Water Resources and Water Pollution Studies

PETER AIREY
Environment Division
Australian Nuclear Science and Technology Organisation, MENAI NSW 2234
Email: pla@ansto.gov.au

SUMMARY:

Nuclear techniques are widely used in the investigation of the dynamics of the water cycle. This paper focusses on their contributions to the development of strategies for the sustainability of environmental resources. Emphasis has been placed on the role of environmental isotopes and radiotracers in evaluating models of complex environmental systems. Specific reference is made to 1) the construction of a marine radioactivity database for Asia and the Pacific, 2) the sustainability of groundwater in regions challenged by climate change, and 3) the applications of radiotracers to off-shore transport of sediments and contaminants.

1. INTRODUCTION

The central theme of this paper is the contribution that nuclear techniques are making to understanding the dynamics of the water cycle. Two underlying themes emerge:

- The role of tracer techniques in validating numerical models of complex environmental processes. Particular reference will be made to contaminant transport models in the coastal zone.
- The role of isotope techniques in assessing the sustainability of ecosystems in a future challenged by competition for environmental resources and changing climate patterns.

It is appropriate to introduce the topic with examples from the oceans which accommodate 97 per cent on the water on the planet. An understanding of ocean dynamics contributes to knowledge of coastal processes and of global precipitation patterns. Radiotracer techniques have been applied extensively to studies of sediment and contaminant transport in the coastal zone. Examples of sewage dispersion and bed load transport studies will be presented. The role of these studies in validating predictive transport models which can be used in the assessment of options for sustainable development will be discussed.

The oceans are the primary source of global precipitation. For almost 40 years, the IAEA has been building up its Global Network of Isotope Precipitation or GNIP database. Recent work has significantly advanced applications of the database to climate change studies at a regional level.

Such studies are linked to groundwater investigations since the isotopic composition of intake water reflects that of the rainfall feeding the intake beds. Since the age of groundwater samples can vary from the very recent, up to millions of years of longer, systematic changes in the isotopic composition of the groundwater reflects past climate change. This has been known for many years. However, the possibility is now emerging of using these insights to evaluate global climate change models, and hence enhance the confidence with which they can be used for prediction.

2. DISPERSION OF RADIONUCLIDES IN THE OCEANS

Extensive surveys of the levels of environmental isotopes in the oceans have been made over the past three decades. These data, together with much other information have led to the 'conveyor belt' picture of global circulation patterns. Cold water is conveyed along the ocean floor from the North Atlantic via the Antarctic region to the North Pacific. The return water comprises warm surface water from the Pacific, via the Indian Ocean to the Atlantic. This pattern as modified

by local conditions provides a fundamental basis for understanding the distribution of radionuclides in the seas as a consequence inputs from the atmosphere and river systems as well as ocean dumping.

