

Megascience: The OECD Forum

THE COSTS AND BENEFITS OF SEAWATCH EUROPE

Brian F. Mannix

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris 1996

35151

Document complet disponible sur OLIS dans son format d'origine

Complete document available on OLIS in its original format

Copyright OECD, 1996

Applications for permission to reproduce or translate all or part of this material should be made to:

Head of Publications Service, OECD, 2 rue André Pascal, 75775 Paris Cedex 16, France.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS AND DISCLAIMERS.....	5
EXECUTIVE SUMMARY.....	6
Introduction and background.....	7
The Global Ocean Observing System	7
Seawatch Europe.....	8
The role of Cost-benefit analysis	9
OECD analysis.....	10
Analytical approach	10
Cost-benefit analysis of megascience.....	10
Discounted net benefits	11
Major conceptual problems	12
Cost-benefit analysis and cost-effectiveness analysis	13
Costs of Seawatch.....	13
Costs of Seawatch Europe / Thailand	13
Estimates of the cost of GOOS.....	14
Global potential of Seawatch.....	15
Benefits of Seawatch.....	16
Marines structural design criteria.....	16
Marine operations.....	17
Benefits estimate	17
Commercial fisheries.....	18
Fish farming.....	18
Benefits estimate	20
Tourism	20
Meteorological forecasting	21
Climate modelling.....	22
Crisis response: spills.....	22
Pollutant transport monitoring and modelling.....	22
Oceanographic research.....	22
Selected cost-effectiveness comparisons.....	23
Distinctive characteristics of Seawatch	23
Ships.....	23
Fixed platforms	24
Satellites	24
Conclusions and implications for the future of Seawatch.....	24
BIBLIOGRAPHY.....	26
APPENDIX: TERMS OF REFERENCE	28

Introduction	28
Proposal	28
1. Fisheries and fishfarming.....	28
2. Offshore industry.....	28
3. Meteorological institutes	28
4. Pollution control.....	29
5. Insurance companies.....	29
6. Research institutes	29
Remarks.....	29
Notes	30

ACKNOWLEDGEMENTS AND DISCLAIMERS

The author would first like to thank Jan Stel of the Netherlands Geosciences Foundation for his constant support and patient instruction throughout this project. Support for this paper was provided by the Marine Science and Technology programme (MAST) of the European Commission, the EKSPOMIL program of the Research Council of Norway, the Netherlands Geosciences Foundation, and the Organisation for Economic Co-operation and Development. Essential co-operation was provided by the Oceanographic Company of Norway and by many users and potential users of Seawatch Europe, including the International Oceanographic Commission of UNESCO, the Dutch National Institute of Coastal and Marine Management, the Swedish Meteorological and Hydrological Institute, Norske Shell, Shell I.P.M., the Norwegian Fishermen Organisation, the University of Trondheim, and the Oceanographic Company of the Netherlands.

Of course, the author maintains his exclusive claim on any inaccuracies that remain.

EXECUTIVE SUMMARY

There is today a strong demand for better information about the ocean environment, and recent technological developments have made it possible to answer this demand. International commitments have been made to expand our capabilities, and there is broad agreement to build a Global Ocean Observing System.

Cost-benefit analysis can help strengthen the case for proceeding with GOOS, and can help in the choice of components from which it will be built. However, some serious conceptual problems as well as data problems ensure that benefits estimates made today are very approximate.

The development of Seawatch Europe involved initial costs of approximately \$10 -20 million. As the technology improves, this investment will rise; but it does not need to be repeated.

The incremental cost of duplicating a state-of-the-art Seawatch system (of ten buoys) is \$2-3 million annually. This has already been done in Thailand, demonstrating not only that it can be duplicated but also that it is a suitable candidate for technology transfer to the developing world.

A complete global network (notionally, 500 buoys) would cost about \$100 million per year to operate and would provide a strong foundation for GOOS.

The most immediate expected benefits are in offshore operations (especially oil and gas) which we estimate at \$150 million annually in Norwegian waters; potentially double that in the larger Seawatch Europe domain; and potentially \$1.5 billion annually for a global system.

Aquaculture also has experienced a demonstrable benefit from Seawatch. We estimate the benefit to be \$2.1 million annually for Norwegian salmon farms, and \$80 million annually in potential global benefits.

A great many other categories of benefit are discussed but are not yet assigned a monetary value. Many of these are public goods, including both improved short-term weather forecasting and improved long-term climate forecasting.

While Seawatch produces commercially viable services that can and do help to finance its development, it will be important for governmental bodies at the national and international level to take a greater role in sponsoring Seawatch. The danger is that if it is forced to survive as a strictly commercial enterprise, the full potential of public goods will not be realised.

Introduction and background

The Global Ocean Observing System

Throughout history the ocean has been a bountiful source of food and a highway for commerce. Today the ocean also serves as a major source of oil and gas and, everywhere you find it, it is the number one tourist attraction. The ocean has the potential to become even more productive: untapped oil and gas reserves are disproportionately offshore, and the advancement of technology makes more of them accessible each year. Dissolved and seabed minerals form a large “backstop” reserve for the time when onshore deposits are depleted. Fresh water may be extracted from salt water when other sources are unavailable.

But there is also the very real possibility that the ocean will become much less bountiful than it has been. In this decade the collapse of commercial fisheries has gone from being a rare local disruption to a global concern. The ocean has ceased to be viewed as a dumping ground of unlimited capacity, as pollution in coastal zones and confined seas has become a hazard to human health, to the environment, and to industries such as fisheries and tourism that depend on a healthy marine environment.

In addition, the public has become concerned that human activities may be causing large scale changes to the earth’s biosphere, and understanding the ocean is a key to answering questions about these processes. Ocean currents transport huge amounts of energy around the globe, and perturbations of these currents may explain the passage of “ice ages” as well as less dramatic—but more immediate—interannual variations in the earth’s climate. The ocean is the largest sink for carbon dioxide and the largest source of water vapour; thus the global warming puzzle can only be solved by learning more about the ocean and its interaction with the atmosphere. Moreover, a rise in the mean sea level is one of the most certain, and one of the most feared, side effects of global warming. The ocean may also be the largest source of atmospheric chlorine, with an unknown contribution to the erosion of the ozone layer.

As a result, there is a tremendous impetus to develop information about the ocean environment. This impetus is driven not only by demand, but also by developments in technology. Satellites are able to make increasingly sophisticated measurements from space, and have also allowed us to look down on the planet and view the ocean and atmosphere as a single dynamic system. Computers are now becoming large enough and fast enough to run numerical ocean/atmosphere forecasting models on a global scale and to assimilate huge amounts of data; communications systems are available both to collect that data in real time and to deliver the results to users in real time.

Already the effort devoted to ocean observation and modelling has had a large payoff. The successful forecast of the last ENSO (El Niño/Southern Oscillation) event helped mitigate widespread agricultural damage in several countries; in the future such forecasts will be more accurate, and they will also be more attended to. They are predicted to reduce agricultural losses by several billion dollars. In short, the tools available to oceanographers have advanced to the point where they can begin to answer the questions that have been posed.

One manifestation of this is the emergence of an international co-operative effort called the Global Ocean Observing System (GOOS), now in the early phases of development. The International Oceanographic Commission (IOC) has, since 1989, supported and prepared the initial development of GOOS. GOOS was included in the UNCED “Agenda 21” which emphasises the importance of a co-ordinated global system for monitoring the oceans. GOOS has also been supported by the Second World Climate Conference (SWCC). The World Meteorological Organisation (WMO), United Nations

Environment Program (UNEP), and the International Council of Scientific Unions (ICSU) have all pledged their co-operation in implementing GOOS.

GOOS is intended to serve as an international framework to co-ordinate systematic observations about the state of the ocean and marine resources. Building from existing observation systems that are often temporary (the World Ocean Circulation Experiment), localised (The Netherlands' coastal monitoring network), or specialised (Japan's tsunami warning system), GOOS aims at assembling a permanent, integrated, global network collecting calibrated data.

GOOS is also intended to serve as a catalyst for transforming the way oceanography is done. Today, the operational side of oceanography is relatively undeveloped (compared to meteorology); and much of the public funding for oceanography is directed toward basic research. It may take the form of grants to conduct particular research projects, whose main product is academic journal articles. Such scientific research obviously will continue as long as there are new things to learn. In twenty years, however, oceanography will have developed to look much more like meteorology does today, with operational organisations -- both public and private, staffed by professionals -- collecting continuous observations and broadcasting continuous reports and forecasts to a diverse community of users.

The components of that system are only now beginning to take shape.

