to measure. Concerted efforts are required to improve this situation by integrated application of hydrological and oceanographic techniques. Standard hydrological and oceanographic methodological approaches are quite different and have rarely (if ever?) been systematically compared by following a considered scientific evaluation process. Hydrogeologists and oceanographers are literally approaching the same problem from different ends. Furthermore, coastal zone managers face the following problems: (1) they may not be fully aware of the growing realization of the importance of SGD; (2) if they are aware, they may not know how to decide whether or not SGD is relevant to their situation; and (3) if they do decide this is important to them, they may not know how to quantify it. In order to develop the scientific and technical knowledge that will enable these issues to be addressed with a higher degree of certainty, we propose a 5-year program which will include carefully designed intercomparison experiments in different coastal environments in order to provide a standardized methodology for assessment of SGD. An important aspect of our program will be to disseminate the results widely, to coastal managers and other relevant parties, in the hopes that national authorities will encourage the scientific community to investigate this phenomena properly.

The first intercomparison is planned for Cockburn Sound, near Perth, Australia, beginning on November 24, 2000 and continuing over the following two weeks.

Introduction and Significance

Although not as obvious as river discharge, continental groundwaters also discharge directly into the sea. Like surface water, groundwater flows down-gradient. Therefore, groundwater flows directly into the ocean wherever a coastal aquifer is connected to the sea. Furthermore, artesian aquifers can extend for considerable distances from shore, underneath the continental shelf with discharge to the ocean at their points of outcrop. In some cases, these deeper aquifers may have fractures or other breaches in the overlying confining layers, allowing groundwater to flow into the sea (**Fig. 1**). While the magnitude of such discharge may be relatively minor in areas dominated by river flow, recent studies have indicated that groundwater may occasionally account for a significant fraction of the fresh water inflow (e.g., Valiela and D'Elia, 1990; Buddemeier, 1996; Moore, 1996). Because the composition of groundwater is normally different than receiving coastal waters, submarine groundwater discharge (SGD) may be important as a pathway for dissolved constituents such as nutrients. The concentrations of many parameters (e.g., nitrate) in groundwater is typically several times higher than seawater, even in pristine aquifers. In areas where groundwater contamination (e.g., organics, metals, radionuclides) has occurred, SGD may also be a pathway for anthropogenic material fluxes. Increasingly, groundwater is being recognized as a potentially significant, but still poorly quantified, source of nutrients and other dissolved elements to coastal ecosystems. A recent report concerning the future of geoscience research by the U.S. National Science Foundation stated that "...at the present time, knowledge of groundwater fluxes is spatially and temporally isolated. Designing field, laboratory, and modeling programs to constrain these fluxes will not be easy, but will likely produce exciting and important results.

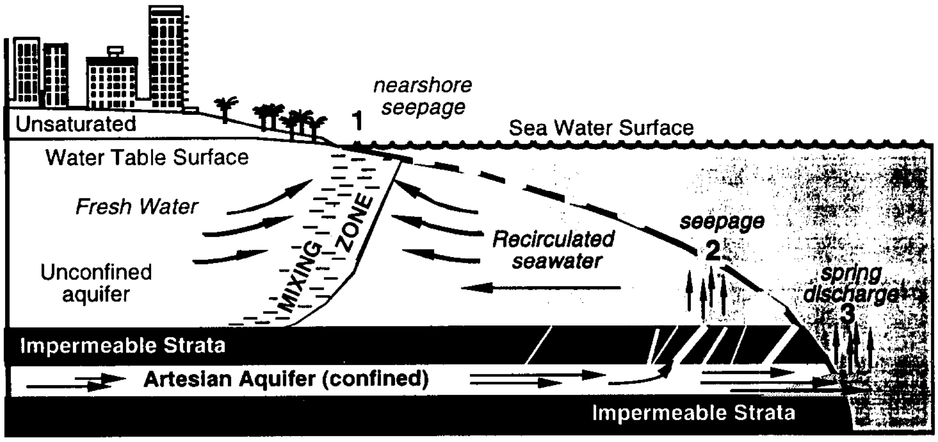

Figure 1. Diagrammatic view of the relationships between coastal aquifers, seawater, and groundwater discharge. Three types of submarine groundwater discharge are illustrated: (1) nearshore seepage; (2) offshore seepage; and (3) submarine springs (Burnett et al., 2000a).

Although submarine springs and seeps have been known for many years (e.g., written accounts exist from at least the Roman period), these features have traditionally been perceived as hydrologic "curiosities" rather than objects for serious scientific investigation (Kohout, 1966). This perception is changing. Within the last decade there has emerged a recognition that, at least in some cases, SGD may be both volumetrically and chemically important (Johannes, 1980). Estimates of global SGD vary widely, some flux estimates are as high as 10% of the river flow; most are considerably lower (Zektser et al., 1973; Dzhamalov et al., 1977; Cathles et al., 1987; Zektser and Loaiciga, 1993). Although this process may not play a significant role in the global water balance, there are reasons to believe that the geochemical cycles of some major and minor elements may be strongly influenced either by the direct discharge of fresh groundwater into the sea or by chemical reactions that occur during the recirculation of seawater through a coastal aquifer system. Very importantly, it is now recognized that groundwater discharge may be an important pathway for diffuse pollution to enter the coastal zone where coastal aquifers have become contaminated by septic systems or other pollution sources.

For many years, investigations of the offshore discharge of groundwater were largely motivated by water resource related issues. There are at least two reasons why scientific studies have developed so slowly in this field. First, the SGD process is inherently very difficult to measure, which tended to discourage serious investigations. Nearshore seepage, for example, typically has very diffuse and highly variable unit fluxes although the cumulative discharge can be very significant when it occurs over a wide area. Second, SGD is a process that occurs across a land-sea interface that spans different scientific disciplines as well as environments. Unfortunately, there are distinct cultural and structural differences that separate terrestrial and marine scientists (Buddemeier, 1996). Literally, hydrologists and coastal oceanographers are looking at the same problem from different ends.

As an example, the intrusion of seawater into coastal aquifers is an important process that leads to groundwater salinization to levels exceeding acceptable drinking and irrigation water standards (Van Dam, 1999). Due to intense population growth and the fact that about 70% of the world population occupies coastal regions, such groundwater contamination is clearly a crucial problem. Seawater intrusion has traditionally been a subject for hydrologists while oceanographers are more interested in SGD. There would be a much greater efficiency, however, if we combined the study of the two processes in terms of scientific, managerial, and technical aspects. For example, it is clear that seawater intrusion into terrestrial aquifer systems and SGD are closely linked processes that directly affect each other. The amount of flow to the sea controls seawater intrusion in some conditions. On the other hand, the rate of seawater intrusion and related processes such as upward movement of saline waters due to over pumping may affect SGD rates. Technically, the tools (flow meters, tracers, models, etc.) needed for study of both processes are virtually identical. Finally, the managers of coastal aquifers require knowledge of SGD to assess the volume of "wasted" fresh water, unavailable for pumping. Our SCOR/LOICZ working group, a combination of oceanographers and hydrologists, can set an example for future studies during this project.

We now have enough information to assert that SGD is potentially an important component of the water and biogeochemical cycles in many coastal environments (based on general hydrogeologic knowledge and water/nutrient budget estimates of certain types of environments (e.g., in karst coastlines), and specific data indicating its importance in some well-studied areas (e.g., Western Australia, Florida, southern coast of Long Island). It is important to stress, however, that it is not an issue everywhere; in some locales, there may be little or no SGD, and in others, its relative importance may be small — for example, in areas where surface water runoff dominates nearshore effects.

Measurement Issues

There are three basic approaches to assessment of SGD: (1) modeling; (2) direct physical measurement; and (3) tracer techniques. There are several modeling approaches ranging in complexity from simple on-shore groundwater balance calculations through to comparatively complex numerical models of sub-surface flow. Direct physical measurements are typically limited to seepage flux meters (although several variations in design of these meters have been developed) and measurement of the direction and magnitude of hydraulic gradient across the sediment-water interface. Tracing techniques make use of either natural geochemical species or artificial tracers.

