Meetings

Planetary Engineering

Three-fourths of the earth's surface is covered by water. Changes in the distribution, circulation, temperature, or optical properties of the marine environment can have far-reaching effects. The ice ages are a manifestation of such effects and, even though we are not certain what caused them, they must involve a close coupling, with feedback, between the atmosphere and hydrosphere. In any case, such an occurrence gives incontrovertible evidence that the state of the physical environment can be changed by natural causes, and that the present climate may not be in very stable equilibrium but can be changed by moderate perturbations. There may even be a number of "quasi-equilibria." We don't know how close we are at this moment to being at the edge of stability.

Thus, there is cause for concern since many unplanned modifications of the environment are now taking place because of human activities—the burning of huge amounts of fossil fuels, with its use of oxygen and sudden release of carbon dioxide; the increase of chemical fertilization with a release of nitrogen compounds into rivers and oceans, and into the atmosphere; the release of vast amounts of biocides and other toxic wastes and of radioactivity; and the release of heat. All of these are leading to a gradual pollution of the rivers, lakes, and even coastal waters which may have far-reaching effects on our climate and even on the oxygen content of the atmosphere.

But there are also planned modifications which are generally designed to produce some immediate beneficial results. What about their long-term effects? Can these be safely predicted and will the net effect, including both short-term and long-term, be beneficial?

The discussion of such topics was the purpose of a symposium held 11 March 1968, in Washington, D.C., under the auspices of the Department of the Interior and the National Research Council of the National Academy of Sciences and the National Academy of Engineering. It was chaired by S. Fred Singer (Deputy Assistant Secretary for Scientific Programs, Department of the Interior). He introduced the theme of the discussion and also pointed out that the technical means are now on hand to make large-scale changes in the marine environment, and to keep track of their global effects by means of earth survey and weather satellites. "We are moving into the age of planetary engineering," and now is the time to discuss proposals for modifications and their consequences, before the actual need for such modifications becomes urgent.

Secretary of the Interior Stewart L. Udall delivered the keynote introductory remarks. His department is responsible for the development of the nation's natural resources, including marine resources. They include nonrenewable resources, such as minerals, oil and gas, and renewable resources, such as fish, as well as water resources. But the department is also concerned with the conservation of resources and with the provision of recreational facilities. As the population increases, the pressure for development and the pressure for conservation both increase. In his thoughtful comments, Udall warned not only against undesirable ecological consequences of various engineering modifications on the earth's surface but, in a more profound manner, he questioned our "ability to maintain quality of life without at the same time limiting the density of population."

Even major modifications can sometimes be accomplished by rather modest means, provided one can find a sensitive point of application where a self-amplifying mechanism can be set up, usually involving some feedback. Such an approach was proposed by J. O. Fletcher (RAND Corporation, Santa Monica, California) in his paper "The polar oceans and world climate." To understand why the presence or absence of ice cover on the ocean makes an enormous difference to the behavior of the atmosphere, one must recognize that the presence of an ice cover effectively cuts off heat exchange between the ocean and atmosphere, both in winter and in summer. For example, in January, the mean surface temperature in the central Arctic is about −30°C, while a few feet below the ice-covered surface the ocean water is near −2°C. If the ice were not there, a great deal of heat would be obtained from the relatively warm ocean. In summer, on the other hand, an open ocean would absorb around 90 percent of the solar radiation reaching the surface, while pack ice reflects 60 to 70 percent of the incident sunlight. Thus, the presence of the ice suppresses heat loss by the ocean in winter and heat gain by the ocean in summer, while the atmosphere cools more intensely during winter and warms more intensely during summer. The second thing to realize is that the Arctic ice layer is quite thin, only about 2 to 3 meters, and that the secular changes are quite large—of the order of 50 percent between 1890 and 1940. The seasonal variation is about 50 percent also, and there is enough solar heat available at the surface to melt all the pack ice during summer, if only the absorptivity of the surface were raised. It should be clear also that the global atmospheric circulation, which is driven by the temperature difference between the equator and the pole, would be affected by the presence or absence of the ice cover.