Seawatch Europe

Seawatch Europe is a regional observation system that is one likely building block for GOOS. Developed primarily under the direction of the Oceanographic Company of Norway (Oceanor), Seawatch began as a Eureka/Euromar project in 1989. It consists of three components:

A set of multi-sensor moored buoys at selected locations in the North Sea collecting:

- a) meteorological data (air pressure & temperature, wind speed & direction);
- b) physical oceanographic data (waves, currents, temperature and salinity profiles);
- c) chemical and biological data (radioactivity, oxygen saturation, nutrient levels, light attenuation);
- d) a computer system for accumulating data from the buoys in real time (by satellite link), adding data from other sources (manual observations, satellite images), running numerical models of the sea, and interpreting the data; and
- e) an electronic delivery system to make information immediately available to Seawatch users.

Seawatch Europe has been operational for several years, yet all of these components continue to evolve. The first version of the light attenuation sensor, which has been in use for several years on the Seawatch buoys, will be replaced with a new generation, now under development, that yields spectral information. Other sensors, like the CTD-string, nutrient analyser, and radioactivity sensor, are continuously improved; while new sensors, such as a detector for petroleum traces, are being developed. Data transmission is now done within a couple of hours of collection via the ARGOS satellite system. Eventually communications will be carried on the INMARSAT system which will allow continuous data collection, as well as two-way communication with the buoys.

One of the reasons for taking a close look at Seawatch Europe is that it can be replicated. Seawatch is designed to be portable and modular, so that many countries around the world may consider whether to install a version of Seawatch in their region. It is also a suitable candidate for technology transfer to developing countries, as has already been done in Thailand. Seawatch provides a complete package that is compliant with the design standards of GOOS. As a result, Seawatch Europe is a closely watched experiment.

GOOS comprises five modules:

- a) climate monitoring, assessment, and prediction;
- b) monitoring and assessment of marine living resources;
- c) coastal Zone management and development;
- d) assessment and prediction of the health of the ocean;
- e) marine meteorological and oceanographic services.

Of these, Seawatch has only limited application to the monitoring and assessment of marine living resources, but is directly relevant to the other four. As a technical matter, Seawatch can be deployed in both shallow and deep waters,ⁱ and may prove to be useful in collecting deep water data that can be used to verify ocean circulation models, satellite observations, etc. However, it is more likely to see extensive deployment within the Exclusive Economic Zone (EEZ) (200 mile limit). Within the EEZ there is a need for observations that are more closely spaced in both time and space (to capture more intrinsic complexity in near-shore phenomena); more importantly, there is far more economic demand for knowledge of the EEZ.

This paper examines the costs and benefits of Seawatch Europe, but the intent is not only to shed light on the merits of that project, but also to help to contribute to future decisions about whether it ought to be replicated elsewhere.

The role of Cost-benefit analysis

For private goods and services traded in competitive markets there is little need for formal cost-benefit analysis. Individual consumers decide what they want to eat for breakfast, using whatever criteria they like. Markets can sort out the individual preferences and match them up with low-cost providers (within the constraints of farm policy, of course). Where there is a market failure, however, there is a rationale for government intervention.

The principal market failure affecting oceanography is that the services it provides are public goods -- defined as those which are nonrivalrous (my consumption does not diminish what is available to you) and/or non-exclusive (if I produce some I cannot easily prevent you from enjoying it too). National defence is the classic example of a public good: no matter how the costs of providing for defence are distributed, the benefits are inevitably shared. Markets do not elicit the socially desirable level of production of public goods -- governments may do betterⁱⁱ.

In the case of oceanography there are two levels at which the public good argument can be made: it produces information which can be usefully and cheaply shared by a large number of users (without

rivalry); and its subject is the ocean, which is itself to a large extent a common property resource that is typically non-exclusive. In this respect (and many others) oceanography resembles meteorology. Weather observations and forecasts are expensive to produce but cheap to share. And the atmosphere is unavoidably a shared resource, for better or -- in the case of a radiation leak, for example -- for worse. This is not to say that there is no room for private weather services and private oceanographic services. But it cannot be expected that such private markets will come anywhere close to satisfying the public demand. This is particularly true with respect to environmental monitoring for the purpose of pollution prevention.

Cost-benefit analysis has become a standard procedure for evaluating public projects throughout the developed world. Even so, it still generates considerable controversy and confusion. At the conceptual level, most agree that it is sensible: a desirable undertaking ought to do more good than it does harm. The difficulty comes in finding methods to assign value to the outcomes -- particularly when the public goods produced by a project include public health, environmental protection, expansion of human knowledge, and other things we are not accustomed to placing a price on.

Yet we all agree that it is worth spending money on these things, and we are all forced to agree that, in a world of limited resources, we cannot spend an infinite amount of money on them. The question eventually must be confronted: How much shall we spend? On which things?

OECD analysis

This paper is being prepared for the OECD Megascience Forum, which was established in 1992 to help encourage the exchange of information relating to megascience projects undertaken by member country governments. Megascience refers to scientific projects of such scope that co-operation (typically international) from a large number of participants is required to carry them out.

Because of its global scale, its cost, the number of participants, and its decades-long time-frame, GOOS clearly qualifies as a megascience project. In September 1993 the Megascience Forum held an expert meeting on oceanography, hosted by Japan, which focused its attention on GOOS. One conclusion from that meeting is that the OECD should use its expertise in cost-benefit analysis to sharpen the estimates of costs and benefits of GOOS and its various components; several such papers are under development. The suggestion to study Seawatch in this context was made at an ECOPS meeting at Heathrow in October 1993.

Analytical approach

Cost-benefit analysis of megascience

Contrary to popular misconception, cost-benefit analysis is not a technique that governments have borrowed from the private sector; from the start it was designed to address public projects. It originated about 1900, in the US Army Corps of Engineers, where it was used to determine whether harbours should be dredged and, if so, to what depth.ⁱⁱⁱ During World War II both Great Britain and the United States developed a variety of operations research methods for deploying military resources; later these were incorporated into cost-benefit analysis and applied to a wide range of public projects.

There are as yet very few examples of cost-benefit analyses of megascience projects. Another paper prepared for the Megascience Forum^{iv} reviews what examples can be found, and enumerates the considerable barriers that must be overcome when cost-benefit analysis is applied to megascience projects.

Some of those barriers are particularly troublesome in the case of Seawatch Europe. Thus we approach this task with humility. The estimates of costs and benefits will be very crude, and the conclusions necessarily tentative.

One barrier to applying cost-benefit analysis to any kind of scientific endeavour is the difficulty of anticipating the outcome of research that is inherently exploratory. Those who wish to encourage governments to commit resources to scientific research point out, correctly, that retrospective evaluations of science and technology projects tend to show very high social returns. This is true for both public and private expenditures. In part, that is evidence that the projects that survive to be evaluated in retrospect are good ones, and that weak projects are weeded out early. The screening mechanisms we use to select projects -- including the peer review process, self selection (as researchers choose careers), and budgetary scrutiny -- appear to be working reasonably well. In addition, it suggests that the opportunities for productive research are nowhere near being exhausted by the resources now made available for it.

This observation is not of much use for evaluating prospective projects, however. We cannot assume that any particular proposal will be beneficial just because projects in the past have turned out well.

Discounted net benefits

Typically a critical ingredient in the analysis of any long-term project is the choice of a discount rate. The longer the delay between the onset of the cost stream and the onset of the benefit stream, the greater the sensitivity to the discount rate. For example, if a project costs \$10 million per year and produces benefits of \$20 million per year, you cannot say whether it is worthwhile until you know when each cash flow begins. If the costs and benefits both begin immediately, then the discounted present value of costs and benefits at 10 per cent annually is \$100 million and \$200 million respectively, for a net gain of \$100 million.^v On the other hand if the costs begin today, and the benefits begin in ten years, then the present value of costs and benefits at 10 per cent annually is 100 million and 77 million respectively^{vi}, for a net *loss* of \$23 million. Lower discount rates will make the project more attractive, but a longer delay will make it less attractive.

Notwithstanding the above discussion, this paper will discuss the costs and benefits of Seawatch on an annual basis; therefore certain cautions are in order. Discount rates can be of critical importance in evaluating projects with long time horizons. Some of the benefits of the Seawatch system can only be realised after years of additional research: improvements in long-term climate modelling, for example, would take at least five to ten years to produce social benefits. Some environmental protection measures that could take advantage of Seawatch data may be farther off.