Modeling of groundwater flow, including discharge estimates to a coastal zone, has become more popular with the availability of powerful PC-based numerical modeling packages such as MODFLOW (MacDonald and Harbaugh, 1988). Basically, methods of calculation and modeling fall into three groups: (1) flow equations, i.e., analytical or numerical solutions of Darcy's Law for groundwater flow in porous media; (2) mass balance approaches which usually consists of a water or salt budget; and (3) hydrograph separation techniques which examine the baseflow from streams and extrapolate the interpreted groundwater flow to the coastal zone.

All of the modeling approaches have certain limitations. For example, estimates made by analytical solutions to Darcy's Law assume that the aquifer system is homogeneous when this is rarely the case. While numerical solutions can handle heterogeneities, these are represented spatially as idealized or lumped parameters and it is especially difficult to obtain representative values for the hydraulic conductivity within an aquifer. These values can vary over several orders of magnitude over short distances. Analysis is frequently limited by the assumption of steady state which may not be correct, especially considering the effect of tidal and density driven forcing functions in coastal zones. Water budget calculations, while relatively simple, are often very imprecise for groundwater discharge estimations because uncertainties in terms used in the calculations are often on the same order as the discharge being evaluated. Evapotranspiration, for example, is usually a very important term but is rarely quantified very rigorously. The hydrographic separation technique, popular with Russian scientists who have made world-wide estimates with this approach (e.g., Zekster et al., 1973), applies only to coastal areas with well-developed stream networks and to zones of relatively shallow, mainly freshwater aquifers.

Modeling is also carried out on a variety of scales, which may or may not correspond to the scales of interest of oceanographers. Near-shore modeling is done on a scale of tens to hundreds of meters, and generally focuses on more enclosed water bodies such as inlets or tidal lagoons. Regional scale modeling is performed on the order of kilometers to tens of kilometers and is based on field data obtained at much greater distances from shore. Inherent in the latter is the assumption that the groundwater flowing towards the coast will discharge at the coast, without regard to the spatial distribution of this discharge.

Effectively, the only way in which a direct measurement may be made of groundwater discharge is with a devise called a "seepage meter." First described by Lee (1977), the seepage meter is simply a chamber inserted open end down into the sediment. Water seeping through the sediment will displace water trapped in the chamber and push it up through a small hole drilled into the top. This water then enters a plastic bag which acts as a collector. The change in volume of water in the bag over a measured time interval provides the flux measurement. These meters are simple and inexpensive and, if used carefully, can provide useful information. Unfortunately, the meters also suffer from some artifacts. Some of these problems relate to mechanical properties of the plastic bags that result in anomalous inflows of water not related to seepage (Shaw and Pregas, 1989; 1990). Other problems may include leakage around the base of the meter, interference from waves, and pressure differentials that may cause flow unrelated to groundwater inputs (Libelo and MacIntyre, 1994). In spite of these pitfalls, many investigators report achieving high quality results with such devises, especially in areas where the groundwater flow is fairly high (>2 cm/d). A recent field evaluation of "Lee-type" meters showed that consistent and reliable results can be obtained if one is watchful of these potential problems (Cable et al., 1997).

Unfortunately, manual seepage meters are very labor-intensive. If one were interested in collecting information from only one location over extended time periods in order to evaluate tidal or other temporal patterns, a considerable man-hour commitment would be necessary. In order to resolve this problem, and also to provide higher-resolution time series data, various forms of automated seepage meters have been developed. One example of such an approach is the heat-pulse devise described by Taniguchi and Fukuo (1993). This meter uses a string of thermistors in a column positioned above an inverted funnel covering a known area of sediment. The basis of the method is a measurement of the travel time of a heat pulse generated within the column by a nichrome wire induction heater. Since heat is a conservative property, the travel time is a function of the advective velocity of the water flowing through the column. Thus, once one has calibrated the system, measurements of seepage flow can be made automatically on a near-continuous basis. The Taniguchi meter has successfully measured seepage over several days at a rate of about one measurement every five minutes.

Perhaps one of the most promising approaches for regional-scale assessments is the use of geochemical tracers. This is the case because the coastal water column tends to integrate natural tracers coming into the system via groundwater pathways. Thus, smaller-scale variations, which may not be of interest, are smoothed out. The small scale variability has been one of the serious drawbacks concerning the use of seepage meters. Many coastal aquifer systems and overlying sediments are by nature very heterogeneous. Thus, one must compensate for this natural variability by making many measurements. Obviously, this restricts the practical coverage of an investigation.

Over the past few years, several studies have employed the use of the natural U decay-series nuclides ^{226}Ra and ^{222}Rn to assess groundwater inputs to the ocean (Moore, 1996; Cable et al., 1996a/b; Burnett et al., 1996; Kontar and Burnett, 1999; Corbett et al., 1999). Ideally, natural geochemical tracers should be greatly enriched in groundwater relative to coastal waters, be conservative, and be easy to measure. While radium and radon meet these criteria fairly well, there are certainly other possibilities which may be exploited for groundwater discharge studies. Helium isotopes would seem particularly attractive although they would not fit the "easy to measure" guideline very well.

No matter what the approach, at this point in our development of methodologies to measure submarine groundwater discharge, there are two fundamental problems: (1) rarely are more than one approach employed in any one study; and (2) uncertainty estimates are almost never provided. Error bars are rarely reported for groundwater flux estimates because there are typically so many assumptions made in the calculation that putting reasonable uncertainty limits on the final result is extremely difficult. Obviously, this is an area where improvements can be made. The observation that most investigations are limited to one measurement approach is not really surprising. Scientists are specialists and often hesitate to go outside certain boundaries. Thus, modelers rarely will apply geochemical tracing or seepage meter approaches while the geochemist may not take advantage of an appropriate hydrogeological model. To some extent, this has already started to change and more team studies include several disciplines.

Management Issues

Coastal zone management is usually done at the local level. Our experience thus far is that SGD is highly variable, both in time and space. Thus it is appropriate and necessary that our efforts should include the involvement of local expertise (both scientific and managerial) and some provision for training be made part of the dissemination effort.

Because SGD is essentially "invisible," the problem that arises, from both a management and scientific standpoint, is determining how to avoid the error of ignoring an important process on the one hand, and wasting valuable resources on an unimportant issue on the other. Where SGD is a significant factor in maintaining or altering coastal ecosystems (either terrestrial, estuarine, or marine), coastal zone managers will need to consider management of water levels and fluxes through controls on withdrawal or alterations in recharge patterns, as well as groundwater quality management (e.g., through controls on land use, waste disposal, etc.). Such major interventions in the coastal zone management system require a sound scientific justification and technical understanding that does not currently exist.

From a management standpoint, a key issue will be the determination of whether SGD is of actual or probable importance in an area of interest. Furthermore, managers must consider the relative relationships and priorities of SGD among the multiple factors considered in management activities. This presents at least two ways that current scientific approaches to study of groundwater discharge will need to be modified:

1. The scale of emphasis would be that of management areas — probably tens to hundreds of kilometers. By contrast, participants in WG-112 are working toward this scale from both ends, by considering measurements (typically made at the scale of km or less) and the typology required for globalization (which conceptually attempts to subdivide the globe into useful coastal classifications).
2. Scientists may study one area for years, often reflecting the typical 2-3 year grant cycle. Managers, on the other hand, will have need for relatively simple and rapid diagnostic and assessment tools to evaluate the local importance and management issues related to SGD in specific settings. The concerns could be either natural processes or human impacts (which may be extreme in some cases).

When one considers management aspects of SGD in the coastal zone, one must be aware of the critical importance of hydrologic fluxes to the linkage of the terrestrial and marine ecosystems. This goes beyond the direct local modifications of such an environment by such activities as dredging, dumping, etc. It must be remembered that surface water and groundwater fluxes are the pathways by which terrestrial changes impact the estuarine and marine environments. This represents a problem in integration of management as it does in science, since those involved in groundwater management rarely have a marine perspective, and vice versa. Further, the trends of coastal development in many areas are such that SGD may be becoming relatively more important, as surface water flows are increasingly impounded and reduced (e.g., China) and activities associated with canal construction and maintenance (e.g., subdivisions in Florida) increases the aerial extent and magnitude of groundwater flow into surface waters.

