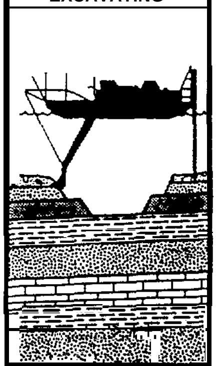
30588

OCS Study
MMS 93-0005

# EXECUTIVE SUMMARY

# SYNTHESIS AND ANALYSIS OF EXISTING INFORMATION REGARDING ENVIRONMENTAL EFFECTS OF MARINE MINING

EXCAVATING



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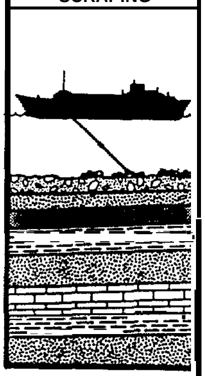

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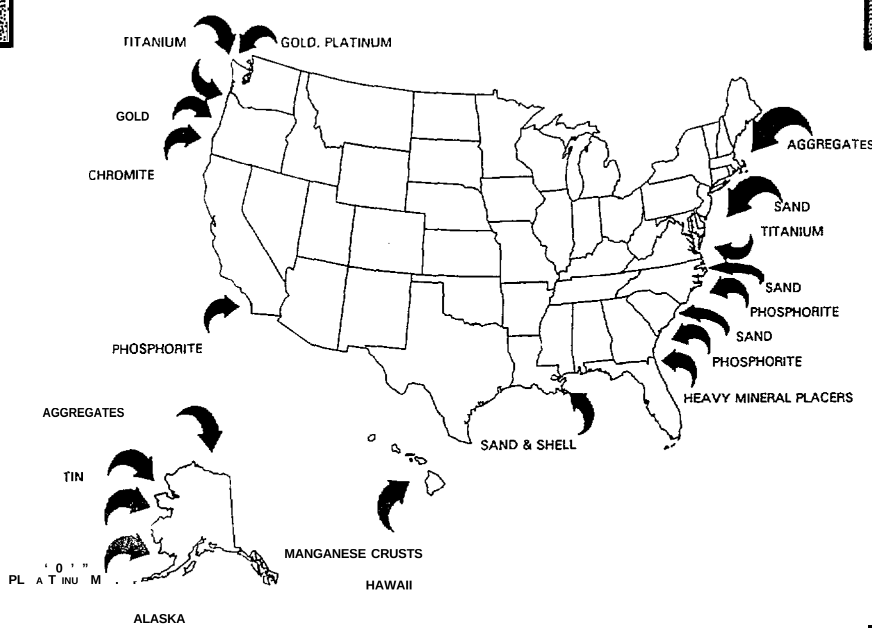


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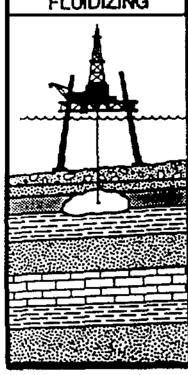

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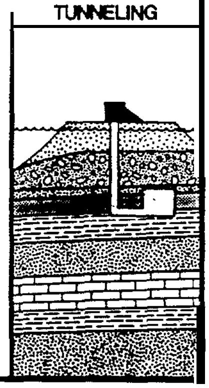

Prepared for:


MMS

U.S. Department of the Interior
Minerals Management Service
Office of International Activities
and Marine Minerals (INTERMAR)

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# EXECUTIVE SUMMARY

## Synthesis and Analysis of Existing Information Regarding Environmental Effects of Marine Mining

March 1993


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Several people at CSA other than the CSA Program Manager and Scientific Editor were instrumental to the successful completion of the program. David A. Gettleson provided direction and support throughout the program. Karen M. Daignault collected information relevant to the program through telephone calls and library visits. David B. Snyder, Luis M. Lagera, Jr., and Brock E. Stanaland wrote the annotations for the program. Alan D. Hart was responsible for the reference database. Suzanne R. Short prepared the figures and tables for the manuscript. Virginia A. Erbrick and Lynn A. Ugartemendia word processed the manuscript. Pamela S. Jones and Melody B. Powell coordinated the preparation of the deliverables, and were assisted by Deborah M. Cannon.

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## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ATOS | anti-turbidity overflow system |
| CEQ | Council on Environmental Quality |
| CLB system | continuous line bucket system |
| CSA | Continental Shelf Associates, Inc. |
| EEZ | Exclusive Economic Zone |
| ESP | Environmental Studies Program |
| HI, DBED | State of Hawaii, Department of Business and Economic Development |
| ICES | International Council for the Exploration of the Sea |
| INTERMAR | Office of International Activities and Marine Minerals |
| MMS | Minerals Management Service |
| MMTC | Marine Minerals Technology Center |
| NEPA | National Environmental Policy Act |
| NOAA | National Oceanic and Atmospheric Administration |
| NRC | National Research Council |
| Ocs | Outer Continental Shelf |
| OCSLA | OCS Lands Act |
| OTEC | ocean thermal energy conversion |
| PCBS | polychlorinated biphenyls |
| USDOC | U.S. Department of Commerce |
| USDOI | U.S. Department of the Interior |

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## ESI .0 INTRODUCTION

### ES1.1 Historical and Regulatory Perspective

in addition to offshore oil, gas, and sulfur resources, there are approximately 90 different mineral commodities available in the marine environment. Industry interest in mining of U.S. marine minerals has focused on sand and gravel, precious and heavy metal placers, cobalt-rich manganese crusts, polymetallic sulfides, and phosphorites. International interest has also been oriented towards a wide array of prospects, including (1) sand and gravel in Denmark, France, Japan, the Netherlands, and the United Kingdom; (2) tin in Burma, Indonesia, and Thailand; (3) diamonds off southwest Africa; (4) phosphorite off New Zealand; and (5) metalliferous muds (containing copper, silver, and zinc) in the Red Sea.