Yet these long term benefits are also those for which it is not now possible to calculate a monetary value. The quantified costs and benefits that appear in this paper are relatively prompt. Collecting design data for offshore structures takes five or six years (after which data collection can stop), prior to the realisation of benefits (which mostly take the form of reduced up-front construction costs). Taking this as a three year delay^{vii} would imply that using annualised costs and benefits will overstate the benefits by 25 per cent relative to costs. Given the coarse nature of the estimates in this paper, distortions of up to 25 per cent are relatively small. The benefits that are easier to quantify (such as operational data for oil and gas platforms, or algal bloom forecasts for aquaculture) are those that are immediately available as soon as the system is operational.

Because the costs of replicating a Seawatch system are not strongly “front-loaded,” and because the stream of *quantifiable* benefits is relatively prompt, it is reasonable to regard them as approximately simultaneous. That is, we can judge the Seawatch concept by comparing estimated annual costs and benefits, without insisting on a net present value calculation. For clarity of presentation the discussion below uses annualised costs and benefits. It should be kept in mind that to the extent that long-term benefits are weighed in the balance, the effect of discounting should not be disregarded.

Major conceptual problems

A cost-benefit analysis summarises the consequences of a decision, and therefore must examine two or more possible choices. It cannot be applied, for example, to an activity -- a benefit-cost analysis of “transportation” would be meaningless because we cannot realistically choose not to have any. This need to specify a clear choice presents two problems in the context of megascience projects. First, it is often difficult to specify exactly what the project will encompass; this is called the identification problem. Second, it can be even more difficult to specify what will happen if the project is not undertaken; this is called the counterfactual problem.^{viii}

In the case of Seawatch, there is no discrete choice that now has to be made, so that the cost-benefit analysis must suppose an artificial one. But it is not easy to specify what this should be. Seawatch incorporates available satellite data into its models, but those satellites are not part of the project to be evaluated. Thus it does not seem reasonable to include the cost of the satellites in the costs of Seawatch. But if we exclude the costs, must we also exclude the benefits derived from the satellites? Defining the boundaries of an integrated information system is problematic.

The counterfactual problem is still more serious. What is the alternative against which to measure costs and benefits of Seawatch? In a world without Seawatch, surely there would still be buoys collecting data and computers running numerical models. Substitute systems would be developed, and many of these would resemble Seawatch -- perhaps very closely. If we allow this to happen we will not be able to estimate costs and benefits. On the other hand, hypothesising a world in which buoys and models are not permitted is too artificial. Perhaps it could be done, but what useful information would it tell us? This problem arises in part because the decision is an artificial construct.

Another paper being prepared for the Megascience Forum considers a proposed North Sea Water Quality Information System (NSWQIS). This proposal has a focus different from Seawatch: it stresses modelling more than observation, and it strives to integrate more macrobiological data. Yet they have much in common. In the base case (no Seawatch) should we assume that the NSWQIS goes forward? If so, then we must assume that it will collect data from many of the same sources, that it will take advantage of fixed buoys as well as other observation platforms, that it will take advantage of new developments in numerical modelling, computer technology, and data transmission, that it will use satellites for data communication as well as for imaging, and that it will respond to the demands of its users. In short, although there may be important differences between the two proposals as they exist today, we cannot be sure that in twenty years we could look at the systems and be able to tell which is which since they will evolve in the same directions.

There appears to be no rigorous solution to this problem. Because we are only making rough estimates of costs and benefits, we can perhaps get by with an imprecise idea of the boundaries of the project. To do this we need to try to focus on the most distinctive characteristic of Seawatch. It has been suggested that *real-time integration* is the most distinctive characteristic of Seawatch: it collects time-intensive observations of a range of correlated parameters, incorporates remote as well as *in situ*

observations, runs a number of numerical models, and delivers observations and forecasts to users in real time. While these features of Seawatch distinguish it from other systems that exist today, a cost-benefit analysis that hinged on timeliness and integration would likely be viewed as artificial and not very useful. That is, if we demonstrate that Seawatch is beneficial compared to a world in which oceanography is not permitted to be integrated and is not permitted to be timely, we will only have demonstrated the obvious.

The Seawatch buoys are a more concrete feature to focus on. While Seawatch has other important components, and while moored instrument arrays are not unique to Seawatch, the buoys are the most prominent feature we can use to draw boundaries to define the project. Moreover, no other system integrates real-time collection of buoy data with numerical models and with prompt availability to end-users. Thus the “no Seawatch” baseline that we will have in mind will be a world in which oceanographic observation and modelling take place, but without the benefit of a network of moored buoys delivering real-time data. This perhaps will overemphasise the buoys at the expense of other components of the Seawatch system, but it seems the clearest distinction to make.

Cost-benefit analysis and cost-effectiveness analysis

An alternative technique, cost-effectiveness analysis, avoids some of the more intractable problems of cost-benefit analysis. Rather than try to quantify the various categories of private and public benefits associated with Seawatch, we can simply assume that there is an undisputed need for collecting oceanographic data. Cost-effectiveness then deals with the question of finding the most economical way of collecting the needed observations.

A cost-effectiveness analysis will not be as useful to a governmental body that has yet to be persuaded of the merits of operational oceanographic observation. But the argument for GOOS has already been made and, to a large extent, settled. In UNCED’s Agenda 21, in the Law of the Sea Treaty, and in innumerable other contexts governments have made either explicit or implicit commitments to fund the development of operational oceanography. When the decision to be made is not whether to proceed, but which projects to pursue in fulfilment of these commitments, cost-effectiveness analysis can be helpful. It is best done, not at a general level, but in the context of a particular site and a particular problem, where competing technological solutions can be identified.

We will begin with a survey of the costs and benefits of Seawatch, followed by some selected cost-effectiveness comparisons.

Costs of Seawatch

Costs of Seawatch Europe / Thailand

While we are interested in the costs that have been incurred to date in building Seawatch Europe, these are not necessarily the most relevant numbers for a cost-benefit analysis whose purpose is to help inform future policy decisions. Because Seawatch Europe was the first application of the Seawatch concept, it has incurred significant research and development costs that do not have to be repeated. Of course, research and development continues to be a large part of the Seawatch budget and the sensors and other components of the system continue to be improved. But if we want to describe the cost of Seawatch Europe there are two ways to ask the question: What did it cost to do it the first time? and: What would it cost to do it again? The historical cost of Seawatch includes large “sunk” costs for developing the system, which do not have to be incurred again if the system is expanded or cloned.

Fortunately, Seawatch Europe does have progeny: Thailand now has an operational 9-buoy Seawatch system. By looking at the cost of Seawatch Thailand, we can get an estimate of what the Seawatch system costs without the heavy start-up burden that was borne by Seawatch Europe. Of course, every deployment of the system will occur under unique conditions and will present its own challenges. But we are only interested in the approximate costs, so that the comparison between Europe and Thailand is instructive.

Oceanor's contract for starting Seawatch Thailand came to \$7 million over 2.5 years. This includes training of personnel as well as installation of equipment and development of the regional model -- expenses that would have to be incurred each time the system is deployed. This figure may understate the true costs because it does not include some of the costs borne by local institutions. On the other hand, the annual cost of operating the system in subsequent years will be lower than in the start-up phase.

If we take one Seawatch "planning unit" to consist of ten instrumented buoys plus associated data systems, it seems reasonable to expect that annual costs will run approximately \$2 and \$3 million. (Single-buoy applications can certainly be useful, but the integrated Seawatch system cannot be much smaller than ten buoys.) Of course, data systems can handle input from a much larger number of buoys without having to be duplicated.

How great are the start-up costs that were borne by Seawatch Europe? It is probably not possible to answer this question precisely, since some of the costs of developing instruments are "joint costs" -- those instruments can be used in other, non-Seawatch contexts. Looking at the Oceanor's annual reports a rough estimate would be on the order of \$10-\$20 million.

Estimates of the cost of GOOS

To put the costs of Seawatch in context, it is useful to look at estimates of the total cost of GOOS, even though GOOS has not yet advanced to the point where its costs are known with any precision. Globally, expenditures on oceanography and marine technology total \$5-\$10 billion annually. It is thought that a fully operational GOOS may require an additional expenditure that is approximately the same as current world-wide expenditures for meteorology, or \$1-\$2 billion annually.

Much research still needs to be done to refine that estimate. The scale of ocean eddies (analogous to atmospheric cyclones) suggests that ocean models may need a resolution ten times finer in horizontal dimensions, and possibly in the temporal dimension, than current atmospheric models. This suggests a need for a thousand times more computer power to run the models and, more importantly, a denser field of observations to support the models. It is not yet known whether simplifying assumptions can be made, nor is it known what the data needs are.