Another point that may not be obvious to a coastal zone manager is that the importance of SGD to the marine/estuarine environment does not necessarily require a useable groundwater resource in the coastal aquifer, or even a net seaward discharge. If tidal ranges and/or seasonal water table fluctuations are high, exchange between groundwater and seawater may result in a significant seaward flux of nutrients, contaminants, etc., even when there is a net long-term intrusion of seawater into the aquifer. It should also be remembered that "groundwater" is not always fresh and that recirculating seawater can also result in increased material fluxes that affect the coastal zone ecosystem.

SCOR/LOICZ Working Group 112 and Relation to Proposed Project

One of the outcomes of the recent interest in SGD has been the establishment of a small group of experts "...to define more accurately and completely how submarine groundwater discharge influences chemical and biological processes in the coastal ocean" (Burnett, 1999; Kontar and Zektser, 1999). This working group (SCOR working group 112, "Magnitude of Submarine Groundwater Discharge and Its Influence on Coastal Oceanographic Processes") is co-sponsored by SCOR and LOICZ. The group has held two meetings thus far (Taipei, Taiwan, 1998; Birmingham, UK, 1999), has produced a work plan for the next few years, and organized itself into three main components: modeling, measurement, and globalization. The measurement group quickly recognized the need to define further and improve the methodologies of SGD assessment. This proposal is basically an outcome of the activities of the measurement component of WG-112.

Goals of Proposed Project

The main objective of the proposed project is to develop a program that will provide both the scientific and coastal zone management communities with the tools and skills necessary to evaluate the influence of submarine groundwater discharge in the coastal zone. A central part of this program will be to define and test the most appropriate assessment techniques via carefully designed intercomparison experiments. A successful program will ultimately result in many more assessments being performed with possible future compilation into a database and/or an atlas of SGD in the coastal zone.

In addition to this main objective, several secondary goals are sought as well:

1. Develop specific technical guidelines for determining the probable importance and functional vulnerability of the marine environment to SGD at local-regional scales.
2. Develop additional insights into hydrological processes governing SGD within type areas.
3. Provide for intercomparison of appropriate analytical techniques and foster instrumental development and improvements.
4. Prepare an initial estimate of the probable actual importance of SGD by region to the extent feasible (note that this is complemented by and will be coordinated with the WG-112 typology efforts).

5. Prepare a methods manual detailing the techniques available (with applications and limitations) for determination of SGD and assessment of its importance within a local context.

Project Plan

General Strategy

The overall strategy for the proposed project, together with its relationship to international science organizations and anticipated outcomes are illustrated in **Figure 2**. In order to meet the project goals, two important scientific tasks include: (1) the site selection for the intercomparison experiments; and (2) the selection of techniques and the experimental design. The procedure should be well documented for identifying sites where SGD is expected to be important. We plan to concentrate on those sites that are best for the comparisons and allow coastal managers to decide which characteristics are most important for their needs. For example, while some sites may have lower flows, the impact of SGD may be greater because of high nutrient contents. We feel that five sites that span a broad range of conditions should be selected for the intercomparison. The intercomparison is critical and has to be scientifically sound and comprehensive. It is highly likely that the results of these intercomparisons will be regarded as benchmarks and influence the field for many years to come.

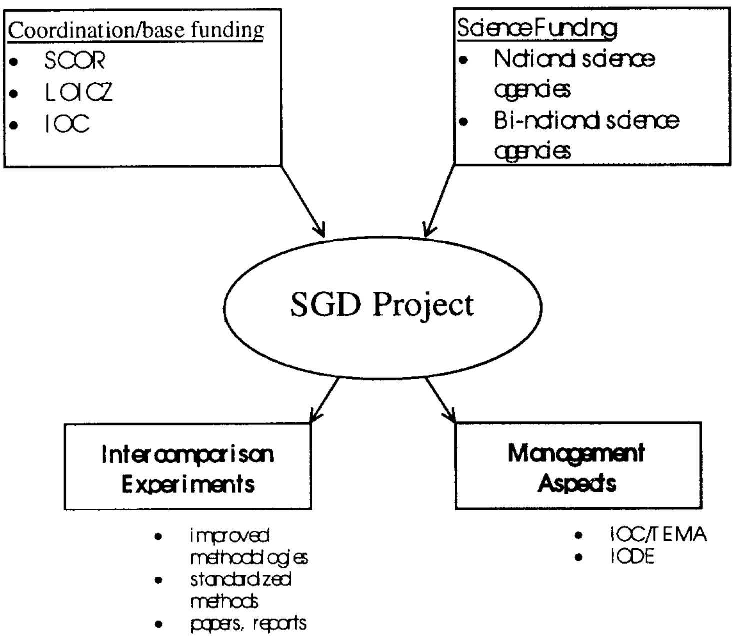

Figure 2 Relationships between international organizations, scientific funding agencies, and the proposed SGD project.

Our plan is to run one experiment per year for a 5-year period. The sites will be selected based on a variety of criteria including logistics, background information, amount of SGD expected, hydrological and geological characteristics, etc. (see list of "flagship" characteristics in appendix). The first two sites have already been selected and several additional sites have been proposed. Additional information concerning these sites is provided in the sections below.

The funding for this project will be derived largely from traditional national and bi-national scientific funding agencies through proposals written by participants. We envision that a research proposal will be prepared each year for the science expenses of the intercomparison experiment for that year. We propose that base funding, needed for travel, logistics, and to ensure continuity over a 5-year period, be provided by SCOR, LOICZ, and the IOC. SCOR and LOICZ have already committed funds to maintain the working group. This proposal requests a comparable amount of funding from the IOC specifically for this project.

Design of Intercomparison Exercises

We will conduct systematic intercomparison exercises which will involve as many methodologies as possible. The methods that should be applied will include modeling approaches (e.g., MODFLOW simulations, water balance approach), "direct" measurements (e.g., seepage meters of varying design, piezometers), natural tracer studies (e.g., radium isotopes, radon, methane, etc.), and possibly artificial tracers (SF_6, ^{18}O-enriched water, etc.).

Because of differences in the nature and scale of each of these approaches, the final experimental design will necessarily vary from site to site. A somewhat generic experimental design for measurement of SGD in a near-shore environment illustrates how an experiment may be set up (**Fig. 3**).

The general experimental plan will consist of transects of piezometers (to measure the hydraulic gradients and conductivities), manual and automated seepage meters (to measure flow directly), with specialized experiments and water sampling at appropriate points within the study area. For example, benthic chambers will be deployed to assess diffusional inputs of natural tracers. Thermistor arrays will also be used to assess subsurface temperature gradients that can be used to model fluid advection rates. Various seepage meter designs will be evaluated both during the field experiment and, when available, in variable head test tanks. Water sampling for tracer studies will be conducted while the hydrological measurements are in progress with most analyses being performed at the field site. Samples for geochemical tracers will be collected from both the water column as well as from the aquifer itself. The specific sampling plan for tracer samples will be determined by the spatial and temporal variations expected at each site. Geochemical tracers will definitely include radium isotopes, radon, salinity, and silica. In addition, depending on personnel and other factors, we also hope to include assessments using natural helium isotopes and tritium as well as artificial tracers such as SF_6 and CFC's.

Analysis of SGD measurements obtained at each intercomparison site can be expected to be challenging because of the complex driving forces and fluid mixing relationships that operate at the coastal interface. The hydraulics of the interface zone are complicated by tidal oscillations and density-dependent flow. Re-circulation of water at the seabed, and wave run-on add further difficulty in isolating an estimate of the fresh water component discharged on the offshore slope. The effects of these processes and the resulting spatial patterns of SGD recorded during the intercomparison experiments may best be understood by constructing a simulation model of subsurface flow and fluid transfer across the seabed at each experimental site.

