Modern Environmental Assessment Procedures for Enclosed Seas

TERRY HEALEY* and KENICHI HARADA†
*Department of Earth Sciences, University of Waikato, Hamilton, New Zealand
†Department of Earth Sciences, Yamagata University, Yamagata, 990 Japan

Enclosed seas on a world scale are typically characterised by low tidal currents and flushing potential, yet are centres of high population and therefore pollution pressure. Accordingly it is appropriate that recognised environmental assessment procedures are applied. For those examples which have little co-ordinated data, a full baseline environmental investigation is needed to establish a data base against which to measure future change. An appropriate way to achieve this is using an integrated multi-disciplinary approach involving the following components:

1.- review of previous work and collation of existing data.
2.- bathymetric and geomorphologic evolution, and changes.
3.- determination of bottom sediment facies and sediment transport pathways and budgets.
4.- investigation of water column and surficial sediment geochemistry and ecotoxicity.
5.- inlet hydraulics, tidal, current and wave climate measurements.
6.- investigation of marine biology and ecology, and the patterns of eco-distribution in relation to the sedimentologic, oceanographic and pollution parameters.
7.- numerical modelling of current hydrodynamics.
8.- numerical modelling of water quality and pollution dispersion.
9.- numerical modelling of hazards such as tsunamis, storm surge and flooding, and the effect of such events on the enclosed sea hydrodynamics, pollution and sediments.
10.- review of the efficacy of the numerical models in relation to the field and empirical data; i.e. how well do the models fit perceived "reality"?

Only by undertaking an integrated, multi-disciplinary study can the best planning decisions be made for future resource utilisation and management of the enclosed seas. Presently such a study is proposed for Osaka Bay, Japan.

Key Words: enclosed seas, environmental investigations, numerical modelling, field data.

Introduction

This paper outlines the methodology and philosophy for modern integrated multi-disciplinary studies of hydrodynamic and sedimentary processes in enclosed and semi-enclosed seas, and such methodology may have application to the enclosed seas of Japan (Healy & Harada, 1990b).

As Japan begins to become more concerned about, and aware of environmental matters, emphasis on such studies can be expected for the future. In the past most matters of environmental concern in Japan have been dealt with by the civil engineers. It has been argued that for the future the best solutions arise from a multi-disciplinary approach to coastal and harbour problems, involving input from a wide range of scientists as well as engineers (Healy & Harada, 1990a).

Enclosed Seas as Pollutant Traps

A clear definition of the terms "enclosed sea" and "semi-enclosed sea" is difficult to obtain and does not appear in the common encyclopediae and glossaries of geological and oceanographic terms (e.g. Baker, et al., 1966; Gary, et al., 1972) . Nihoul (1982) notes that there is no clear definition of semi-enclosed sea, but states that " they are essentially bounded by land and there is limited communication with adjacent seas or oceans." For the "enclosed sea" it appears that one can use the term synonymously with "semi-enclosed sea" although it seems to have a connotation of being somewhat more sheltered, surrounded by considerable land mass, and bounded by submarine sills or ridges (Baker, et al., 1966). Geologically they are marine marginal basins.

For those enclosed seas that have submarine sills inhibiting gravity outflow from the marine marginal basin, the potential for deposition of fine particles, organic matter and various pollutants is enhanced. Some of the factors why enclosed seas are favoured sites for both geological and pollutant deposition are:

Marine Pollution Bulletin, Vol. 23, pp. 355–361, 1991.
Printed in Great Britain
0025-326X/91 $3.00+0.00

(i) the enclosed seas are usually zones of hydrodynamically low energy. They are characterised by restricted fetches and low wave heights. Accordingly the waves usually do not act on the bottom sediments in water depths greater than about 15m. They are thus sediment and pollutant "traps", and once fine sediments and pollutants become deposited they are likely to remain. A classical example is Kiel Bay in the Western Baltic (Healy & Werner, 1987; Healy, et al., 1987).