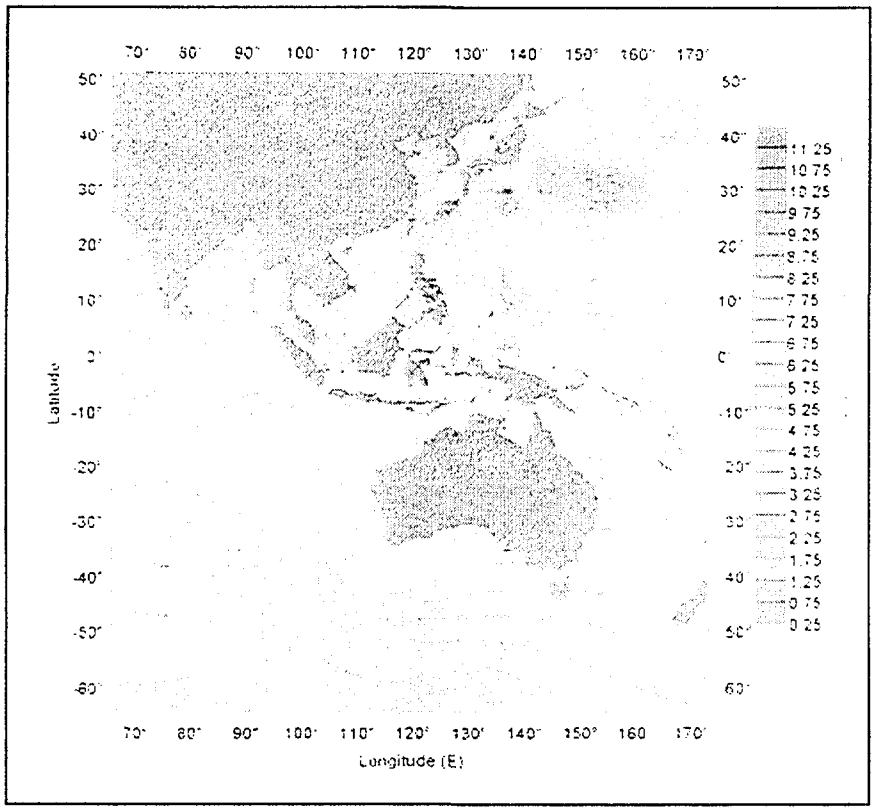

Figure 1: Spatial distribution of Cs-137 average activity (Bq/m^3) in surface sea water based on data from 1975 to 1999 (Duran(1))

The IAEA supports a Global Marine Radioactivity Database (GLOMARD). Until recently, there was very little systematic information available form Asia and the Pacific. This situation has been addressed within the framework of the IAEA Regional Cooperative Agreement Project *Managing the Marine Coastal Environment and its Pollution* which is being coordinated by ANSTO. As a component of this project, the Philippines Nuclear Research Institute (Duran (1)) has compiled an Asia Pacific Marine Radioactivity Database (ASPAMARD).

The database includes information on seawater, sediments and marine biota. In all cases particular attention was paid to Cs-137 and to Pu239+240 because of quantities released or their potential radiological risk. Lead-210 activity concentrations in sediments and Po-210 in marine biota were also collected. The latter is considered a major contributor of dose from the ingestion of seafood (Jeffree et al (2)). As an example, the spatial distribution of Cs-137 in surface sea water is shown on Figure 1.

3. ISOTOPES IN PRECIPITATION

The IAEA and the World Meteorological Organization (WMO) (3) have been surveying the content of hydrogen and oxygen isotopes in precipitation since 1961. A Global Network of Isotopes in Precipitation (GNIP) stations has been established.

The data were originally collected as part of the IAEA program for monitoring the worldwide impacts of atmospheric nuclear testing. They were soon applied to hydrological studies as noted in the following section.

Currently applications are being extended to issues of global climate change, as it is recognised that embedded in the database are systematic changes due to *ia*:

- El Nino (Southern Oscillation) events; and
- The impact of large scale land use change on rainfall patterns For example, Henderson-Sellers et al (4) recently used the database to demonstrate an impact of deforestation on climate and hydrology over the Amazon basin.

4. GROUNDWATER STUDIES

The isotopic composition of groundwater at intake reflects that of the precipitation at the time of recharge. Traditionally, environmental isotopes have been used to date water over the ranges 50 years or less (tritium), hundreds to tens of thousands of years (carbon-14) and up to 2 million years (chlorine-36). The residence time of a groundwater sample reflects the time which has elapsed since the water seeped underground and is a good measure of the ease

of replenishment of the extracted water. 'Young' groundwater is readily recharged and is said to be farmed; 'old' groundwater is essentially irreplaceable by natural recharge and is said to be mined.

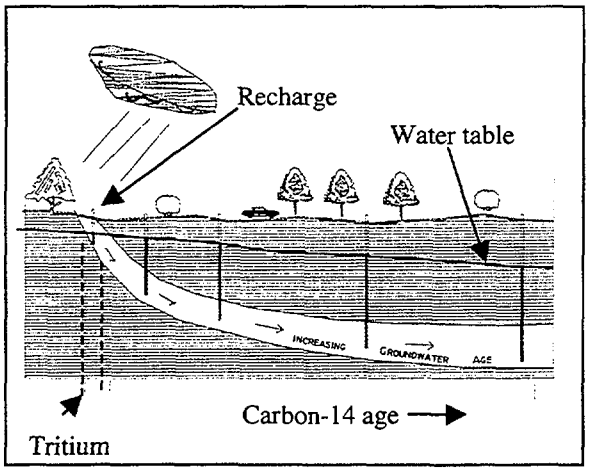

Figure 2: Schematic representation of groundwater flow in a confined aquifer (after Lowenthal and Airey (5))