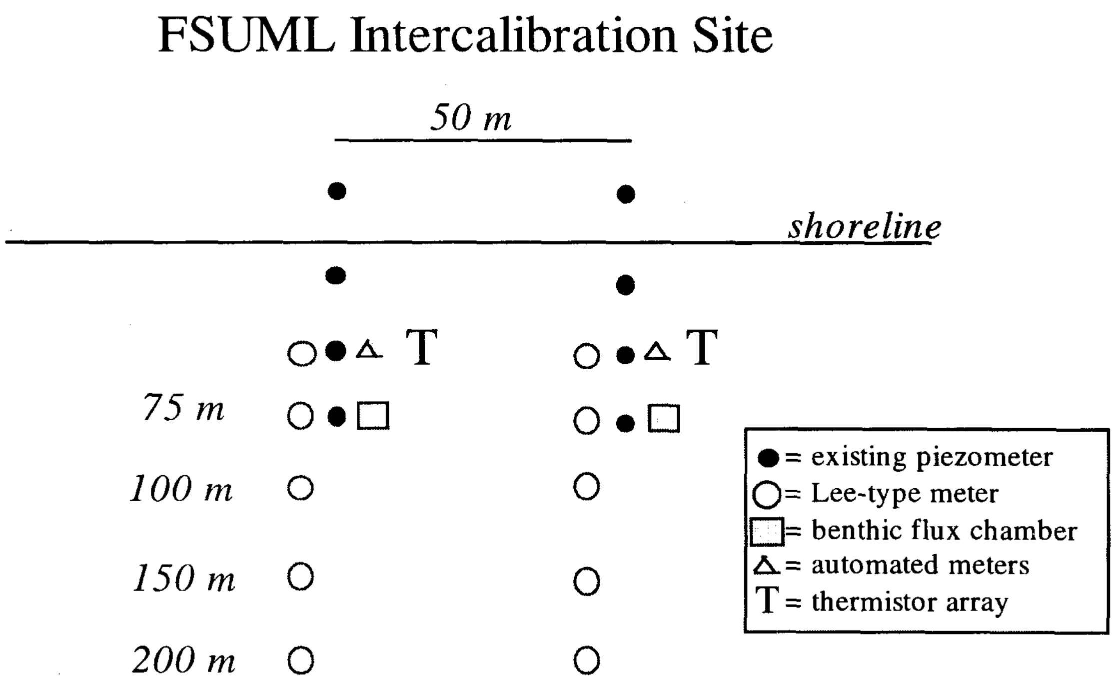

Figure 3 Basic experimental design consisting of parallel transects of seepage meters, piezometers, and other devises. This design was intended for a site near the Florida State University Marine Laboratory (Florida, USA), but the same type of approach may be used at other sites with allowances for site specific differences.

It is preferable that the hydrogeologic setting in the immediate vicinity of each SGD site be relatively simple. Ideally, the sites will have a single homogeneous geologic unit extending across the coastal interface. Large-scale variations in hydraulic conductivity are an inherent feature of any aquifer, even in a unit classified or mapped as homogeneous. This variability leads to some degree of channelized or focused flow as the fresh water from recharge areas on land reaches the salt water interface. It is unknown, however, how this variability may be translated into spatial variations in SGD offshore. Model studies will be helpful in understanding the magnitude of this effect at each site; as it relates to both experimental design, and in the resolution of potential discrepancies in estimates of SGD based on measurements collected on different sampling scales.

Role of Modeling

Simulation models will form an integral part of each intercomparison experiment. We envision model studies to serve three key purposes:

1. Model calculations have historically been one of the principal methods used in deriving estimates of SGD. These models range in complexity from a simple application of Darcy's law using representative values for hydraulic conductivity and the hydraulic gradient, to a water balance formulation, to a detailed simulation of the seaward movement of freshwater using a model such as MODFLOW. More complex models, such as the SUTRA code, are employed for assessing density-driven flow such as would be important in a coastal aquifer. At each site selected for an intercomparison experiment, these model-based approaches would be completed prior to the collection of offshore measurements. Post-experiment comparisons with direct measurements will

provide the opportunity to evaluate the accuracy and limitations of the various model-based methods of estimatirg SGD.

2. A groundwater flow model can also be used prior to an intercomparison experiment to provide insights useful in the final selection of measurement locations. This analysis would focus on the land-based portion of the groundwater flow system. Model calculations can provide estimates of the likely magnitude of SGD, how the SGD flux may vary as a function of distance offshore, and how SGD may vary on a seasonal basis. Insight would also be provided into the influence of the geometry of the shoreline and surface water/groundwater interactions on focusing of SGD along the coastline. These surface water features may include streams, ponds, or near-shore wetlands.

3. A fresh-saline water interface model is needed to aid in the integration of SGD data collected at different scales during the intercomparison experiment. This model could range in complexity from a sharp interface model to a fully-coupled, miscible transport model. Modeling of SGD provides the most effective means of integrating point measurements of SGD (single seepage meters or piezometer nests) with the larger-scale variations in SGD in space and perhaps time that will be present in the data set. Modeling should also aid in separating the components of measurement error and true variability in SGD.

The intercomparison experiments should provide reliable data sets to permit an examination of how point measurements of SGD can be averaged or scaled up to provide an estimate of the SGD flux at the scale of hundreds of meters to several kilometers. Numerical simulation models of SGD are the link to relate direct measurements on the seabed, with complementary estimates of SGD based on sampling tracers in the water column above the seabed.

Following completion of each intercomparison experiment, the opportunity exists to update the initial groundwater flow models to better link the observed magnitude and pattern of SGD to the land-based portion of the flow system.

Flagship I — Cockburn Sound, Australia

We will perform our first intercomparison at Cockburn Sound, located in the southwest margin of continental Australia, near metropolitan Perth and Fremantle (**Fig. 4**). Cockburn Sound is a marine embayment protected from the open Indian Ocean by reefs, a chain of islands including the dominant Garden Island, and a man-made causeway. The area has recently been the subject of extensive environmental assessment in order to address strategic environmental management and the management of waste discharges into Perth's coastal waters.

Cockburn Sound itself is flanked on its eastern margin by a low-lying sandy coastal plain. Much of Perth's commercial and industrial activity is focused along the southern metropolitan coastline and includes the shoreline of Cockburn Sound. Influx of pollutants to the nearshore marine environment from these activities has been a point of major concern in recent years and SGD has been recognized as an important pathway for contaminants. Accordingly, a significant amount of baseline environmental information has been gathered over the past 20 years.

The following points provide a listing of the various onshore and offshore attributes of Cockburn Sound in relation to its potential as a site for an SGD intercomparison. In general, Cockburn Sound meets and exceeds practically all the required attributes we have identified for an intercomparison experimental site.

Onshore Attributes

- Management and knowledge of on-shore groundwater resources and characteristics is well advanced.
- The hydrogeology is well characterized and numerous on-shore monitoring bores are accessible.
- Groundwater gradients and seasonal groundwater level fluctuations are well known.
- Groundwater modeling of the onshore system is already available, albeit with different objectives in mind (e.g., rate of contaminant transport). Adaptation of existing modeling approaches (physical and hydrogeological characterizations) to the SGD can be readily achieved.
- Several onshore contaminant sites are well known and have been characterized. While assessment of these contaminant issues is not within the scope of the present program, they do provide motivation for in-kind support from relevant agencies. Known contaminants include NH_4SO_4 and NO_3, hydrocarbons, trace metals (Ni, Cu, Cd), NaOH, fertilizers, and sewage.
- A relatively "uncomplicated" groundwater region (unconfined, shallow sandy aquifer with some limestone.
- Full laboratory resources within a 40-minute drive and high likelihood of being able to locate or establish an on-site secure storage and work area from in-kind support.

Offshore Attributes

- The bathymetry, sea bed slope, and morphology are all well known.
- Extensive baseline data exists on environmental values, e.g., seagrass distribution, sediment characteristics: DEP Report.
- The immediate offshore beach environment consists of sand and silt, "uniform sediments".
- Open-sea shelter by Garden Island, reefs and offshore islands.
- Local protection from heavy seas by breakwaters — particularly within the confines of the Northern Harbor at the northern end of Cockburn Sound (Jervois Bay, see **Fig. 4**). This protection is particularly important in the event of poor weather (heavy seas) during the intercomparison period — if such an event occurred and there was no real fall-back option, the two week program could be a failure.
- SGD is known to occur in either Cockburn Sound itself, or in the local marine vicinity, and a variety of measurements based on a number of approaches are already available. These are summarized in the section below and in **Table 1**.