The rough estimates for GOOS do not include all of the costs of local and regional oceanography. In particular, planners recognise that models of much higher resolution -- and much denser observation sets -- will be developed to meet particular needs in coastal zones and other limited areas. These local and regional observation systems will benefit from the availability of GOOS. In turn, GOOS will draw data from the local and regional systems, so that planning for the compatibility of data sets will be mutually advantageous. It is expected that some of the costs of local systems will be supported by local users.

GOOS will also incur joint costs in some other areas, especially satellites. Satellites will be used for meteorology and terrestrial observation, as well as oceanographic observation. Communications satellites that carry GOOS data will have many other users as well.

While the \$1-\$2 billion estimate for GOOS was made as an aggregate and was not assembled from smaller pieces, N. C. Flemming has made a rough breakdown of how the costs may be attributed to GOOS components. [OECD 1994(a)]:

“The applications of different technologies in GOOS -- drifting buoys, subsurface floats, moorings, autonomous vehicles, tomography, etc -- are each likely to incur costs on the order of \$100 million per year. Global data telecommunications, data management, and modelling centres will add a further cost of the order of \$100 million per year.”

Global potential of Seawatch

If the Seawatch concept is successful and is widely deployed, how large might it grow and what would it cost? For the purpose of this thought experiment, we will try to imagine a Seawatch system that covers all shelf seas, coastal zones, archipelagos, key straits and topographical choke points. It can be considered complete when it covers these areas to a resolution that is technically and economically justifiable.^{ix} We shall assume away the various political barriers to the global deployment of Seawatch (or any *in situ* system). For example, in the Mediterranean there are governments that will only consider participating in a joint venture if certain other governments do *not* participate. Some developed countries may insist on building their own system for coastal zone observation. Such obstacles make improbable the idea of a global system bearing the label “Seawatch”; nonetheless this thought experiment is illustrative in that it puts Seawatch on the same scale as GOOS for the purposes of comparison.

An assessment of sampling needs^x estimated that GOOS might require more than 100 moored instrument arrays for deep ocean observation. For shelf seas the same table contains a “?” with the footnote: “The question marks indicate complete uncertainty.”

By looking at Seawatch, we can at least put some bounds on this complete uncertainty. If we think in terms of ten-buoy planning units, the Gulf of Thailand contains one such unit; the Baltic/North/Norwegian Seas contain one unit and ought to have another to provide more complete coverage. The number of opportunities for productively deploying similar systems is certainly greater than ten. On the other hand, it is unlikely to exceed 200, since 200 units would cover all of the earth’s wet surface with the same density of buoys that now exists within Seawatch Europe; fewer than 100 such units would cover all of the EEZ (roughly corresponding to all of the shelf seas and continental shelves). If we use 50 as an illustrative estimate -- i.e., 500 Seawatch buoys^{xi} world-wide -- then the cost is \$100-\$150 million per year. This is likely to be an overestimate of costs because 500 buoys would allow for economies of scale in data management, modelling, instrument manufacture, maintenance, etc.

Thus a fully deployed 500-buoy global Seawatch network would cost roughly \$100 million annually, which is commensurate with the guesstimate made by Flemming above for other components of GOOS.

Benefits of Seawatch

Marines structural design criteria

One of the most straightforward benefits of Seawatch is its ability to collect time-series that allow the estimation of extreme events (waves, currents, etc.) for the purpose of engineering design. Coastal design criteria are important in river deltas and other low-lying areas wherever engineering solutions to storm erosion are considered. The Netherlands obviously has the most experience with this, and has its own coastal monitoring system, including three fixed platforms at sea. As the sea level rises, and as land subsides, the question of whether barriers are adequate must be constantly reconsidered.

In the design of coastal flood barriers, maximum wave height is less important than maximum water level during a storm surge. Such barriers, of course, tend to be designed on the basis of historical experience and coastal measuring systems. Since Seawatch buoys do not measure the water level directly, their ability to forecast maximum storm surges is limited and their importance for designing coastal protection is therefore probably much less than is the case with offshore structures. Even so, Seawatch data that describe water transport and circulation patterns, erosion, resuspension, and other coastal dynamics are likely to be of interest to coastal engineers.

Seawatch can play a more important role in developing design criteria for off-shore oil and gas platforms, which must be able to withstand the sea for up to 50 years. This application does not require real time data, but it does require long time series measured *in situ*. The Norwegian Petroleum Directorate requires one to two year current measurement and ten year wave measurement prior to the development of a field.

Although the offshore oil and gas industry is a steady customer of Seawatch Europe, many of the platform design criteria are not derived from Seawatch data simply because most platforms predate Seawatch. As exploration extends to new areas, this will change. For example, on 1 January 1993 a Seawatch buoy at Nordkappbanken in the Barents Sea recorded a significant wave height of 13.6m (previous 100-year estimate: 12.5m). Further measurement will clarify whether this represents new information or whether it indicates a trend driven by climatic changes. Whichever is the case, it is likely to cause significant changes in the design of future platforms for the Barents Sea.

The meteorological and physical ocean data are most important for platform design, although some of the other data can be useful as well. In the Spring of 1994 Norske Shell had one production platform shut down for most of a six-month period due to repeated clogging of injection-water filters with algae. A redesign of the filtering system allowed normal operations to resume. Thus knowing the frequency and density of algal blooms can help in the design filtration systems. Biological data also are useful for measuring a baseline (including natural variability) prior to constructing a platform, so that the effect of the platform on the local environment can be accurately gauged.

Offshore design criteria are important anywhere oil and gas reserves are developed, particularly at the early stages when the first platforms are being designed and there are no existing platforms from which to take measurements. The benefits of improving design criteria take two forms: cost savings from the avoidance of overdesigned structures, and reduced losses (including reduced loss of life) from the avoidance of underdesigned structures. Since the consequences of underdesign are so catastrophic, engineers tend to deal with uncertainty by overdesign.^{xii} Overdesign may add on the order of 10 per cent to the development cost of a platform (the difference in cost between a platform that is just adequate to meet forecast environmental conditions and one that has a margin of safety to account for uncertainty in

environmental conditions). The value of improved environmental design criteria is some fraction of that 10 per cent, the exact amount depending on how much of an improvement is made.

Marine operations

In addition to providing time series that contribute to structural design criteria, Seawatch buoys can provide data that helps optimise operations in real time. Many marine operations have limitations with respect to weather, current, and waves. An important example is the tow-out of large platforms. By knowing when currents, winds, and waves are favourable -- or at least do not exceed a prohibitive threshold -- such operations can be concluded successfully in the earliest available window. More commonly, the benefits of now-casting and forecasting take the form of reduced standby for tug-boats, crane vessels, diving vessels, and other resources sensitive to currents and waves.

Another example is the operation of subsea pipelines which are sensitive to the bottom temperature. Seawatch has been able to monitor the intrusion of deep cold water into the Norwegian trench, enabling pipeline operators to optimise the use of chemical additives that are used to prevent condensate/precipitate formation when the bottom temperature falls below a critical threshold. Such chemical injection costs on the order of \$2-\$3 million annually.

To a lesser extent, the operation of active coastal defence structures -- such as The Netherlands' \$2.4 billion Delta Works or Britain's Thames barrier -- may also be improved by monitoring Seawatch real-time data. The same is true for harbour operations that are sensitive to currents and wave patterns.

Improved off-shore weather forecasts and sea-state forecasts are important for the operation of transportation systems:

- a) merchant vessels need current, wind, and wave data to optimise routing for efficiency as well as safety reasons;
- b) Roll-On/Roll-Off ferries are particularly vulnerable to adverse sea conditions;
- c) recreational boaters need adequate warning systems for sea conditions that threaten small boats;
- d) coastal rescue operations need detailed information in real time;
- e) many helicopters will not fly over water when the wave height would prevent rescue.

There is no obvious way to estimate the benefits in these areas. Offshore transport is a large consumer of weather forecasting and sea condition information (especially by shipboard radio and weather-fax), but the incremental contribution of Seawatch to improved forecasting cannot be quantified.

Benefits estimate

One way to estimate the value of improved information is to consider the effect of accelerated cash-flows. Offshore oil and gas production is extremely capital intensive: most of the costs are incurred before the revenues begin. As a result, start-up delays are very expensive (since revenues get delayed, but costs do not). At an annual discount rate of 10 per cent, a one-year delay in bringing a well into production results in a 10 per cent reduction in the present value of the revenue stream from that well.