(ii) They are often, but not exclusively, characterised by low tidal ranges, for example, the Baltic and Mediterranean seas, and are thus not well flushed of suspended materials, or pollutants in solution.

(iii) They are often, but not exclusively, surrounded by catchments of young, soft, or highly weathered rocks, so that a large proportion of the matter entering the coastal zone is in the form of suspended silts and clays.

(iv) Throughout human history they have been sites of coastal settlement, and today they are frequently surrounded by high population densities with resulting high effluent output.

Accordingly, enclosed seas are prime sites for severe pollution potential.

Procedures for Comprehensive Investigation of Enclosed Seas

Field investigations provide basic "real world" information, and thus should be an integral part of such projects. Numerical models alone do not provide a reliable basis for decision making. To have confidence in the output of numerical models it is essential to have rigorous calibration and verification data (Black, 1983; Healy, et al., 1987; Black, et al., 1989). Accordingly a substantial field program involving several aspects is necessary. Because of the size of enclosed seas, and scale problems associated with physical models, as well as the modern expertise with numerical modelling, physical modelling is considered inappropriate for enclosed seas.

Although ultimately all pollution impacts upon the biological ecosystems, our view is that the physical attributes of the system should be investigated in conjunction with the ecosystems. Accordingly, the major components for study of enclosed seas are as follows:

(1) Collation and review of existing data and literature on the physical oceanography, hydrodynamics, sediments, ecology and water quality of the enclosed sea. Most enclosed and semi-enclosed seas of the world already have considerable research undertaken on them, but it may be disparate and unco-ordinated, especially where the enclosed sea is transected by political boundaries. Of fundamental importance is the available water level and tide data, wave and current data, storm surge and natural hazard (e.g. tsunami) data. The review would need to include information particularly on bathymetry, sediment transport and bottom sediment facies maps, integrate data from side-scan sonar and shallow continuous sub-bottom seismic profiling (CSSP) surveys, bottom photographs and video records of the sea floor. Sediment sampling and textural analysis data is also of fundamental importance. Information on the marine ecology also needs to be reviewed and assessed to guide the extent of new biological investigations. For example the distribution of certain benthic organisms may be already well known, but the ecotoxicity effects on the distribution of that organism may not be known.

From assessment of the existing data base, the extent of additional field investigations required for the study can be evaluated.

(2) Bathymetry and morphologic evolution. Existing and historical bathymetric data needs to be analysed for trends of sea floor morphologic change, and in conjunction with known sedimentation history, a conceptual model for morpho-sedimentation evolution of the enclosed sea developed. For the application of numerical hydrodynamic modelling, accurate modern bathymetry is essential. This may require a full hydrographic survey of the enclosed sea.

(3) Bottom sediment facies and sediment transport budgets. A sediment facies analysis needs to be undertaken based on integration of field data from side-scan sonar mapping and sub-bottom profiling, sea floor photographs and video records, bottom sediment sampling, and textural analysis based on hydraulic grain size. This data is needed (a) as baseline environmental data with major implications for distribution of benthic organisms; (b) to provide a basis for calculation of appropriate friction factors for the numerical hydrodynamic modelling; and (c) to co-ordinate with the current and wave data to draw conclusions concerning sediment transport patterns. Of most importance, the sandy bedformed zones imply active sediment transport pathways, while zones of mud deposition suggest pollutant sinks.

Sediment transport and sediment budget are extremely difficult to ascertain, but can be determined by numerical modelling if the expertise is available. This requires substantial field calibration and verification data of bed and suspended sediment loads (Black, 1983). The suspended sediment load is usually measured in conjunction with full tidal cycle velocity profile gaging (Danish Hydraulics Institute, 1982; Healy, et al., 1987).