The stable isotope ratios D/H and $^{18}O/^{16}O$ characterise water at recharge and can be used to quantify the extent of mixing of sub-surface waters from different sources. This information, combined with age dating of samples over a basin is a powerful supplement to conventional hydraulic observations.

Isotope hydrology has been applied to a large number of groundwater basins throughout the world. A major comprehensive review of isotope hydrology and its applications supported by the IAEA has recently been posted at

http://www.iaea.org/programmes/ripc/ih/volumes/ volumes.htm

It has long been recognised that systematic variations in the chemical and isotopic compositions of groundwater may be interpreted in terms of past (or paleo) climatic changes. Groundwater basins with recharge areas in arid or semi-arid areas are particularly sensitive. Examples include:

- Studies of the stable isotopes in water from the Mereenie Sandstone aquifer supplying Alice Springs which showed that only water form the much higher than average rainfall events contributed to the groundwater reserves (Airey et al (6));
- ^{14}C isotope data from groundwater in this aquifer suggest that there were three major periods of recharge over the past few thousand years This work confirms the general conclusions of earlier studies by Pearson et al (7) in the Northeastern Province, Kenya that in arid zones, recharge did not occur uniformly over recent millenia.
- Extensive studies of the isotope hydrology of the Great Artesian Basin have been made. One such study indicated that systematic variations in water quality from the major aquifer within the Basin may correlate with changing conditions in the recharge area in Queensland over the past few hundred thousand years (Airey et al (8)).

These studies all confirm that the isotopic and in some cases the chemical properties of groundwater can reflect the variability of ancient climates in the recharge areas. It is now recognised that knowledge of past climate from a range of sources including groundwater can contribute to the evaluation of global climate change models, and thereby increase confidence in their use as tools for predicting future trends. Details are beyond the scope of this text.

5. RADIOTRACER STUDIES OF OFF-SHORE CONTAMINANT TRANSPORT

The release of pollutants into the marine environment presents a major challenge to the sustainable development of the coastal zone. Strategies for the management of the coastal zone should therefore be based on a scientific understanding of the immensely complex environmental systems.

There are few fundamental approaches to the study of such systems. One involves the incorporation of field observations into large scale numerical models. The second approach uses tracer techniques to study in great detail the individual component of the complex system which has been labelled. Both approaches have their limitations, but together they form a uniquely powerful method for studying the dynamics of environmental systems.

Examples of studies in which ANSTO has played a major role include:

- The release of sewage to the sea from outfalls off Sydney, off Burwood Beach, Newcastle NSW, off Penang, Malaysia and off Hong Kong;

- The impact of major river systems on the coastal zone within the framework of the international TROPICS (Tropical River - Ocean Processes in Coastal Settings) program; and
- The study of effluent dispersion within Manila Bay

The investigations may be classified as either engineering investigations or projects with a research component.

5.1 Engineering investigations:

Most of the Sydney and Hong Kong studies involved the post commissioning trials of the off-shore sewage outfalls.[1] Local investigations focussed on the Malabar and North Head Outfalls. In one study, the tracers gold-198 and tritium were used to track sewage from Malabar, as far south as Stanwell Park over a 24 hour period (Pritchard et al (9)). Samples of the bacteria from within the plume were collected and assayed. The observed values were corrected for the dilution factors obtained from the isotope data. The corrected values showed that the 'die off' rate of the bacteria at the time (June 1992) was such that the concentrations decreased by a factor of two in about eight hours.

In Hong Kong, radiotracer investigations were made of the Black Point, Pillar Point, and Sui Ho Wan outfalls, as well as aspects of the Tolo Effluent Export Scheme. This work was recognised by the Hong Kong Australia Business Association Award 2000 (Export of Services category).