Current revenues from oil and gas production in the Norwegian sector of the North Sea amount to \$15 billion. Since Seawatch costs roughly \$3 million, the “break-even point” occurs at 1.75 hours. That is, if Seawatch can avoid, on average, a delay of 105 minutes in the start-up of oil and gas production, then it will have covered its costs of operation -- even without considering all of the other categories of benefits that it produces. Seawatch data can affect oil and gas operations in a variety of ways,^{xiii} but it seems reasonable to expect that the cumulative effect far exceeds a few hours worth of delay in the production stream.

Rough estimates of the benefits of GOOS have used a benchmark of one per cent of the value added in all marine-based activities.^{xiv} In the case of oil and gas operations in the North Sea, it is plausible to believe that Seawatch can produce benefits of this magnitude, implying benefits on the order of \$150 million annually. Expanding Seawatch Europe to other North Sea sectors could double the benefits.

World-wide revenues from offshore oil and gas production total \$150 billion annually. If similar efficiencies can be achieved in other regions, the potential benefits of a global Seawatch system may approach \$1.5 billion.^{xv}

Commercial fisheries

Fishery scientists embraced the concept of “sustainable yield” long before everyone else borrowed it. Yet the management of fisheries has to be judged one of the tragic failures of twentieth-century technology. The global catch (now approximately 100 billion kilos with a value of \$100 billion) has not increased since 1988. The UN has estimated that 70 per cent of the world’s commercial stocks are fully fished, overfished, or already depleted. On average, fishing effort is gradually shifting to lower value species as the more desirable species become scarcer.

There are many obstacles, both technical and social, to improved fisheries management. The most important long-term contribution that Seawatch can make is to contribute to a better understanding of the factors -- besides fishing effort -- that affect fish stocks and their variability. Improved models of water movement, pollution transport, nutrient availability, algal blooming, and climate variation, all can help our understanding and management of fishery stocks.

Seawatch can also improve the efficiency of fishing operations. Ocean fishing is a hazardous occupation, and improved weather and sea-state forecasting can save lives as well as improve productivity. By mapping temperature and salinity gradients, Seawatch may help find cod and other fish, thereby lowering the effort involved in the catch. With the present degree of concern about fisheries, improving the productivity of fishing effort may not seem very attractive. Nonetheless, in the context of well-managed sustainable fisheries, productivity improvement should be regarded as an unambiguous benefit.

Fish farming

At its root, the problem of fishery management is a failure of property rights. A fisherman does not own a fish until he catches it, and he has no economic incentive to care for the fish that he does not catch. Thus fisherman, and even whole nations, may engage in a race to catch the fish, unwilling to let go what may be caught by someone else tomorrow. Exclusive fishing zones have helped somewhat in creating national claims on some fisheries, so that national governments may more effectively manage

them. Improved international co-operation has also helped. Still, management by regulation has not been a very successful strategy.

As an alternative, aquaculture allows the development of true private property rights in the immature fish. No fish farm ever collapsed from overfishing, and if it did its more efficient neighbour would simply expand to replace it. Because it offers a simple, self-enforcing, solution to the problem of fishery management, many analysts see aquaculture as the dominant form of fish production in the future.^{xvi} On land the transition from “hunter-gatherer” to farmer took place thousands of years ago; at sea we may be just beginning that same transition. One of the benefits of high-yield agriculture is that it allows so much land to return to a relatively wild state. Similarly, by meeting demand for fish, aquaculture may allow many ocean fisheries to return to an essentially wild state.

On the other hand, the technology of marine aquaculture as it exists today has some inherent limitations. Fish farms can have serious environmental impacts, and these need to be monitored. Naturally, production has initially been concentrated in high-value species like shrimp and salmon. On land, the most desirable species for human consumption are herbivores, but for some reason the most desirable marine species are carnivores. Much of the feed consumed by aquaculture is fishmeal produced from low-value wild stocks. The result is that, while aquaculture is producing real economic value-added, it does not, in its present form, promise to increase the gross productivity of the sea nor solve once and for all the problem of fishery management.

Overall, aquaculture is a promising technology and it has been expanding rapidly. World-wide, the output from aquaculture is growing at 7 per cent annually, with 85 per cent of output coming from Asia. One of the benefits of aquaculture is that it provides the opportunity and incentive to do research to advance the technology. Genetic engineering, using both traditional selection and modern molecular biology, can improve the stocks. Feed conversion can be raised and alternative sources of feed can be found. Its ultimate potential is difficult to judge.

It is important to acknowledge that lower prices are the mechanism by which aquaculture produces most of its benefits. The traditional fishing industry often regards lower prices as a cost, because of the losses experienced within the industry. From a social point of view, however, the lower prices produce benefits to consumers that outweigh the losses to high-cost producers. Moreover, lower prices can produce environmental benefits. For example, the growth of salmon farming in Chile, Norway, and Scotland has lowered the market price for fresh and frozen salmon in the United States by 25 per cent. One result is a reduction of fishing pressure on the salmon fisheries of the Pacific Northwest and western Canada, which are seriously depleted. Inevitably, the perception of the North American industry will be that lower prices are just one more problem they have to face in addition to the depletion of wild stocks. From a broader social perspective, however, the effect of lower prices is to conserve the wild stocks, providing an additional benefit.

Seawatch Europe has made a number of contributions to salmon farming in Norway. Ninety per cent of salmon grow-out operations are insured with three companies that sell insurance for both equipment and for fish stocks. All three companies provide funding to Seawatch and require that their clients participate in the monitoring and alert network maintained by Oceanor. Data from the Seawatch buoys are supplemented with data collected by the farmers themselves. Losses are reduced by improved warning of storms, forecasts of water temperature changes, and monitoring pollution. Feeding schedules can be adjusted based on water temperature and conditions, conserving feed as well as reducing mortality.

The main benefit of Seawatch, however, is the ability to monitor algal blooms. Farmers who are warned that a toxic bloom is developing can take preventive action, which may involve moving the cages or harvesting the stock before it is affected by the bloom. Accurate tracking of blooms also can help avoid unnecessary preventive action by providing reassurance to farmers who will not be affected. In this regard, the value of Seawatch should increase with the planned upgrade of the light attenuation sensor, which will allow the system to distinguish (without manual sampling, as is done now) between toxic and non-toxic blooms. A sharper distinction between alarms and false alarms will enable fish farmers to respond efficiently and effectively.

Benefits estimate

Norway produced 170 000 tons of farmed salmon in 1993, with a market value of approximately \$500 million. The insurance companies pay Oceanor approximately \$150 000 annually for the services provided to clients. Losses (paid by insurance companies) due to toxic algae were only \$100 000 in 1993 but averaged around \$8 million annually in the preceding three years. In 1991 annual losses due to storm damage (equipment and escaped stock) were estimated at \$12 million annually; a single severe storm 1 January 1992 caused \$14 million in losses.

The interannual variability of storms and algal blooms makes it impossible to perform a statistical assessment of the effect of Seawatch. Based on their experience with particular incidents, salmon farmers and their insurers believe that the Seawatch system is very effective in avoiding both storm damage and algal poisoning. The benefits of Seawatch are greater in the case of algal blooms because there are fewer alternative sources of information. For the purposes of this paper, I will assume a loss-reduction benefit of approximately 25 per cent for algal blooms, and 1 per cent for storm damage.^{xvii} This amounts to about \$2 million and \$0.1 million respectively, for a total of \$2.1 million annually -- almost enough, by itself, to justify a Seawatch system on the Norwegian coast. Within Seawatch Europe, this system could be expanded to Scotland, Sweden, and other areas where aquaculture is important.

The global potential is difficult to estimate because the nature of aquaculture, and the threats that it faces, varies from region to region. But algal blooms are a threat in many areas where fish farming is developing, and the threats from coastal pollution, oil spills, and radioactivity can also be addressed by the Seawatch system. In 1992, it was reported that shrimp farming losses in China were approximately \$700 million, mainly due to red tides.^{xviii}

The total world-wide fisheries catch is roughly 100 billion kilos, with a value of \$100 billion dollars. Aquaculture production is about 20 billion kilos, of which about half is from salt water species. The value of aquaculture production varies a great deal, but we will assume that on average the 10 billion kilos of marine production is worth \$20 billion dollars.^{xix} We assume that the rate of loss from storm damage and natural (algal) and manmade pollution is similar to the rate of loss in Norway, about 4 per cent annually, or \$800 million. If we assume that Seawatch could reduce losses by 10 per cent overall, this amounts to \$80 million dollars annually at current levels of production.