(4) Water and surficial sediment bio-geochemistry and ecotoxicity. A field sampling program is necessary with large numbers of sediment samples for analysis. These should be analysed for standard pollution indicators, including DO, BOD_5, COD, organic C, hydrocarbons, major heavy metals of Hg, Cd, Cr, and Sn, and S, PO_4 and NO_3 (Healy, et al. 1988; West, 1989). From these analyses, indications of ecotoxicity can be inferred. For enclosed seas likely to be suffering from heavy human effluent discharge, analysis of viral contamination of the waters and surficial sediments are required. Investigation of the thermal and salinity structure of the water column, and its seasonal variation, is also envisaged. This would require seasonal monitoring of the water column temperature and salinity.

(5) *Entrance hydraulics, tides, currents and waves.* Tidal water levels and field measurement of current data are critical for both calibration and verification of the numerical models. The field data are also necessary to co-ordinate with the bottom sediment patterns, benthic ecology, and side-scan sonar mapping data, and to ascertain the appropriate friction factor to be used for the numerical model.

Tidal data needs to be obtained from a number of recording tide gauges within and outside of the enclosed sea. The tidal stations need to record simultaneously over a 2 month duration, during which period the necessary current measurements would also be taken. All tidal gauges need to be "precisely levelled" to a common tidal datum.

Current data of three different types is needed:

(i) continuous recording, vector averaging current meters of the S4 type or similar, would be required to be deployed simultaneously at several locations, including locations within the enclosed sea, in the inlet gorges, and outside of the enclosed sea so as to determine the boundary conditions.
(ii) vertical velocity profiles and a tidal gauging need to be taken across the inlet gorges for the duration of a full tidal cycle, for both spring and neap tides;
(iii) drogue tracking is needed to obtain current vectors for verification of the hydrodynamic modeling output. Both flood and ebb tide on spring and neap conditions need to be monitored.

Data from the tidal and water level gauges, and current velocities, need to be processed and presented in a suitable form for the numerical modellers.

Wave data would need to be recorded by wave recorder, or otherwise numerically simulated based on wind records.

For tidal hydraulics a full spring tidal gauging of the bay may be considered a useful adjunct. Available remote sensing data would likewise provide additional data for comparison of the thermal characteristics and structure of the enclosed sea.

(6) Marine biology and ecology. The physico-chemical condition of the enclosed sea impacts markedly upon the marine biology and ecology. For some investigators, the biological component may be paramount for the study. Biological studies will likely include (a) benthic ecology, especially population associations, patterns and distribution in relation to sediment types and pollution; (b) ecotoxicity patterns, that is, investigation of pollution impact on the ecology; (c) microbiological investigations, including the distribution of micro animals such as diatoms, foraminifera, and algae in the sediments and in the water column. Where expertise is available, modelling of pollution impacts on population dynamics may be appropriate.

(7) Numerical modelling of hydrodynamics is now widely available with different schemes. However to have confidence in the models, it is absolutely critical that they are calibrated and verified by the field data program involving the tidal, current, and bottom roughness data from disparate locations within the enclosed sea.

(8) Numerical modelling of pollution dispersion is envisaged to be undertaken, driven by the hydrodynamic model developed above. The effect of the new constructions on overall current flows, sediment transport patterns, pollution dispersion and residence time within the enclosed sea, are some perceived problems that can be investigated with the aid of the numerical models. Remote sensing may likewise provide valuable comparative data (LeDrew & Franklin,1987).

(9) Numerical modelling of hazard events: Depending upon the location of the enclosed sea, tsunamis, storm surge, flooding, pollution hazard, and their effects on the bottom sediments and ecology, may result in severe impacts. Because such events have occurred relatively frequently in historical time, this modelling will aim to identify the impacts of the hazard on bottom sediments and ecological patterns. of the enclosed sea and its coastal zone.

(10) Review of the modelling and field information. All modelling and field data for such large co-ordinated interdisciplinary projects as envisaged here need independent critical review and assessment of compatibility

between the model and field data. For such large studies considerable basic research evolves, and it is appropriate that the results are widely disseminated, perhaps in book form as occurred with the NERC project in Japan (Horikawa, 1988).