Fletcher presented data for both the Arctic and the Antarctic and showed rather important differences which have to do with the fact that the Antarctic is a continental mass with a high plateau which never loses its ice and snow cover. In the Arctic, on the other hand, there is the possibility that the Arctic Ocean would remain ice-free once the ice is removed. Various Russian workers have suggested such schemes as the damming of the Bering Strait, to induce a greater influx of oceanic heat into the Arctic Basin. Fletcher suggests the possibility of melting the Arctic ice by injecting aerosols into the stratosphere from aircraft; it would reduce the infrared radiation loss to space without greatly reducing incoming solar radiation.

William Donn (Lamont Geological Observatory) and S. Fritz (National Environmental Satellite Center, ESSA) partly reinforced the presentation of the main speaker, but raised doubt about the validity of some data. They raised the question whether all important side effects had been considered. It was finally agreed that Fletcher's proposal could form a kind of framework against which various questions can be tested; it certainly provides a plan for gathering the right observations.

Many islands and coastal continental regions of the world lack adequate freshwater sources. Robert D. Gerard and J. Lamar Worzel (Lamont Geological Observatory) proposed a method whereby potable water may be obtained by condensing atmospheric moisture. The necessary conditions are: (i) coastal location; (ii) being situated in the regular path of humid maritime air masses; and (iii) offshore ocean depths which provide cold ocean water close to shore. In their scheme, the deep offshore seawater used as a cold source is brought up through a large-diameter pipe and pumped through a condenser array located onshore which intercepts the flow of humid maritime air masses. This air, when cooled, condenses much of its moisture, which is then conducted away and stored for future use.

There are additional benefits. The seawater that is used as a coolant is brought up from a depth zone which has the highest phosphate and nitrate content. This water, if discharged into a nearby lagoon, could greatly increase biological productivity and support various schemes of aquiculture. Furthermore, air with lowered humidity and temperature would be available on the leeward side of the condenser and could give the residents all of the advantages of air conditioning.

Gerard and Worzel studied a particular application for the island of St. Croix in the Virgin Islands, where the cost of well water delivered by tank truck is as high as \$14 per 1000 gallons, and the cost from a commercial desalting plant would be about \$1 per 1000 gallons. More than 758,000 cubic meters (200 million gallons) of freshwater per day, contained as vapor in the lower 100 meters of air, sweep across every kilometer of the windward shores of the island. They assume a plant producing 3790 cubic meters (1 million gallons) of freshwater per day. If maritime tropical air at 25°C with relative humidity of 70 to 80 percent were cooled to 12°C and 100 percent humidity, then about 6 grams of water would be recovered per cubic meter of air. They estimate that about 90 units of seawater must be pumped through the condenser for each unit of freshwater condensed, and show that it may be possible to pump the water by using windmills driven by the trade winds. The power requirement would amount to a little under 4000 horsepower, and could be further reduced by recovering some of the waterpower from the seawater being returned to the sea surface. On the other hand, power might be obtained by a scheme suggested by J. Hilbert Anderson and James H. Anderson. They propose driving a turbine by boiling propane under suitable pressure at a temperature of 21°C to 27°C (surface water temperature) and condensing it at about 13°C, using deep water of about 9°C.

The discussants in general supported the proposal. Earl Droessler (State University of New York at Albany) described a simple wire screen already tested which extracted drinking water from low-level clouds or fog. Helmut Landsberg (University of Maryland) pointed out that extraction of drinking water from the atmosphere is possible even in the Sahara Desert and described his experiences in World War II with the "Royal Condenser Corps." He showed world charts of surface distribution of water vapor which illustrated vast areas having over 15 grams of water per cubic meter.

The Great Lakes are considered a part of the marine environment by the Marine Resources Development Act of 1966 which set up the Federal Marine Council and the National Marine Commission. Indeed, many of the problems of the Great Lakes are similar to problems in the estuaries and coastal zones.