Tourism

International tourism produced receipts of \$300 billion in 1990.^{xx} If domestic tourism and travel are added, the total exceeds \$2 trillion. A very large share of this total is associated with coastal tourism:

the Mediterranean alone is estimated to account for 36 per cent or more of international tourism. Of course, even without tourism the world's population is highly concentrated in the coastal zone. But tourism is particularly sensitive to water quality. In 1990, one-fifth of Mediterranean beaches were so polluted that they were closed to bathing.^{xxi} Pollution around Athens caused Athenians to drive 70 km. to find a clean beach.

Nations with a significant tourist industry will find it increasingly important to monitor water quality and to determine the factors that influence it. France conducts some 20 000 tests of water quality each summer to ensure that coastal waters are safe for bathers.^{xxii} In many areas Seawatch would be an important supplement to coastal data collection.

Meteorological forecasting

On land, a dense array of meteorological observation stations forms a global network that is increasingly integrated, particularly as communication and computer technology allow forecasters to work with wider scope. Unfortunately, this dense network stops at the water's edge. One reason for this is that the demand for data is greater on land: more people live there, of course, and airports in particular have a great demand for accurate and current met data. But offshore activities also demand accurate and current data. And some of the most important meteorological events -- hurricanes and typhoons, storm surges, polar lows, monsoons, etc -- develop at sea or from the interaction of the atmosphere with land/sea/ice surfaces, so that offshore data is critical to forecasting these events.

The second and more important reason that met observations are much denser on land is that meteorological stations on land are far cheaper than those at sea. Very few meteorological platforms are available on the ocean, and those are often very expensive to build and maintain. When viewed as a network of weather observation stations at sea, Seawatch represents a dramatic reduction in the cost of expanding the land-based met network.

Generating an accurate estimate of the social benefits of a weather forecasting station is nearly impossible, despite the fact that we build them all the time and that the benefits of the met system are unquestioned. We can approach the problem in a different way, however. If we suppose that the social benefits of a marginal land-based weather station is sufficient to justify its cost, we can ask whether the cost of a Seawatch buoy is anywhere close to the cost of its land-based counterpart.

In the United States, NOAA is implementing a technology called Automated Surface Observing System (ASOS) which is designed to improve aviation safety as well as weather forecasting. Designed to be installed at small airports and other ground stations, ASOS incorporates seven automated sensors to provide 24-hour continuous observation of wind speed and direction, temperature and dew point, liquid precipitation accumulation, visibility, cloud height, precipitation type, and barometric pressure. A sensor to detect freezing rain will be fielded later in 1995. Since 1992, NOAA has installed over 600 ASOS units, primarily at airports. An estimated 950 ASOS units are planned to be installed by 1998. ASOS adds a surface weather observation capability to small airports that previously had none, and in other cases it replaces older, manned stations.

ASOS stations are roughly comparable to Seawatch buoys in complexity and function. They collect more atmospheric information, but no marine observations. Data are collected automatically and sent over telephone lines, rather than satellites, to a central computer. ASOS stations cost \$150 000 each to install which, amortised over ten years at a 10 per cent discount rate, represents an annual cost of \$24 000. Operation and maintenance are estimated by NOAA to cost approximately \$15 million annually

for the 950-station network, adding an additional \$16 000 per station. Thus the total annual cost of an ASOS station is about \$40 000; the per-buoy cost of a large Seawatch network is about \$200 000.

With a cost five times as great as comparable land-based stations, Seawatch buoys are not likely to be deployed as densely as the land-based network.^{xxiii} Given the current paucity of sea-based observations, however, it seems likely that the marginal benefit in terms of improving the scope and accuracy of the meteorological network is at least as great as land stations. Thus it is reasonable to estimate that a ten-buoy Seawatch system provides benefits of \$400 000 or more annually to subscribing meteorological services and their users.

Climate modelling

As a regional component of the GOOS system, Seawatch produces a continuous record of oceanographic data. For much of the ocean surface we now have only rare and expensive surveys conducted by ship, and satellite data that does not penetrate below the ocean surface and is difficult to interpret without “ground truth” information from *in situ* sensors. Thus the Seawatch buoys should work synergistically with satellites and with limited deep-ocean data, to provide a sufficient foundation for higher-resolution climate models.

Crisis response: spills

One unique aspect of Seawatch is the inclusion of a highly accurate sensor for radioactivity. It can, therefore, serve as an early warning system for detecting leaks from discarded nuclear reactors or weapons, from weapons tests, from nuclear ships, or from coastal nuclear powerplants. The buoys can detect unauthorized dumping of radioactive waste, and the transport models can help determine the source.

Seawatch data can also help forecast the behaviour of oil spills. While the buoys do not (yet) have an oil sensor, the wind, wave, current, and temperature data, and accompanying numerical models, allow much more accurate predictions of how a spill will behave.

Pollutant transport monitoring and modelling

By supporting the development of detailed circulation models of the coastal zone, Seawatch can also help monitor the fate of continuous pollution from river mouths and coastal sources. There is broad international agreement that measures are needed to protect the ocean, and especially the coastal zone, from pollution. There is also broad agreement that these measures need to be cost-effectively designed. Policymakers cannot design such measures, nor enforce them, without accurate information about the sources and fates of pollutants.

Oceanographic research

Seawatch Europe has already made a significant contribution to oceanographic research that may have important economic consequences. For many years nations around the Baltic have watched the deterioration of its health. Nitrate and phosphate runoff accumulated, oxygen saturation declined, salinity declined, and long-term stratification depleted the benthic fauna. Very expensive remedies were undertaken to reduce the pollution load entering the Sea.

In 1993 a rare event occurred that was well documented through the use of Seawatch buoys. Sustained westerly winds built up a water mass from the North Sea to a level that allowed it to recharge the Baltic. This saltier North Sea water was able to cross the shallow straits at the mouth of the Baltic, then flow along the bottom to the deeper basins. The last time the Baltic had been recharged by a large volume of ocean water was 1976. In light of this new information, the dynamics of the Baltic ecosystem are being re-evaluated. While pollution is still a major concern, there is now a greater understanding of how pollution may interact with the natural cycles of Baltic recharge, so that interventions can be designed effectively.

Selected cost-effectiveness comparisons

Distinctive characteristics of Seawatch

A full cost-effectiveness analysis is beyond the scope of this paper, because there are so many technical criteria on which oceanographic data must be evaluated, and such a wide range of applications for that data. Those planning coastal defences and warning systems in Bangladesh will have priorities that are very different from shrimp farmers in Thailand, and the choice of observation systems will have to be made in the context of those particular needs.

Nonetheless, it is worthwhile to compare and contrast the basic characteristics of the Seawatch system with other systems that are used for oceanographic observation -- particularly since the discussion of benefits and costs did not highlight those differences.

Seawatch produces continuous real-time series of linked physical, chemical, and biological data. One can watch the parameters change as a storm develops: winds shift and quicken, air pressure drops, waves develop, vertical mixing flattens the salinity and water temperature profiles, suspended bottom sediments increase turbidity. Similarly, one can watch over a longer term as an algal bloom develops: surface salinity may drop and surface temperature rise, nutrient loads increase, turbidity rises, oxygen rises and then falls. No other observation system gives so complete a picture of developments at sea without actually putting the observer at sea.

A strong point of the Seawatch system is that it can be applied anywhere in the world as a complete system or, based on local needs, as a stripped down version. It is a highly adaptable platform for placing a range of instruments *in situ* and extracting data in real time.

Ships

Historically, oceanography has relied on measurements from research ships, but such ships can be expensive to operate. Many routine observations are made by merchant ships, but the need to avoid interference with commercial activities limits the scope of these measurements.

Mounting a major global survey involves enormous costs. The World Ocean Circulation Experiment (WOCE) will, between 1990 and 1997, require some 15 ship-years of sea time at a cost on the order of \$100-\$200 million to collect a global hydrography data set at 24 000 stations. An advantage of ships is that they can bring sophisticated laboratories, complete with trained personnel, to the measuring site. Samples can be taken and analysed. Sensors and other equipment can be easily maintained and calibrated on board. But in the future a survey that combined ships and buoys would be able to reduce costs and, more importantly, maintain continuous measurements not possible from ships alone.

Fixed platforms

The Netherlands uses three fixed platforms as part of its coastal observation network. When fixed platforms are available (e.g., either abandoned or operational oil and gas platforms), they can be excellent instrument platforms. If they are manned, personnel on the platform can maintain the equipment. If they are not, a helicopter pad can make them more accessible to service than a buoy that requires a ship visit. Moreover, fixed platforms can host a broader array of instruments, and are better adapted to measuring the water level.