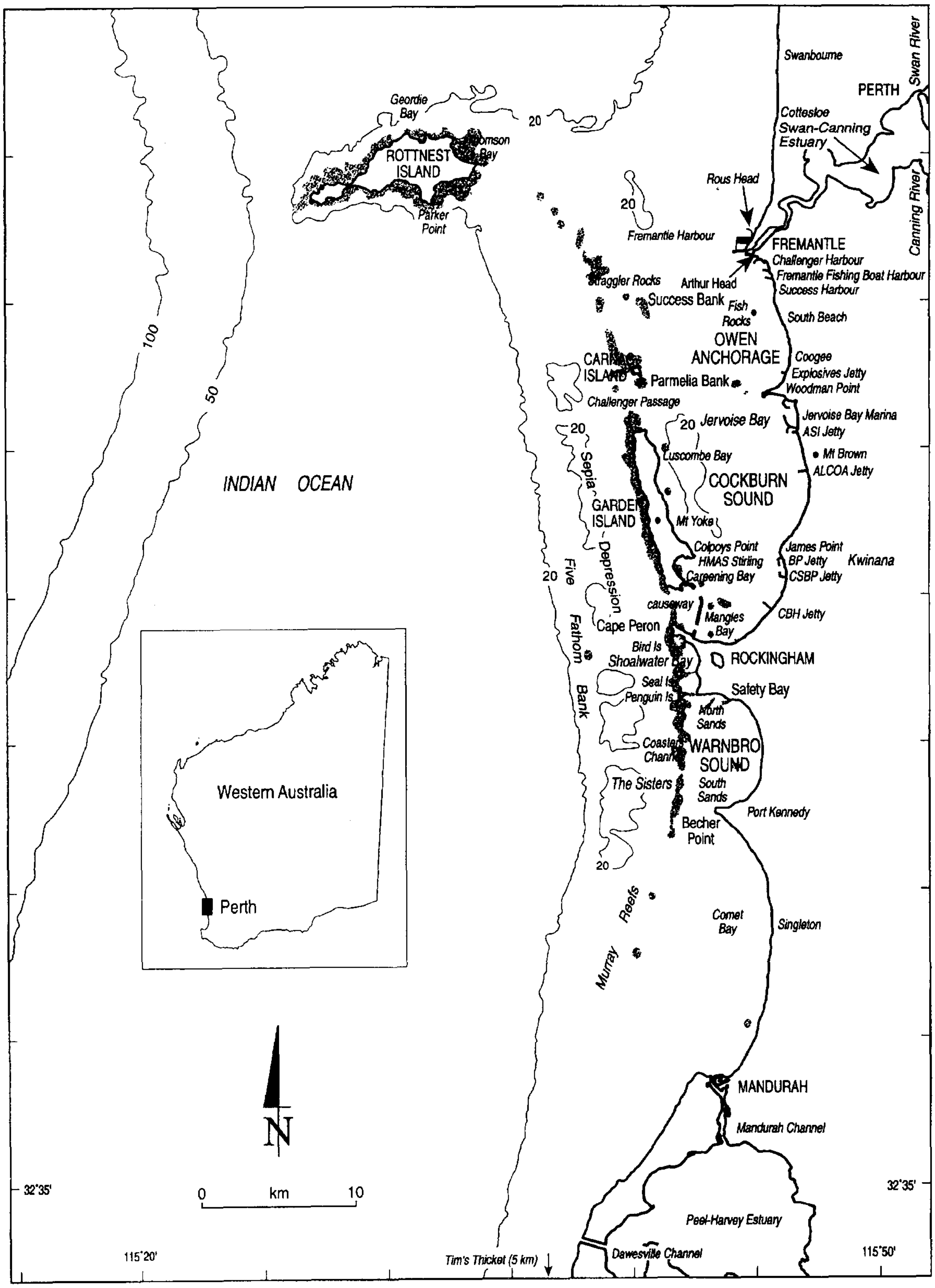

Figure 4 Location map of Cockburn Sound and the surrounding region in Western Australia (from Turner, unpublished).

General Attributes

- Liaison with stakeholders regarding the SGD intercomparison has shown that the relevant state agencies and consultants are willing to share SGD and related data, including open access to numerous shoreline boreholes.
- A CSIRO proposal has been funded by Environment Australia (2000-2002) with industry, and state agency support to look into the groundwater flux into Cockburn Sound and novel on-shore groundwater remediation strategies.
- Synergies and travel efficiencies due to the HYDRO 2000 International Hydrology and Water Resources Conference, Perth - November 2000 (Other IOC and Indian Ocean-related meetings are also occurring in Nov., 2000).

Previous Estimates of SGD into Cockburn Sound

Assessments have been made of the shallow unconfined groundwater discharge into Cockburn Sound from the largely unconsolidated superficial sediments. It is speculated that SGD from the deeper confined aquifers occurs at significant distances offshore. No measurements are available and locations as to where this might occur are speculative. Thus the estimates of SGD that are available are estimates of net discharge that occur via regionally advected groundwater flow from the superficial formations. The SGD appears to occur within tens to hundreds of meters from the shoreline.

Prior estimates of SGD into Cockburn Sound identified that the rate of SGD was seasonally dependent, with the highest rates occurring in late spring to early summer and the lowest rates occurring in late summer. Hydrogeologically this is consistent with the commonly observed seasonal maximum in groundwater level that occurs in October/November and the minimum that occurs in May/June. Thus the period of maximum estimated SGD coincides with the timing of maximum hydraulic gradient in groundwater toward the coast. The seasonal, cyclical variation in groundwater level of the shallow unconfined aquifer has a range of about 0.7 m. Direct measurement of SGD has been carried out using conductivity profiling of the seawater column at distances up to several hundred meters offshore in water depths of up to 10 m. These measurements have been focused in the Jervois Bay and Northern Harbor sections of Cockburn Sound as indicated in **Figure 4**. The Northern Harbor measurements of SGD based on conductivity profiling of the water column are possible due to the partial enclosure provided by the groins that restricts open-water circulation within the harbor. **Table 1** summarizes the available estimates of SGD. Results given by consultants HGM (1997) and more recently by PPK (1999) show good agreement. Overall, the estimates of SGD obtained by a variety of methods give remarkably consistent results. This provides a good indication of the SGD fluxes that can generally be expected at Cockburn Sound.

Table 1. Various estimates of SGD into Cockburn Sound (CS) and related sites

Source	Location	Basis of estimate	Date of estimate	Flux ($m^3/m/day$)
HGM Report (1997)	Jervois Bay (within CS)	CTD water column profiling	1997/8	3-8
PPK Estimate (In DA Lord Report)	Northern Harbor (enclosed harbor within CS)	CTD water column profiling	1999	5
Allen (1981), (reported in Johannes *et al.*, 1985)	Local coastline north of Perth and Swan River	Coastal Plain groundwater balance.	1981	~8
Linderfelt & Turner (In press)	Swan River estuary foreshore	Groundwater modeling, & seepage meter	1997	2.4
Appleyard (1994)	Cockburn Sound	Darcy law flux calculation	1994	2.5
Hearn (1991)	Cockburn Sound	Data Review	1991	~4

<u>Other Candidate Sites</u>

We have decided that it would be much more prudent to have the benefit of experience of the first intercomparison before final selection of other sites. Using the list of criteria for selection of "flagship" sites (see appendix), we have identified several additional candidates. These are listed below according to type of geologic environment:

1. Karst — Turkey Point, Florida (USA), Yucatan Peninsula, East Africa, Lingayen Bay (Philippines), and various sites around the Mediterranean Sea (Italy, Greece, others)
2. Coastal Plain — Cockburn Sound (Australia), Great South Bay (New York), eastern Mediterranean (Israel)
3. Soft Muddy Sites — Baltic Sea, Hudson Bay
4. Volcanic — Japan, Hawaii, New Zealand
5. Crystalline Bedrock — British Columbia
6. Inland Seas — Aral Sea (Uzbekistan), Caspian Sea

Obviously, not all of these sites will be addressed during this project. Many other considerations, beyond geologic environment, will be considered in making the final decisions. Different land use (urban, agricultural, etc), for example, is an important aspect, particularly for management implications. Planning workshops will be held, either in conjunction with our working group meetings or other SCOR or LOICZ activities, to evaluate the results from each intercomparison and plan the exercise for the following year.