The methodologies used in most of these studies as well as the Burwood Beach and Manila Bay projects mentioned below were similar. Field data from the tracer studies coordinated by ANSTO (or, for Manila Bay, by the Philippines Nuclear Research Institute) were used to validate the outputs of 3D hydrodynamic models developed by the Water Research Laboratory. (King (10)).

[1] The Sydney outfall studies were undertaken in collaboration with the UNSW Water Research Laboratory for the Sydney Water Corporation on behalf of the NSW Environment Protection Authority. The Hong Kong investigations were commissioned by the HK Environment Protection Department and implemented in association with EGS (Asia) and the UNSW Water Research Laboratory under the management of either Montgomery Watson (HK) or Mouchel (Asia).

5.2 Projects with a research component:

Burwood Beach: The aim of this investigation was to study the fate and behaviour of particles released at a depth of 23 m at a distance of about 1.5 km off-shore from the Newcastle sewage treatment works.

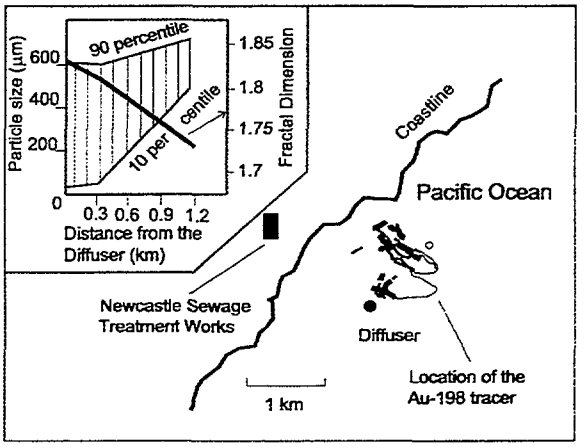

Figure 3: Dispersion of labelled sewage from Newcastle Sewage Works Outfall, Burwood Beach (28 May 1998). The location of the radiotracer is shown in bold. The insert shows the increase in the particle sizes (bounded by the 10 and 90 percentile levels) with distance from the outfall and the corresponding decrease in fractal dimension which correlates with increasing porosity

The principal aim of the work was to evaluate the mathematical modelling using tracer techniques to facilitate management of the outfall. However, there is considerable research interest in the behaviour of sewage particles in the marine environment. Tracer techniques were used to ensure that the samples taken were of diluted sewage released through the outfall during the time of the injection.

Gold-198 and tritiated water HTO were selected.. The gold was rapidly adsorbed to the particles while the tritiated water was used to monitor the aqueous component of the effluent. Gold-198 is a gamma emitting isotope and is monitored continuously by a radiation detector deployed overboard. An example is shown in Figure 3 where those segments of theboat path intersecting the radiotracer are shown in bold.

In this investigation samples from the effluent plume were collected periodically and returned to ANSTO for assay. Tritium was measured in one aliquot to monitor the increasing dilution

as the effluent disperses into the sea. The remaining sample was used to measure properties of the particles; namely the particle size distributions and the fractal dimensions.

As shown in Figure 3 (insert) the particle sizes are generally increasing with increasing distance from the diffuser. At the same time the fractal dimension which correlates inversely with porosity is decreasing. It would appear that the enhanced aggregation is accompanied by enhanced porosity. The entrapped water would be relatively less dense than the surrounding sea water as the effluent is transported for the diffuser to the sea and diluted. The particles would be subject to buoyancy which is consistent to their rising through the water column to the surface.

Manila Bay:

A study has been undertaken of contaminant transport within Manila Bay within the framework of the IAEA/RCA Project: *Managing the Marine Coastal Environment and its Pollution.* The overall aim of the study was to contribute to the much wider challenge of minimising the frequency of occurrence of harmful algal blooms which have a major effect on the local fishing industry. A number of approaches are being used including the extension of tritium methods for the rapid and accurate assay of saxotoxin and the use of lead-210 techniques to study the frequency of occurrence of past blooms by identifying cysts in dated sediment cores collected from the Bay.