Of course, when fixed platforms are not already available, it will seldom make sense to build them simply to serve data collection needs. Fixed platforms are far more expensive than moored buoys, they are more of a navigational hazard, they are limited to certain water depths, and they cannot easily be moved.

Satellites

Satellites play a central role in any meteorological and oceanographic observation system. They can collect images and data from large areas of the earth's surface.

What they cannot do is penetrate the ocean surface to survey the "ocean space" underneath. Seawatch buoys give continuous readings of the temperature and salinity profiles in the water column, allowing one to look at stratification, vertical mixing, etc. An example is the recent recharge of the deep basins in the Baltic. Using Seawatch data it was possible to see how meteorological and sea surface conditions (sustained westerly winds; water level) correlated with subsurface events. Another example is the flow of cold water into the Norwegian trench, affecting pipeline operations.

Even the surface data that satellites collect (wave direction and height; visible algal blooms; etc.) need verification and calibration with *in situ* data. When properly combined in a computer model, there is considerable synergy between the overview provided by satellites and the fixed point measurements provided by buoys.

Conclusions and implications for the future of Seawatch

What, if anything, can we conclude from this crude analysis?

First, it is clear that Seawatch Europe has passed an important test. It has been built, is operational, and is generating real economic benefits in excess of its costs. The strongest evidence for this is simply the observation that commercial customers in fish-farming and in offshore oil and gas operations are paying to participate in Seawatch and express enthusiasm about the value it has had in their operations.

Second, the costs of Seawatch Europe are joint costs, producing a wide range of services that includes both commercial services and public goods.

The combination of commercial products and public services can be an uncomfortable one to manage, but generally is a healthy state of affairs. If Seawatch did not produce commercial services, the benefits would still be in the speculative realm and its fate would be uncertain. Moreover, the commercial clients impose a discipline on the enterprise, holding down costs, insisting on useful and accurate data delivered when needed.

If it is confined to supporting itself through the sale of commercial services, in Europe and elsewhere, Seawatch will likely survive. The technology appears to be cost-effective for those industries that need the data. And the North Sea contains enough industry -- oil and gas, fishing, and commerce -- to support such a network. It may also be replicated in other locations where commercial activity can justify it. Potential sponsors among governments and international organisations may be tempted to let Seawatch be carried by its commercial clients.

This is particularly the case when national budgets are strained. In classifying goods as either public or private, we have glossed over an important distinction. Some public goods are strictly *national* goods: defence, for example. National governments are well situated to make a decision about whether it is in the interest of its citizens. International public goods are a little more difficult. National governments may evaluate them from a narrow perspective, and there may be “free rider” problems to overcome. International organisations are not as well situated in terms of financing and authority to make decisions about what projects to fund; these necessarily must be sold to the national governments. In this respect Seawatch is like other megascience projects.

In addition, by its focus on the ocean, Seawatch is further handicapped. Each nation may be tempted to spend money instead on the particular problems of interest in its own coastal zone, rather than chip in to develop a system with a broader focus.

A further problem is that Seawatch is competing with academic and governmental institutions. Meteorological offices, coastal zone management agencies and so forth may see it as competing for funds when viewed as an operational program. When viewed as a research venture, it must compete for national funds that traditionally go to universities and to support scholarships. The agencies that allocate these funds may view their mission as national educational, and may be reluctant to support a foreign venture unless it appears to offer opportunities for students and professors. This again is a familiar problem with megascience programs. It may be more difficult for Seawatch because one of its advantages is that it is less labour-intensive than traditional means of doing oceanographic research. Thus it provides less employment for scientists and less training for students, but more of the other public goods. To the extent that national research agencies focus on the manpower aspect of their missions, they will undervalue Seawatch technology.

There is a danger, however, in going too far down this path. Seawatch may survive with commercial sponsorship, but it will not survive in the form that it was originally conceived. There will likely be a substantial loss of public benefits. To the extent that Seawatch must be sustained on a commercial basis, it will necessarily be responsive to the specific needs of its paying clients. That means that buoys will be located where they are needed by oil drillers and fish farmers, but not necessarily where they can contribute the most to meteorological and oceanographic models and to science. Variables and sensors will be tuned to operational needs of the users and perhaps to regulatory requirements as well; they will not necessarily collect the most scientifically useful data. Time series may be truncated rather than long-term. Opportunities to build large-scale models will be limited. And Seawatch will feel continuing pressure to provide data on a proprietary basis, rather than share it with the broader community of users.

For these reasons it is important for public authorities at the national and international level to participate in Seawatch and help to steer it towards the potential it was designed to fulfil.

BIBLIOGRAPHY

- BAILEY, Ronald, ed., (1995), *The True State of the Planet*, The Free Press, New York.
- BRISCOE, Melbourne G., (1994), *Some Frequently Asked Questions About the Global Ocean Observing System*, U.S. National Oceanic and Atmospheric Administration, Washington, September.
- BROWN, Martin, (1995), *Cost/Benefit Analysis of Large-Scale Science and Technology Projects: Some Methodological Issues*, OECD Megascience Forum, Paris.
- CENTRAL INTELLIGENCE AGENCY, (1994), *World Factbook*, Washington: CIA, Available on CD-ROM from Chestnut, Cambridge 1995.
- FLEMMING, N.C., (1993), *EACMST Survey of UK Requirements for GOOS Data and Product*, December.
- HINRICHSSEN, Don, (1990), *Our Common Seas: Coasts in Crisis*, Earthscan Publications Ltd, London.
- INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (OF UNESCO), (1993), *The Approach to GOOS*, IOC/INF-915, January, IOC-XVII/8 Annex 2, Paris.
- INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (OF UNESCO), (1993), *Global Ocean Observing System: Status Report on Existing Ocean Elements and Related Systems*, IOC/INF-958, December, Paris.
- JEFFREYS, Kent, (1991), *Who Should Own the Ocean?*, Competitive Enterprise Institute Environmental Studies Program, Washington.
- KING, Ken, (1993), *The Incremental Costs of Global Environmental Benefits*, Working Paper No. 5 of the Global Environment Facility, World Bank, Washington DC.
- LOAYZA, Eduardo A., ed., (1994), *Managing Fishery Resources*, Proceedings of a Symposium Co-Sponsored by the World Bank and Peruvian Ministry of Fisheries in Lima, Peru, June 1992, World Bank Discussion Paper No. 217, Washington DC.
- O'BRIEN, James J., (1992), *Workshop on the Economic Impact of ENSO Forecasts on the American, Australian, and Asian Continents*, Florida State University, Tallahassee.
- OCEANOGRAPHIC COMPANY OF NORWAY AS, (1991-1993), *Annual Reports*.
- OCN and DELFT HYDRAULICS, (1993), *Seawatch Netherlands, Final Report Feasibility Study, Part 1: Managerial Report*, March, The Hague.
- OECD, (1989), *Aquaculture: Developing a New Industry*, Organisation for Economic Cooperation and Development, Paris.
- OECD, (1991), *The State of the Environment*, Organisation for Economic Cooperation and Development, Paris.

- OECD, (1992), *Global Warming: The Benefits of Emissions Abatement*, Organisation for Economic Cooperation and Development, Paris.
- OECD, (1993), *Coastal Zone Management: Integrated Policies*, Organisation for Economic Cooperation and Development, Paris.
- OECD, (1994), (a). *Oceanography*, OECD Megascience Forum, Paris.
- OECD, (1994), (b). *Review of Fisheries in OECD Member Countries (1992)*, OECD, Paris.
- OECD, MEGASCIENCE FORUM, (1995), (R. Kerry Turner, Eze Ozdemiroglu, J.C. Powell, Pawan G. Patil, Paul Steele, authors), *The North Sea Water Quality Information System (NSWQIS): A Cost Benefit Assessment*, Draft of 6 January, OECD, Paris.
- PETERS, Hans J., (1993), *The Maritime Transport Crisis*, World Bank Discussion Paper No. 220, Washington DC.
- SINGER, S. Fred, (1986), *Fisheries Management: Another Option*, in *Rethinking Fisheries Management*, Proceedings of the Tenth Annual Conference, Center for Ocean Management Studies, Jon G. Sutinen and Lynne Carter Hanson, eds., June, University of Rhode Island.
- TANGEN, Karl et al, *Seawatch Europe, (1993), Annual Report, Quarterly Reports 4/93, 1/94, 2/94, 3/94*, Oceanor, 1993-4, Trondheim.
- TOLBA, Mostafa K., (1992), *Saving Our Planet: Challenges and Hopes*, Chapman and Hall, London.
- THE ECONOMIST, (1992), *Atlas of the New Europe*, Henry Holt & Company, New York.
- WEBER, Michael L. and GRADWOHL Judith A., (1995), *The Wealth of Oceans*, W.W. Norton, New York.
- WOODS, John, (1993), *Questions and Answers on GOOS*, October.
- WOODS HOLE, (1993), *Preliminary Analysis of Benefits and Costs of a Proposed Coastal Forecast System*, A Report on a Workshop held at the Woods Hole Oceanographic Institution, June 7-8, (September , Woods Hole,).
- WORLD BANK, (1991), *Tropical Aquaculture Development: Research Needs*, World Bank Technical Paper No. 151, Washington DC.
- WORLD BANK, (1993), *Fish for the Future: Summary Report*, A Study of International Fisheries Research, World Bank, Washington DC.