Project Outcomes

Scientific and Management Outcomes

We anticipate that scientific results will be presented, as usual, at professional meetings and published in scientific, peer-reviewed journals. This project will have the following scientific outcomes: (1) improved methods for making groundwater discharge assessments; (2) necessary data to better evaluate the water/salt balance in coastal zones from various environments; and (3) development and testing of groundwater and seawater interaction models under different hydrological and hydrogeological conditions.

In addition to the scientific results which will be forthcoming as a result of the intercomparison experiments, the project participants will engage in activities that relate to the management issues raised earlier (**Fig. 5**). Specifically, we will: (1) provide information for broad dissemination; (2) engage local stakeholders; (3) provide metadata to IODE; (4) prepare a methodology for information transfer and training programs; and (5) report site characteristics for globalization exercises.

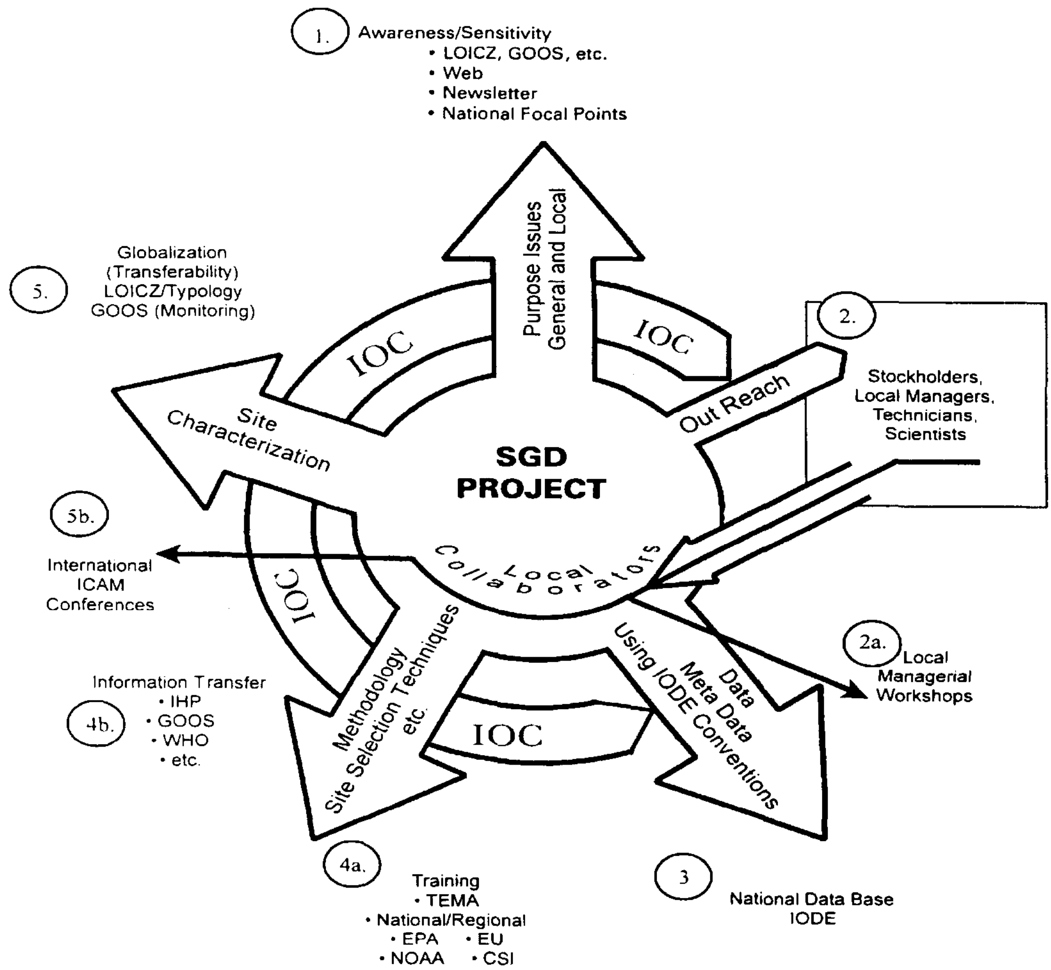

Figure 5 Illustration of the ICAM applications and training components envisioned for the SGD project (Bokuniewicz, unpublished).

These steps, as illustrated above, are described more completely below:

1. Coastal managers need to become aware of SGD as a potentially important ecological process. At the onset of the project the project participants will prepare fact sheets to be widely distributed through IOC and LOICZ channels. Information will include descriptions of the nature of SGD, its relevance to issues of ICAM, the general objectives of the project and site-specific information. Both IOC and LOICZ have established mechanisms for the dissemination of this information to both intergovernmental organizations (IGO's) and non-governmental organizations (NGO's). These mechanisms include web sites, newsletters and national focal points. The intention is to increase the awareness of coastal managers to the concept of SGD and the nature of the project.

2. Project participants will identify and contact local stakeholders at each site. Local managers, technicians and scientists will be engaged as local collaborators. They will be invited to assist in the design of the site study, participate in the implementation, help with the assessment of the data, and in the interpretation of the results. Although this project is concerned with the volume fluxes of water, secondary objectives are possible at particular sites. Depending on the identification of local issues, add-ons to the basic study, such as remote sensing or geochemical measurements, can be tailored to local needs (at local expense). The local collaborators will be encouraged to convene a workshop on local management issues associated with SGD and to provide a local forum for the dissemination of results (2a). To the extent possible, project personnel will encourage and facilitate the participation of local collaborators in international ICAM conferences to further disseminate the results of this project (2b).

3. Data will be maintained by the principal investigators in the usual ways. In addition to the raw and derived data, however, metadata will be incorporated into the national oceanographic data center particular to each site. At each site the appropriate national data center will be identified and arrangements made for the timely transfer of data. This will ensure that data will be accessible through IODE. All data will be prepared using the IODE conventions.

4. The principal product of this project will be a methodology for the measurement of SGD. The methodology will include considerations for site selection, technical procedures, experience in addressing stakeholders, and provisions for incorporating results into ICAM. Information will be provided to IOC who would then transfer it through existing mechanisms to relevant programs and agencies (e.g., IHP, GOOS, WHO).
   (4b) For training purposes the methodology and illustrative material will be provided through IOC to TEMA for incorporation into their existing training programs. The training component of GOOS will also have the opportunity to utilize the methodology. The appropriate regional or national agencies will also be encouraged to provide training using tools developed by this project. These may be run, for example, by the EPA in Australia, NOAA in the USA, or the CSI small islands program (4a).

5. The project will provide a final report of site characteristics for inclusion in global information systems such as the LOICZ typology. Secondary users may include IHP and GOOS. The studies will provide reference sites that could be used as ground truth to broadly base classifications that may include efforts to develop remote sensing techniques for SGD.

Calibration for Remote Sensing and Typology

In addition to the scientific and management oriented outcomes discussed above, there is a high potential for future use of the "flagship" sites for calibration of remote sensing techniques and as baselines for a global typology. Although we do not necessarily plan to utilize remote sensing techniques as part of our intercomparisons, we recognize that these techniques have been used and developed for a variety of purposes in marine sciences over the last two decades. For example, satellite imaging is used for remote estimates of primary production (e.g. Antoine et al., 1996), sea surface temperatures (Schweitzer, 1993), sea ice coverage (Garrity, 1991; Massom et al., 1999), and coastal change processes (Howarth et al., 1982; Hanslow et al., 1997). It has also been suggested that remote sensing techniques may be useful for groundwater tracing on land (Uzmann et al., 1989; Batelaan et al., 1998) as well as for the detection of submarine springs (Kohout et al., 1973).

In comparison to ship- or land-based measuring technologies, the great advantage of satellite imaging is the possibility to survey simultaneously large areas and regions that are difficult to access. These methods provide rapid data acquisition and continuous data coverage over geographically well-defined areas. Once a satellite-based technique is established, large amounts of data can be obtained for time series as well as for comparative investigations. Therefore, satellite based data acquisition tools are very appropriate for large and global scale surveys.