Type of Study:

It is argued that studies of the type outlined above, should be encompassed within a multi-disciplinary project involving a number of institutions and disciplines. This approach permits access to the best available expertise to address the wide range of problems in order to attain the optimum long term answer. As pointed out elsewhere (Healy & Harada, 1990a), research and investigation in the area of environmental earth sciences in Japan is predominantly the domain of the civil engineer. The great danger when problems become perceived as the domain of one dominant discipline is that a "we know best" attitude tends to develop. But in the field of engineering, which deals primarily with surficial geological phenomena and processes, many engineers in different parts of the world now recognize that their knowledge is far from perfect, and that non-engineers may make significant contributions (Aoki, 1985; Ikeda 1985; Okusa, 1986; Ikeda and Ouchi, 1989; Okimura, 1989). Scientists concerned with the environment also are recognising the need to co-operate more closely with the engineers (Suzuki, 1989).

Logistic Support Needed

It is envisaged that each participating institution will be able to provide the necessary logistic support in the form of research vessels, equipment, laboratory and computing facilities, and personnel. Most important is access to research vessels with suitable accurate position fixing capability, and with the necessary equipment for deployment and retrieval of the oceanographic equipment. For the modelling, if different institutes are involved it is clearly advantageous for the computers used to be compatible.

Role of multidisciplinary Investigation in Enclosed Coastal Seas Planning and Management

The requirement to undertake multidisciplinary investigation in enclosed coastal seas is not simply for the sake of scientific research *per se*. For optimum return on the research dollar the project needs to be planned and executed in response to the local and national government planning and management needs and aspirations of the environmental managers of the enclosed sea. Moreover the scientific project manager needs to interact closely with the managers and planners, both to ensure that the investigation is sufficient for the planning purposes as well as ensuring that the results of the investigations are made available for rational planning and optimum management decisions. The modern scientific project manager also needs to liaise with the public and concerned citizens groups. It is axiomatic that the best planning and management decisions for the long term future are based upon (i) the results of such multidisciplinary studies, and (ii) the availability of the investigation results and management plans for public discussion.

The above concepts are illustrated conceptually in Figure. 1.

It should be noted that the philosophy expounded in this paper has largely been adopted by the "Seto Inland Sea Declaration" adopted by the plenary session of the EMECS"90 Conference in Kobe August 1990.

Possible Application to Osaka Bay

Osaka Bay is a very important physical feature of significance to some 15-20 million people who live surrounding the bay.

Physiographically, Osaka Bay is a shallow, oval-shaped, enclosed sea, with a narrow inlet through to the Harima-nada of the Seto Inland Sea, and opening through the Tomo-ga-Shima to the funnel-shaped Kii-suido embayment exposed to the Pacific Ocean to the south. Because of this topography, Osaka Bay is extremely susceptible to storm surge and tsunami effects (Kawata & Tsuchiya, 1988; Tsuchiya & Kawata, 1988).

There are several important reasons why a major study should be undertaken:

1. Environmental issues are now assuming a greater importance for Japan, one of the two largest economies in the world. Environmental science problems are identified as one of the "priority research areas" by Monbusho (1989).

2. Osaka Bay is arguably the most polluted and under the most development stress of any part of the Seto Inland Sea, and available baseline environmental data is not comprehensive. It is prudent to ensure that environmentally stressed areas are investigated and monitored so that environmental deterioration can be detected and action taken to ameliorate any problem, to repair environmental damage, and attempt to enhance the environment for future generations.

3. The scientific results and principles resulting from such a study would be applicable to other densely populated Asian lands in the future. Of major concern for many situations are the sediment and water quality, and hydrodynamics of water exchange.