Complementing these studies are the investigations of the sources and transport of nutrients in the Bay. A three dimensional model of the Bay was developed by the Water Research Laboratory which was validated by radiotracer techniques coordinated by the Philippines Nuclear Research Institute and ANSTO. In this case, technetium-99m tracer was used eluted from a 300 GBq Gentech® medical generator.

Details are described in ref (11). It suffices to say, that during the period studied, solute transport was dominated by the effect of winds. The tracer data greatly enhanced the quality of the modelling by providing direct measurements of dispersion both on the surface and at depth under the influence of a wind field.

6. RADIOTRACER STUDIES OF BED LOAD TRANSPORT

Radiotracers are widely used to validate models of bed load transport with a range of applications in coastal engineering including: optimisation of the alignment of dredging channels and the location of dredge spoil grounds; the development of ports and harbours and the fate and behaviour of contaminants associated with particulates.

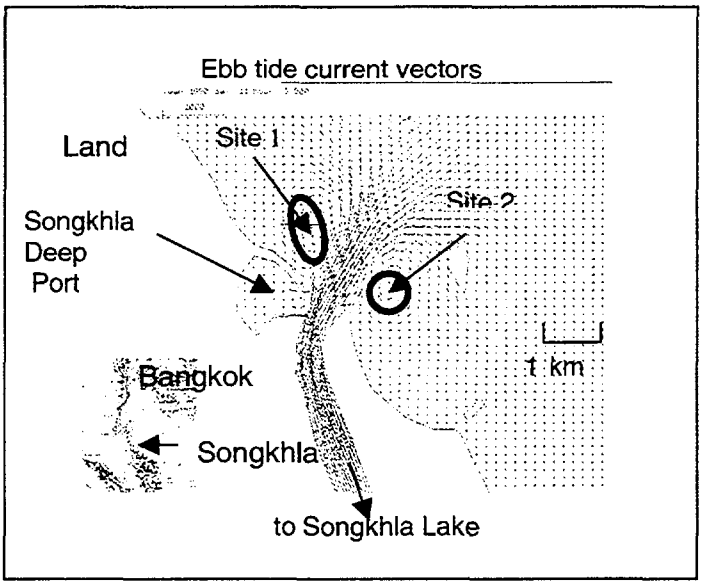

Figure 4: Superimposed on the ebb tide current vectors in the vicinity of the Port of Songkhla are the locations of the two tracer injections made on 25 November 1000 and the approximate location of the tracer plume approximately six weeks later.

The principal aim of the investigation was to validate the model prediction of the bedload transport in the vicinity of the Port of Songkhla using tracer techniques.[2] The tracer was ^{192}Ir incorporated within glass beads with the same density and particle size distribution as the sand. The points of injection and the location of the plume after six weeks (7 January 2000) are depicted in Figure 4. As shown in the table below, very satisactory agreement between the observed and predicted values was found (Nielsen et al (12)). This enhanced the

[2] The project was supported by the IAEA RCA and undertaken by the following organisations: Office of Atomic Energy for Peace (OAEP), ANSTO, the Thai Harbour Authority, the Pronce of Songkhla University, and the UNSW Water Research Laboratory.

confidence with which the model could be used to plan on-going Port development.

Injection	**Transport** (kg/m)		**Bearing**	
	Model	Tracer	Model	Tracer
Site 1	16,560	22,400	321°	333°
Site 2	4,337	1,470	162°	168°

7. FUTURE DEVELOPMENTS

Isotope techniques will continue to be an integral part of many investigations of the water cycle. The demand will arise out of the need for sustainable freshwater and other quality environmental resources in a world challenged by climate change and increasing populations especially in the coastal zones.

Three major outcomes of isotopic studies can be identified: The first is the improved understanding of the changing properties of existing fresh water resources as an aid to better management.

The second outcome is an improved understanding of the processes of environmental degradation which can be addressed by engineering intervention. These include the fate and behaviour of contaminants and the transport of sand and sediments. A powerful approach is the use of radiotracers to validate numerical models of the processes.

Thirdly, isotope techniques may be used to assess the impact of climate change by contributing to the evaluation of climate models.

8. REFERENCES

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