The idea of using satellite imagery for the detection of SGD is based on anomalies in measurable physical parameters such as sea surface temperature (SST) and turbidity that cause changes in spectral properties. This, in turn causes a change in sea surface radiation (UV, VIS and IR). These anomalies in sea surface radiation can be transferred back into relevant physical properties using appropriate algorithms allowing detection and quantification of SGD.

For example, in temperate latitudes, coastal waters cool down during winter to temperatures just above freezing. Due to temperature inertia, groundwater is discharged at temperatures significantly higher than that of the wintry water column. Temperature and salinity related differences in water density result in discharged water ascending through the water column which creates a positive SST anomaly above submarine springs if the discharge rate is high enough. This sea surface temperature anomaly can be localized by mid and far infrared (thermal) channels of color scanning satellites such as the LANDSAT system (**Fig. 6**). Spaceborn SGD imagery would require high resolution which was not realized on NOAA type satellites (spatial resolution 2.5 km) but is now much improved (e.g., LANDSAT 7 has 60 m spatial resolution in the thermal IR band, 10.40 - 12.50 μm wave length; see also Eurimage™ web page "http://www.eurimage.com/Products/ls7/l7summ.html").

The development of remote sensing tools as well as appropriate data processing algorithms have to be calibrated against land- and sea-based reference measurements. If only one particular location was investigated, there would be a high chance to overlook significant contributors to SST and other anomalies and, thus, to obtain artificial results. The planned intercomparison exercise proposed here would provide an ideal opportunity to compare satellite information to the results obtained from several SGD locations which have now been well investigated.

Since the strength of satellite imagery for SGD monitoring is the global scale dimension, more than one location has to be taken for reference in order to learn how to separate SGD-related anomalies from all kinds of important interfering phenomena. In addition, satellite techniques are very capable of supplementing the intercomparison experiments by providing additional geographic information about the setting. This can then be used for classification of the chosen test sites which, in turn can feed into the LOICZ typology efforts. It is clear that in order to make regional to global assessments, one must develop a means to extrapolate from well-studied areas, as the sites of our intercomparisons, to other coastlines.

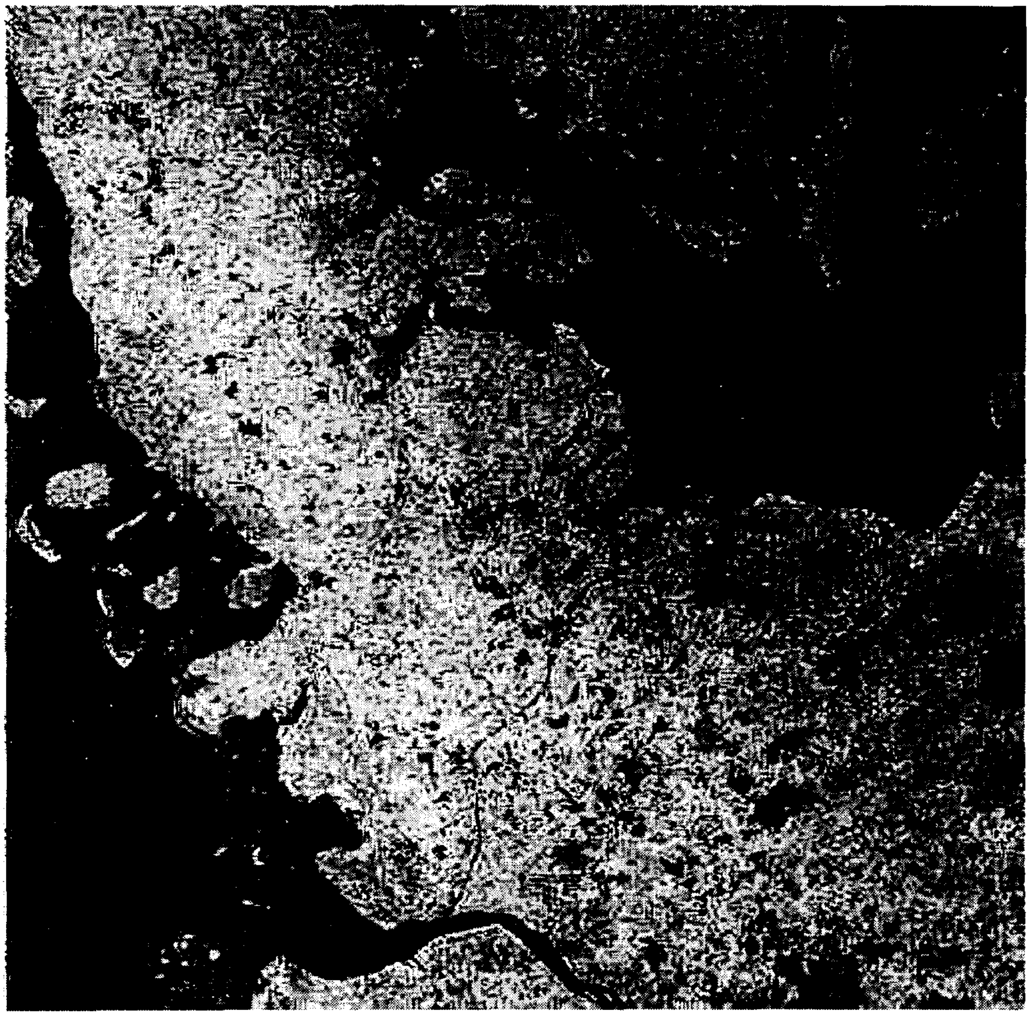

Figure 6 RGB composite satellite image of LANDSAT 5 (September 3, 1996) using bands seven (mid-infrared), five (near-infrared) and two (visible - green). Scene of Danish and German Baltic and North Sea coast. Ship-based studies have shown that SGD occurs in red-boxed areas and especially at the tip of the red arrow. Picture from Eurimage™ quick look server (http://www.eurimage.com/einet/qls.html).

Personnel and Timetable

The personnel required for the intercomparison efforts will be drawn largely from the group of scientists active in SCOR/LOICZ Working Group 112 (**Table 2**). Additional personnel will be recruited as necessary. In view of the great interest which has been shown on this subject over the last few years, we do not anticipate any problem finding scientists willing to contribute. We envision that each intercomparison should include at least 2 modelers accustomed to working on applied issues at the appropriate scale, up to 4-5 people with direct SGD measurement experience and/or a background of deploying instruments on the sea bed (the exact number should depend upon how many different devices are to be evaluated), and about an equal number of tracer experts. Assuming about 4 people on site to help with sampling and logistics (boats, deploying equipment, etc.), a typical intercomparison experiment will likely involve 12-16 participants.

Table 2. Key personnel and responsibilities for the proposed project. Additional personnel will be recruited from the SCOR/LOICZ working group and elsewhere as required.

Principal Investigator	Affiliation/email	Project Responsibilities
William C. Burnett	Department of Oceanography Florida State University Tallahassee, Florida 32306 USA wburnett@mailer.fsu.edu	• WG Chair, overall coordination • tracer studies, radon
Evgeny A. Kontar	P.P. Shirshov Institute Oceanology Russian Academy of Sciences 36 Nakhimovskiy prospekt Moscow 117218, Russia kontar@cityline.ru	• WG co-Chair, coordination • sea-bottom instrumentation
Henry Bokuniewicz	Marine Sciences Research Center State University of New York Stony Brook, NY 11794 USA hbokuniewicz@notes.cc.sunysb.edu	• coastal management issues and training • direct SGD measurements via seepage meters
Willard S. Moore	Department of Geological Sciences University of South Carolina Columbia, SC, 29208 USA moore@epoch.geol.sc.edu	• geochemical tracers • radium isotopes
Leslie Smith	Department Earth & Ocean Sciences University of British Columbia 6339 Stores Road Vancouver, BC V6T 1Z4, Canada lsmith@eos.ubc.ca	• modeling • hydrological measurements
Makoto Taniguchi	Department of Earth Sciences Nara University of Education Nara 630-8528, Japan makoto@nara-edu.ac.jp	• direct SGD measurements via automated seepage meters • geophysical measurements
Jeffrey Turner	CSIRO Land and Water Private Bag, PO Wembley, WA 6014, Australia jeff.turner@per.clw.csiro.au	• coordination of Cockburn Sound (Australia) intercomparison • hydrological measurements

In terms of a timetable, we have already planned our first intercomparison experiment to run for 14 days beginning on November 29, 2000, just a few days after HYDRO 2000 (International Hydrology and Water Resources Symposium; November 20-23, 2000) which will be held in Perth. SCOR/LOICZ WG-112 plans to meet in conjunction with HYDRO 2000 so this timing provides considerable savings in additional travel. Further details about this experiment are given above (see "Flagship I — Cockburn Sound, Australia"). The 2nd intercomparison experiment at Turkey Point, Florida has not been scheduled as yet although we anticipate that in will be in July or August, 2001.