4. Osaka Bay has suffered natural hazard disasters in the past including both storm surge and tsunami wave effects (Kawata & Tsuchiya, 1988; Tsuchiya & Kawata, 1988; Tsuchiya, et al.,1989). It is prudent to continue researching the hydrodynamics and nature of the bottom sediments of the bay in order to better understand, and therefore be better prepared for, future hazard events.

5. A new international airport at Kansai is under construction. Almost all airports suffer occasional aircraft accidents, and for the case of the new Kansai airport, for such an unfortunate event, there would need to be knowledge available concerning the bottom sediments and currents within Osaka Bay to assist the recovery operations. This is a compelling reason for this study.

6. There is the possibility of a second artificial island airport to be constructed for Kobe.

There are two issues that we anticipate arising. One concerns the question of whether a full biological/ecological study should run in conjunction with the above proposal. Although we can be convinced otherwise, our present thinking is that inclusion of biological components such as plant and animal ecology, micro organisms, ecotoxicity and stress levels, ecological modelling and monitoring might make the project too unwieldy. However, once the results from such a study become available, the task of the ecologists and biologists becomes much easier as the dynamics and sediments of the physical system will have been precisely defined.

A second issue is the proposal to utilize multidisciplinary and the the "best available expertise" for the various components of the study. It is highly unlikely that the best available expertise for all of the disparate components will be located within one government ministry. This may therefore lead to difficulties in arranging funding for the project. Altruistically, however, it is preferable to pursue the ideal of a multidisciplinary approach to the study, as this will produce a study commensurate with international trends, and also produce the best results.

Conclusion

This paper has outlined the procedures required for a modern environmental hydrodynamic and sedimentological investigation pertaining to enclosed seas such as Osaka Bay. It is argued that a multi-disciplinary co-ordinated approach produces the best long term answer to environmental investigations, a situation well established overseas (Healy, 1980). Examples of such studies include Tauranga Harbour, New Zealand, and Westernport Bay, Australia, and an integrated study on the North Sea supported by the European Community nations, has commenced.

For such studies it is critical that the numerical modelling is not seen to be the "tail that wags the dog". The modelling is an integral part of the study, but without substantial field data and model verification, as well as critical review of how well the models perform, there can be little confidence in the models. Indeed, critical peer review of the results of these large studies should be an integral part of the study design and objectives in order to minimise the possibility of misinterpretations which might then become the basis of subsequent environmental management decisions.

Projects on environmental investigation of enclosed seas as outlined in this paper, are clearly dependent on available finance and expertise. But rational decision-making and management of enclosed seas for effective long term future use and resource utilisation can only be achieved if such studies are carried out.

References

Aoki, S. (1985). Natural disaster researches by Japanese geologists - past present and future. *Geol. Soc. Japan Mem.*, **25**, 543-463.

Baker, B.B., Debbel, W.R., & Geisendorfer, R.D. (1966). *Glossary of Oceanographic Terms.* U.S. Naval Oceanographic Center Special Edition, 204p.

Black, K.P. (1983). Sediment Transport and Tidal Inlet Hydraulics. D.Phil. Thesis, University of Waikato, 313 p.

Black, K.P., Healy, T.R., & Hunter, M. (1989). Sediment dynamics in the lower section of a mixed sand and shell-lagged tidal estuary, New Zealand. *Journal of Coastal Research,* **5**, *503-521.*

Danish Hydraulics Institute, (1982). Proposed Forestry Terminal, Marsden Point. Hydraulic Model Studies, 132 p.

Gary, M., McAfree, R. (Jnr), & Wolf, C.L. (1972). *Glossary of Geology*, American Geological Institute, Washington, 805p.

Healy, T.R. (1980). Conservation and management of coastal resources - the earth science basis. In Anderson, A.G. (ed.), *The Land our Future, Essays on Land Use and Conservation in New Zealand,* Longman-Paul, 239-260.