APPENDIX: TERMS OF REFERENCE

Introduction

During the OECD Megascience meeting on oceanography (Tokyo, 27-30 September 1993) Seawatch was introduced as a possible regional component of the GOOS system. During the ECOPS meeting on GOOS (Heathrow, 26-27 October 1993) it was suggested that a cost/benefit analysis of Seawatch should be performed by the OECD. The idea was discussed with the management of Oceanor and full co-operation has been obtained.

Proposal

Seawatch is a concept in which marine environmental data are collected in real time and presented to clients through a user friendly information system. The technological objective of Seawatch Europe is the integration of the relevant results of the Euromar program, in the field of marine surveillance technology and information into an international marine monitoring system. Seawatch Europe consists of a buoy network which operates in an area covering the Barents Sea, the Norwegian, the north-eastern part of the North Sea, and the Baltic Sea. As a regional system Seawatch is complementary to national, mostly coastal marine monitoring systems.

The cost/benefit analysis should address the following issues:

1. Fisheries and fishfarming

Three elements are at present important. The first one concerns the (future) possibility to locate fish shoals (temperature fronts). The second one is related to the state of the sea in order to protect fishing vessels from unexpected changes. Forecasts of wind, waves, and temperature have improved the safety of fishing. The third one concerns water quality and the threat of toxic algae to the fish farming industry. Some figures with reference to some of the latest events should be evaluated.

Forecast of jellyfish and low temperature water in relation to the culture of mussels. Optimisation of food consumption as a result of water temperature forecast. Preparation of analysis for release of mussels for consumption.

2. Offshore industry

The present services concern among others the preparation of statistics on wave, wind, current, and temperature as a basis for the protection and operation of platforms, design criteria, and pipelaying, lifting operations, traffic control, etc. Forecast of cold water displacement is relevant for minimising hydrate condensation problems in pipelines.

3. Meteorological institutes

Synoptic air pressure, wind, and wave observations from fixed buoys in the North Sea, Norwegian Sea, and the Barents Sea give data from an area where such observations are scattered. As

such the weather forecast for the coastal areas improves as well as the capability to predict a Polar Low. Moreover, these data are used for ship-routing.

4. Pollution control

Seawatch gives data on the environment in respect to nutrients, oxygen and radioactivity leakages. Those data can be used as reference to follow up international agreements as well as for discovering radioactive leakages from nuclear power plants and surveillance of nuclear waste deposits. Seawatch also gives current and wave data on short time notice to improve oil-drift calculations in connection with an oilspill accident. Documentation of water quality including sea-surface temperature is relevant for tourism.

5. Insurance companies

Insurance companies contribute to Seawatch in relation to the reduced risk in the fish farming industry, offshore marine operations and, in general, risk along the coastal areas (wave damage, coastal erosion, etc.). The potential benefits of a reduced risk because of an improved storm surge forecast are substantial. Seawatch may or may not have a contribution in this area.

6. Research institutes

Data available for research purposes. Contemporary data of 20-26 physical, biological, and chemical parameters are available. Optimisation of data collection programs and the real time transmission of buoy data will indicate more interesting period from less interesting ones. A question which should be addressed is the reluctance of the scientific (and part of the existing national monitoring) community to apply the Seawatch data.

Remarks

It is important that the present and potential capability of the Seawatch system is fully discussed. In this respect the present Seawatch Europe system is just an example of the potential of Seawatch. An important aspect of Seawatch Europe is the sharing of cost and infrastructure between countries and among governments, universities, and the private sector. Another element is the need for a good observational coverage for forecasting purposes. This should be considered and evaluated as an alternative to individual monitoring systems in each country. Seawatch should also be seen as a regional building store towards GOOS. As such Seawatch should be compared with alternative systems. Thus it would be necessary to discuss the possibilities and limitations of each system.

Notes

ⁱ Shallow-water buoys are less expensive to place, maintain, and recover than moored or drifting deep-water buoys. This advantage is somewhat offset, however, by greater disturbance from fishing and traffic.

ⁱⁱ Not all public goods are provided by government: nature supplies clean air and scenic vistas; private charities can provide wilderness preserves and homeless shelters. Moreover, not everything that governments do can be easily explained as a public good. Nonetheless this is the most useful paradigm for government sponsored research.

ⁱⁱⁱ In the United States the Army Corps of Engineers is responsible for navigational civil works, even when there is no relationship to national defense.

^{iv} Brown, 1995.

^v For this simple case, discounting is straightforward. The usual formula calculates the present value, PV , of a stream of payments in year i , a_i , over n years at an interest rate r :

$$PV = \text{Summation [for } i = 1 \text{ to } n] \{a_i (1 / (1+r)^i)\}.$$

When the payments are perpetual and constant, the result is that $PV = a/r$. For example, if $a = \$10$ million and $r = 10$ per cent, or 0.1, then $PV = \$100$ million. The easiest way to make this intuitive is to think of the reverse transaction: a bank deposit of \$100 million earning 10 per cent interest will pay \$10 million per year in perpetuity. Thus \$100 million today, and \$10 million per year forever, are equivalent.

^{vi} Perpetual annual payments of \$20 million are worth \$200 million on the day they begin. If that is ten years hence, then an additional discount factor of $(1 / (1+r)^{10})$, or 0.386, reduces their *present* value to \$77 million.

^{vii} Measuring from the midpoint of the cost stream to the midpoint of the benefit stream.

^{viii} See Brown, 1995.

^{ix} Alternatively, we could consider deploying Seawatch throughout the EEZ. In practice, there is not much difference between these two approaches.

^x OECD 1994(a), p. 94 Table 1.

^{xi} Oceanor reports that in making plans and proposals to various countries, it has so far examined on the order of 200 potential sites for Seawatch buoys.

^{xii} Errors of underdesign do occur, however. Some Ekofisk platforms had to be redesigned and reinforced due to an underestimate of wave height as well as an underestimate of sea-floor subsidence; costs were \$1-2 billion.

^{xiii} In the North Sea the full potential may not have been realized, since planning and design for platforms mostly occurred before Seawatch was operational. In frontier areas, the use of a Seawatch system from the beginning would likely result in a greater improvement in efficiency.

^{xiv} OECD, 1994(a).

^{xv} Of course, a global Seawatch system by itself would not produce all of the benefits that have been forecast for GOOS. In the case of oil and gas development, however, it is reasonable to assume that all of the benefits could be realized with Seawatch because 1) Seawatch is designed to operate in all of the areas where offshore development is possible, and 2) almost all of the oceanographic data series of interest to oil and gas development are available through the Seawatch system. One exception is marine life—the interaction between offshore development and fisheries, marine mammals, etc.

^{xvi} “As much as we may yearn for the traditional mode of fishing, the development of technology, in the presence of finite stocks, is driving us in the direction of privatization, away from a common property resource.” Singer, 1986.

^{xvii} Anecdotal evidence from fish farmers and insurers suggests higher savings, but such anecdotes need to be discounted until more experience is accumulated.

^{xviii} Oceanor memorandum by Per-Erik Sørås, 15 March 1995. Many Chinese shrimp farms are land-based, and used pumped salt water. Bloom forecasts would allow the planned suspension of pumping to exclude contaminated water.

^{xix} Farm product tends to be more valuable per ton than the wild catch, simply because farmers choose to produce the higher-valued species.

^{xx} Tolba, 1992, p. 170.

^{xxi} Hinrichsen, 1990.

^{xxii} OECD, 1991.

^{xxiii} Estimates of the ultimate size of GOOS typically suggest that the technically optimal scale for oceanographic modeling is an order of magnitude denser than the scale for atmospheric modeling. Here we are only discussing Seawatch’s contribution to meteorological forecasting, however, so that observation about the ocean does not apply. Due to topological simplicity, and the effectiveness of satellite observations over water, the technical need for *in situ* observation platforms at sea is probably less dense than it is on land.