For the last hundred years, the Great Lakes have been regarded as an infinite sink for waste materials brought in by streams and discharged by communities located on the shores. Only in the last decade has it become clear to everyone that this assumption was not justified, and that the inflow of wastes, mostly in the form of sewage and agricultural runoff containing large amounts of nutrients, has produced a condition of eutrophication which has decreased the dissolved oxygen level and, in some cases, turned portions of the Lakes anaerobic during certain times of the year. Even if it were possible to eliminate the influx of further nutrients into the Lakes, it would be many years before the quality could improve. One way of decreasing the recovery time would be to flush the Lakes with clean water; various schemes have been proposed to achieve deeutrophication by water transfers. This general subject was reviewed and discussed anew by William C. Ackermann (Chief of the Illinois State Water Survey). He reviewed various water diversion schemes, such as the Grand Canal concept of T. W. Kiernans which would bring Canadian river water now emptying into Hudson Bay into the Lakes; the NAWAPA Plan of the Parsons Company which would reverse the course of several major rivers now emptying into the Pacific and Arctic Oceans in Alaska and northwestern Canada; and the scheme to divert the Wisconsin River to Lake Michigan by way of the Fox River. He also discussed a proposal to divert Kankakee, Des Plaines, and Fox rivers of Illinois into Lake Michigan.

Surprisingly enough, however, he finds that the quality of the water is so poor at present that it would not improve the water quality of the Lakes. Critical contents for eutrophication are 0.3 milligram per liter for nitrates and 0.015 milligram per liter for soluble phosphorus. The river waters in most cases exceed both values. Even more surprising were the high nitrogen values reported for precipitation; hence increasing the rainfall over the Lakes would not help either. Ackermann was of the opinion that treatment of municipal and industrial wastes would be the most immediate step to take, particularly tertiary treatment, which would remove phosphates at a cost of 5¢ per 1000 gallons. He also suggested the possibility of diverting certain streams away from the Lakes, as is done in Chicago. This might be done, for example, at Milwaukee, Cleveland, and Toledo, and would have the advantage of diverting the diffused agricultural wastes which would be difficult to treat in any case.

In discussion, Leonard Dworsky (Office of Science and Technology, on leave from Cornell University) pointed to the need for establishing improved institutional arrangements for upgrading water quality in the Lakes. J. P. Bruce (Director of the Canada Centre for Inland Waters, Burlington, Ontario) discussed the great importance of the Lakes to the Canadian economy and described briefly the organization and purpose of his research center.

"Modification and management of water flow in estuaries" was the title of the last paper of the symposium, presented by Donald Pritchard (Director of the Chesapeake Bay Institute of Johns Hopkins University). An estuary, strictly speaking, is the river mouth. The term sometimes includes both the semienclosed coastal body of water within which seawater is diluted by freshwater, as well as portions of an ocean which are affected by freshwater, such as the Baltic Sea. For the purposes of this paper, however, the Chesapeake Bay was taken as an example. Geomorphologically, it is a drowned river valley or coastal plain estuary, as opposed to three other types: fjord-type estuaries, bar-built estuaries, and estuaries formed by tektonic processes. Coastal plain estuaries are further classified in terms of the degree of vertical mixing, which depends on the rate of inflow of freshwater versus the magnitude of the tidal current, and on the physical dimensions of width and depth. Depending on these factors, an estuary may go from a salt-wedge type (no mixing) to a completely mixed situation.

The most obvious parameter to control is freshwater inflow. An example is Charleston Harbor, located on the estuary of the Cooper River. Prior to a water diversion made some 30 years ago, the amount of freshwater flowing down the Cooper into the estuary was quite small compared to the volume rate of inflow and outflow of the tide, and the estuary was vertically homogeneous. When freshwater was added, it changed into a characteristic two-layered flow pattern with a surface layer flowing seaward and a deeper layer flowing up the estuary. Thus, Charleston Harbor became a trap for the increased amounts of sediment, and the dredging required to maintain the channel increased by more than an order of magnitude.

Nor is it always a good idea to reduce the very large seasonal variations in freshwater flow by controlling the river discharge through dams and through low-flow augmentation. Pritchard pointed out that the circulation in the small tributary embayments of the Chesapeake Bay is produced by salinity differences between the tributary and the Bay proper. Since the water is derived from the main Bay, the salinity in the tributary must lag behind the salinity in the Bay. If the discharge of the Susquehanna River were to be controlled to the extent that the seasonal changes in the salinity of the upper Bay were to disappear, then the prime mechanism for the flushing of a number of tributaries would also disappear. Pollution problems within the tributaries would increase and lead to significant ecological effects.