Healy, T.R., Black, K., & de Lange, W. (1987). Field Investigations required for numerical model studies of port developments in large tidal inlet harbours. In Gardiner, V. (ed.), *International Geomorphology 1986.* J.Wiley & Sons, 1099-1112.

Healy, T., Erlenkeuser, H., Winn, K., & Werner, F. (1987): Theoretical post-glacial sedimentation rates for a semi-enclosed sea; example of Kieler Bucht, Western Baltic. *Boreas*, **16**, 201-207.

Healy, T.R, & Harada, K., (1990a) Are Japanese Earth Scientists doing the best for the Earth Sciences in Japan? *Episodes* (in press).

Healy, T.R, & Harada, K., (1990b). Principles for an Environmental Interdisciplinary Study of Hydrodynamics, Sediments and Pollution applied to Osaka Bay. *Journal of the Sedimentological Society of Japan* (in press).

Healy, T., Mc Cabe, B., Grace, R., & Harms, C. (1988). *Environmental Assessment Programme for Tauranga Harbour Dredging and Inner Shelf Dumping*. Report to the Bay of Plenty Harbour Board, Tauranga, New Zealand, 43p.

Healy, T., Ryan, S., & Harms, C. (1988). Recent environmental issues concerning dredge spoil dumping. *Proceedings of the Ecopolitics III Conference*, University of Waikato, 98-102.

Healy, T. & Werner, F. (1987). Sediment budget for a semi-enclosed sea in a near homogeneous lithology; example of Kieler Bucht, Western Baltic. *Senckenbergiana maritima*, **19**, 32-70.

Horikawa, K., ed. (1988). *Nearshore Dynamics and Coastal Processes*. University of Tokyo Press, 522p.

Ikeda, H., & Ouchi, S. (1989). Fluvial processes and landforms. *Trans. Japan. Geomorph. Union,* **10A**, 47-56.

Ikeda, T. (1985). Significance of geomorphological observation and interpretation for civil engineering projects. *Trans. Japan. Geomorph. Union,* **6**, 153-162.

Kawata, Y., & Tsuchiya, Y. (1988). Extremal statistics of tsunamis in Osaka. *Proceedings of the 6th Congress I.A.H.R.*, 241-247.

LeDrew, E., & Franklin, S.E. (1987). Mapping potential effluent pathways in the Long Point region of Lake Erie from LANDSAT imagery. *Journal of Coastal Research*, **3**, 219-243.

Monbusho, (1989). *The University Research System in Japan.* Ministry of Education, Science and Culture, Tokyo, 33p.

Nihoul, N.C.J., (1982) *Hydrodynamics of Semi-enclosed Seas*. Proceedings of the 13th International Liege Symposium on Ocean Hydrodynamics. Elsevier Scientific Publications, 555p.

Okimura, T. (1989). Man-made landform transformation. *Trans. Japan. Geomorph. Union,* **10A**, 139-145.

Okusa, S., (1986). Marine geotechnology. A new interdisciplinary branch of science and technology. *J. Geol. Soc. Japan,* **92**, 879-903

Suzuki, T., (1989) Hierarchy of geomorphological understanding and the recent status in Japan. *Trans. Japan. Geomorph. Union,* **10A**, 1-12.

Tsuchiya, Y., & Kawata, Y., (1988). Historical changes of storm surge disasters in Osaka. In El-Sabh, M., and Murty, T. (eds), *Natural and Man-made Hazards,* D.Reidel Publishing Company, 279-303.

Tsuchiya, Y., Kawata, Y., Sakai, T., & Shimada, Y., (1989). Flooding due to the Ansei Nankaido tsunami in Osaka. *Proceedings of the Japan-China Joint Seminar on Natural Hazard Mitigation, July 1989*, 505-514.

West, N. (1989). A preliminary review of water quality parameters and recreational user perceptions of nearshore water quality. *Journal of Coastal Research*, **5**, 563-572.