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Budget Request

General

We propose that this project be base funded through SCOR, LOICZ, and IOC. SCOR and LOICZ have already committed funds for this year and similar amounts are expected in the future. This base funding will provide for participant travel to the intercomparison sites, subsistence, and essential logistical arrangements (car rentals, shipping, etc.). The science funding (salaries, equipment, etc.) will be provided through research grants written by project participants to traditional national or bi-national funding agencies. For example, the U.S. participants will seek funding from NOAA or some other appropriate agency for the intercomparison which will be held in Florida in year-2.

Year-1: Australia

The first intercomparison will be held in Cockburn Sound, Western Australia, beginning Nov. 29, 2000 and lasting for 14 days. Dr. Jeff Turner, of CSIRO, has already received commitments for in-kind funding which will provide us with boats, support personnel, and access to laboratory space. In addition, two science members of Turner's team will be available to participate in the intercomparison. This will significantly reduce the cost of running the initial intercomparison.

We show in **Table 2** below the general activities anticipated and the number of individuals needed to participate in each. This results in an estimated total of 15 scientists. Three of these are local, so we need to fund 12 scientists to Perth for 14 days.

Table 2. Anticipated activities and number of scientists required for each during the first "flagship" SGD intercomparison at Cockburn Sound, Australia.

Personnel Required: Scientific/Technical

Technique	**Number of Participants**
Manual seepage meters/piezometers	3
Automated seepage meters	2
Geochemical tracers: Rn-222, Ra-226, CH_4, short-lived Ra isotopes	4
Other geochemical tracers: artificial tracers (SF_6, ^{18}O-enriched water, etc.), He isotopes, tritium, stable isotopes, ^{14}C	2
Geophysical methods: temperature probes, remote sensing (?)	2
Hydrological modelers	2
Total =	15

We estimate below (**Table 3**) the funds required to send 12 scientists to Perth, Australia for participation in the intercomparison exercise. The $2,500 average airfare is based on fares from North America (average ~$3,000) and Europe/Asia (average ~$2,500). The per diem rates and car rentals are expected to be close to actual costs. Shipping costs for equipment and supplies and cost of expendables is difficult to estimate but we believe the figures shown are reasonable. We estimate a total cost of $60,000 for this exercise.

Table 3. Estimated expenses required for 12 scientists to participate in the first "flagship" SGD intercomparison at Cockburn Sound, Australia.

	Unit cost	**Number**	**Total**
Air tickets, average price =	$2,500	12	$30,000
per diem @ $100/day =	$1,500	12	$18,000
rental vans/cars =	$500	3	$1,500
shipping =	$1100	5	$5,500
expendable supplies =	$1,000	5	$5,000
		total =	$60,000

We have firm commitments from SCOR ($15,000) and LOICZ ($20,000) totaling $35,000. In order to meet our budget then, we request funds from the IOC of $25,000 for the first year of the project. We anticipate that the budget request for the following years would be comparable. A report of each intercomparison will be made to the IOC with a specific request for the following year.

Appendices

- IOC Resolution XX-2
- Planning Meeting Agenda, Feb. 2-4, 2000
- Planning Meeting, List of Participants
- Characteristics of a "Flagship" Intercomparison Site

Adopted Resolution: Twentieth Session of the IOC Assembly; Paris, June 29 - July 9, 1999

Resolution XX-2

MEASUREMENT AND MANAGEMENT OF SUBMARINE GROUNDWATER DISCHARGE IN THE COASTAL ZONE AS A CONTRIBUTION TO THE IOC/ICAM PROGRAMME

The Intergovernmental Oceanographic Commission,

Recalling Resolution XIX-5 of the IOC Assembly to establish an Integrated Coastal Area Management Programme (ICAM) and to invite Member States to initiate new co-operation projects,

Noting that the flow of groundwater directly to the sea, or submarine groundwater discharge (SGD) is an important component in marine geochemical budgets and may influence ecosystems within the coastal zone,

Emphasizing that the proposed project has important links to ICAM, IOC Marine Science programmes such as OSLR, OSLNR, GIPME and the coastal component of GOOS,

Takes note that the measurement of the SGD process has proven very difficult, and has hampered the scientific understanding of this process;

Instructs the Executive Secretary IOC to convene a group of experts with the following Terms of Reference:

(i) to draft a basic plan for a SGD Project in the context of ICAM in close collaboration with LOICZ, the GOOS Coastal Panel, the UNESCO International Hydrological Prograrnme and Programme on Environment and Development in Coastal Regions and Small Islands, and SCOR / LOICZ WG-l 12;

(ii) to prepare an intercalibration programme to resolve existing measurement problems and develop new techniques as appropriate; and

(iii) to report progress to the Thirty-third Session of the IOC Executive Council and submit the draft plan and programme to the Twenty-first Session of the IOC Assembly.

Financial implications: US$15,000 from Extra-budgetary Sources

SCOR/LOICZ Working Group 112
Intergovernmental Oceanographic Commission

Measurement and Management of Submarine Groundwater Discharge

Planning Meeting

Feb. 2-4, 2000

Agenda

Venue: Room 6.19 (6th floor) UNESCO Building, batiment 6, entrance: 1, rue Miollis, Paris 75015, France: February 2-4, 2000

Wednesday, February 2:

9:00am: Welcome, Introductions

Background matters — how we got to this point. Overview of knowledge base.

Burnett -- objectives, purpose, and approach of present meeting; brief history of research on SGD and SCOR/LOICZ Working Group 112

Kontar -- background on possible IOC interest in SGD

Identification of Management Needs:

Bokuniewicz -- Relevance of SGD to coastal zone management — what are the important issues? What do coastal zone managers need to know about sgd?

12:00pm Lunch break

1:30pm: **Measurement and modeling issues**:

Turner: Design of an intercalibration experiment — site selection, approach. How many people do we need? How much will it cost?

Smith: Modeling SGD — modeling isn't "measuring" yet its a way to estimate what we want to know. How can modeling fit into an intercalibration?

Yechieli: Reverse SGD — salt water intrusion. Can (should) these processes be studied together?

Schlueter/Sauter/Dahlgaard: Effect of submarine groundwater discharge on the influx of methane and nutrients to the bottom water of the Coastal Zone.

5:00pm: adjourn

Thursday, February 3:

9:00am Draft Project Outline

Measurement issues — what are the problems, how can they be best approached?
Intercalibration exercises — what environments need to be covered? List specific sites or environments? How can an intercalibration exercise best be designed?
Candidates for case studies — if part of a proposed program, which areas would be most suitable? Criteria for best SGD sites may be different than for CZM studies.

Additional coastal zone management issues: linkage of terrestrial and marine ecosystems; groundwater as a pathway of diffuse (non-point source) pollution; does reduced SGD effect coastal marine ecology? How can this be measured? How can we involve local czm's? Can training be part of the intercalibration experiments?

~10:30am Working sessions -- split into 2 working groups to draft main project part of proposal
(1) measurements (Burnett, Turner, Smith, Schlueter, Dahlgaard); and (2) management (Bokuniewicz, Sauter, Yechieli, Kontar)

12:00pm Lunch break

1:30pm Continue drafting proposal sections

Finish drafts, select reporter for presenting overview next morning

5:00pm: adjourn

Friday, February 4:

9:00am Presentation of two sections, discussion, feedback (especially between the two groups) improvements, areas for integration, identify voids remaining to be filled

Assignments for final draft -- timetable, set deadlines and goals

12:00pm: adjourn

SCOR/LOICZ Working Group 112
Intergovernmental Oceanographic Commission

Measurement and Management of Submarine Groundwater Discharge

Planning Meeting

Feb. 2-4, 2000

List of Participants

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