Another mechanism contributing to the flushing of tributary estuaries occurs when the tributary has a channel depth approximately equal to the depth of the parent estuary. Pritchard illustrated the peculiar convection pattern which arises from the gravitational convection induced by salinity differences. In Baltimore Harbor, the surface waters are higher in salinity than the surface waters in the Bay, and gravitational convection requires that the Bay waters flow into the Harbor at the surface. Near the bottom, however, the Bay waters are more saline than the waters of the Harbor at the same depth. The Bay waters must, therefore, also flow into the Harbor along the bottom. This inflow of water at the surface and bottom is balanced by an outflow at mid-depth. The existence of such a mechanism offers the possibility of artificially increasing the flushing rate of embayments which have little freshwater inflow but are tributaries to a partially mixed estuary, and also have a depth greater than the depth of the halocline in the adjacent estuary. One way to do this is to increase the vertical mixing in the embayment, thereby reducing the vertical salinity gradient and consequently increasing the horizontal difference in salinity between embayment and parent estuary at the surface and at the bottom.

Pritchard discussed various methods to achieve mixing, but also pointed out that engineering schemes which had been proposed for the Bay might result in unanticipated circulation patterns. For example, the present enlargement of the Chesapeake and Delaware Canal will result in the diversion of fairly fresh water from Chesapeake Bay and would undoubtedly affect the salinity regime of the upper Bay. This example, again, indicates the complex interrelations which must be considered when evaluating the balance between possible beneficial and detrimental changes which will result from a man-made modification to an estuary.

Ecological considerations were further reinforced in the discussion by L. Eugene Cronin (Director of the Natural Resources Institute of the University of Maryland), while Joseph Caldwell (Chief of the Coastal Engineering Research Center of the Army Corps of Engineers) stressed the engineering aspects of various modifications, such as hurricane barriers, again pointing to the need to investigate thoroughly the physical and biological consequences.

The symposium concluded with remarks by Stanley A. Cain (Assistant Secretary of the Interior) on the growing awareness of ecological consequences by physical scientists. "Maybe the Age of Ecology hasn't arrived yet, but we are certainly approaching it."

The program was arranged by Allen Kneese, Helmut Landsberg, and S. F. Singer. It was decided to organize it in the form of a major presentation, followed by two invited discussants who had had a chance to study the main paper in detail. In this way, the audience could witness an exchange of views by informed people, sometimes critical, sometimes complimentary, always complementary. The full account of the papers and of the discussion is to be published in *Symposium Proceedings* by the National Academy of Sciences.

S. FRED SINGER

Department of the Interior, Washington, D.C. 20240

Calender of Events

Courses

Remote Sensing of Earth Resources, Berkeley, Calif., 25–27 September. Theory, current techniques, and future developments will be covered, with emphasis on applications in a wide range of disciplines including geography, geology, agriculture, forestry, range and wildlife management, hydrology, civil engineering, urban area analysis, and archaeology. Fee: $100; students, $60. (Letters and Science Extension, University of California, Berkeley 94720)

Radiation Effects in Semiconductors, Rolla, Mo., 26–30 August. The course will cover experimental approaches of the interaction of energetic nuclear and space radiation with semiconductor materials and devices, sources of the various types of radiation, and dosimetry involved, theories of the interaction of radiation with matter, and nature of crystalline imperfections. (Extension Division, University of Missouri-Rolla, Rolla 65401)

Laboratory Methods in the Detection of Rabies, Atlanta, Ga., 30 September–4 October. Laboratory training course. *Deadline for applications*: 5 August. (Training Office, Laboratory Program, National Communicable Disease Center, Atlanta 30333)

Aerospace Frontiers: Physics of Fluids, Boulder, Colo., 22 July–24 August. The courses offered are: *Quantum Fluid Dynamics*, including the two-fluid model, macroscopic quantum phenomena, and analogies with superconductivity and electromagnetism; *Dynamics of Interplanetary Material*, including theory of solar wind with and without solar rotation and magnetic field, anisotropic velocity distribution, and dynamics of cometary plasma and solar plasma; *Cosmic Gas Dynamics*, including convective zones, noise, wave propagation, shock waves, heating of chromosphere, and hydromagnetic waves. (Professor Mahinder S. Uberoi, Department of Aerospace Engineering Sciences, University of Colorado, Boulder 80302)