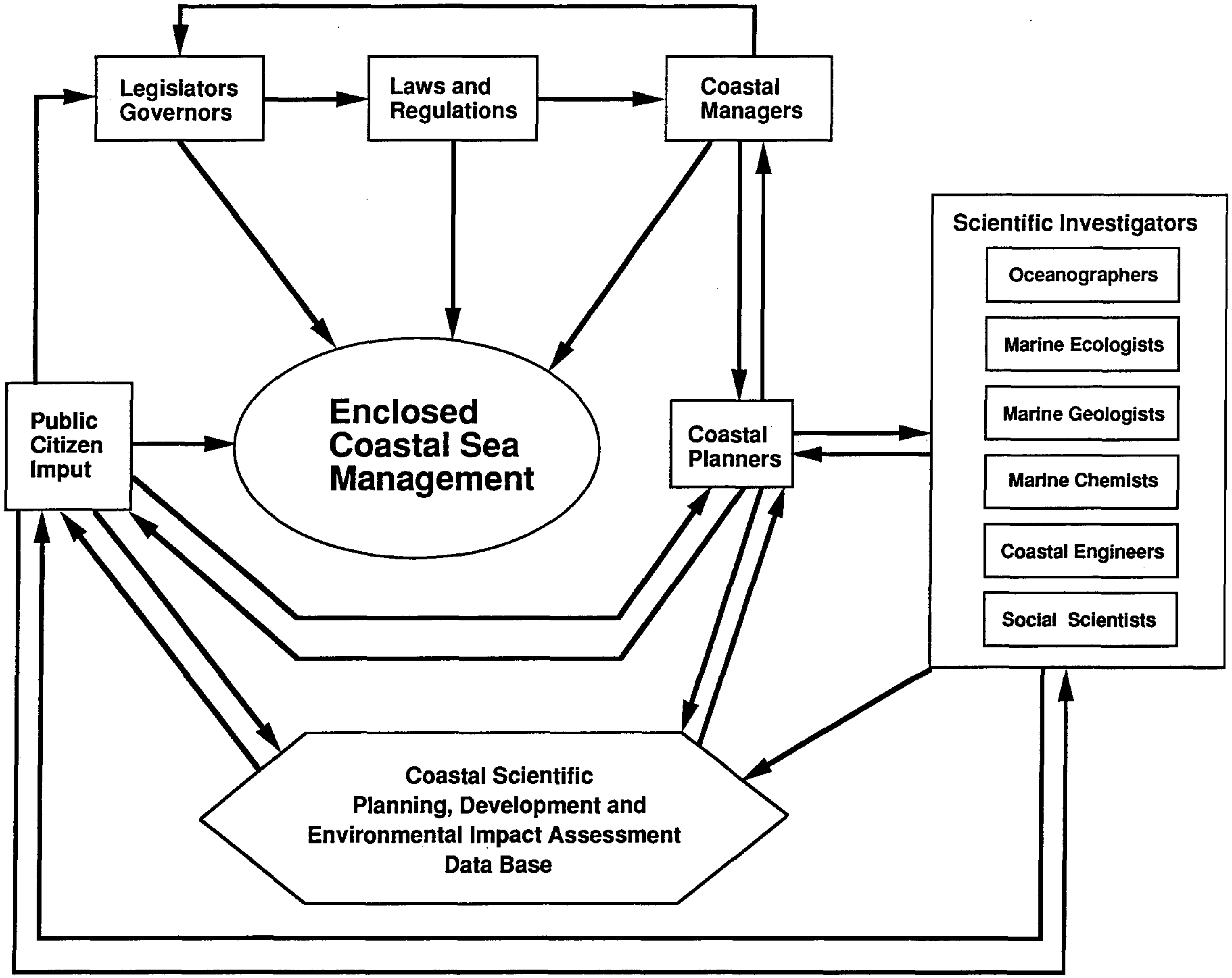

Fig. 1 Interactions involved in coastal planning and management.