The U.S. recognizes a strategic importance and potential economic benefit of marine mining, as well as the potential for environmental impacts associated with marine mining activities. The U.S. Department of the Interior's (USDOI), Minerals Management Service (MMS) is responsible for the management of exploration and development of mineral resources on submerged Federal lands on the Outer Continental Shelf (OCS) seaward of State boundaries. On behalf of the MMS, its Office of International Activities and Marine Minerals (INTERMAR) functions as a liaison for agency involvement in international activities, and provides policy direction for management and regulation of marine mineral resource activities on the OCS for minerals other than oil, gas, and sulfur.

Under the Environmental Studies Program (ESP), the MMS has funded numerous studies relating to potential environmental impacts of OCS oil and gas activities. Although considerable information from these ESP studies is transferable to an evaluation of potential impacts of marine hard minerals mining, the MMS has sponsored only limited research on non-fuel marine minerals, due primarily to the lack of marine mining industry activity. Until recently, the level of domestic marine mining activity may have been inhibited by marginal economics, high risk, and the lack of comprehensive regulations applicable to the recovery of non-energy minerals. This is in contrast to Europe, Asia, and other international locations where marine mining industries have developed within a framework of supportive government regulation. Domestic rules and regulations have recently been designed to dispel uncertainty and demonstrate governmental commitment to environmentally compatible OCS marine minerals development and production.

The MMS has a strong mandate with respect to the potential environmental impacts of marine mining. Existing rules and regulations governing domestic marine mining provide a framework for comprehensive environmental protection during prospecting and scientific research activities and postlease operations (e.g., 30 CFR Parts 280, 281, and 282). Requirements exist for site-specific and commodity-specific evaluations and lease stipulations that include appropriate mitigation measures.

Guidelines for protecting the environment stem from a wide variety of laws, including the OCS Lands Act (OCSLA), National Environmental Policy Act (NEPA), Endangered Species Act, Marine Mammal Protection Act, National Historic Preservation Act, Clean Water Act, and others. The provisions require activities to be conducted in a safe manner to prevent or minimize the likelihood of any occurrences that may cause damage to the environment, Such provisions also permit the cancellation or suspension of operations if there is a threat of serious, irreparable, or immediate harm to the marine, coastal, or human environments. The MMS takes a case-by-case approach in conducting environmental analyses, as required by NEPA and the Council on Environmental Quality regulations (40 CFR Parts 1500-1508). Protection of the environment is a high priority at each stage of the marine mining process, from prospecting through postlease operations.

Under the OCSLA, the MMS is required to conduct environmental studies to obtain information useful for decisions related to marine mineral activities. The MMS has developed an environmental strategy to provide this information. Several efforts are currently in progress. Existing State-Federal task forces are being directed to identify key environmental issues and develop action plans to address issues of concern. The Marine Minerals Technology Center (MMTC) and Sea Grant Program are developing environmentally-sound technology applicable to marine mining. The MMS has also initiated the design of generically-oriented environmental studies to provide information for programmatic marine mining decisions at MMS Headquarters and OCS Regional Offices.

This manuscript and attendant deliverables represent the first environmental program to be administered through the MMS Office of International Activities and Marine Minerals using ESP funds. Entitled "Synthesis and Analysis of Existing Information Regarding Environmental Effects of Marine Mining," this study effort was initiated by Continental Shelf Associates, Inc. (CSA) in September 1991 under MMS Contract No. 14-35-0001-30588. In addition to CSA scientific, editorial, and support staff, this study effort employed the marine mining expertise of Drs. Michael J. Cruickshank and Charles L. Morgan who served as consultants to CSA and are associated with the University of Hawaii.

## ES1 .2 Study Objectives

The primary objectives of this study were as follows:

- To survey and analyze existing literature regarding the environmental impacts of marine mining; and
- To summarize this literature in a single, monograph-style manuscript.

In addition to addressing the environmental impacts of marine mining, the secondary objectives of this study were as follows:

- To summarize the various marine mining technologies currently available and the respective target minerals and/or deposits of interest;
- To discuss viable mitigation measures;
- To evaluate models designed to predict the fate of mining-related discharges and determine the biological impacts of mining operations; and
- To identify data gaps and research needs.

Select environmental documents consulted during the study have been annotated and compiled in both printed form and in a electronic format that will allow them to be incorporated into the Minerals/Mining Reference Database administered by the MMS Office of International Activities and Marine Minerals. In meeting these objectives, the manuscript and associated deliverables should prove invaluable in the preparation of more accurate and detailed lease sale environmental impact statements and assessments, and for making other decisions concerning potential offshore non-energy minerals activities.

## ES1.3 Study Methods

The major tasks and milestones for this study effort are outlined in Figure ES1.1. Tasks were organized into the following categories and subcategories:

Information Collection and Annotation
- Information Collection
- Reference Citation
- Reference Description

Information Analyses
- Analysis of Extent of Environmental Information
- Analysis of Mitigation Measures and Techniques
- Analysis of Models
- Identification of Data Gaps and Research Needs

Preparation of Study Products
- Preparation of Manuscript
- Executive Summary
- Technical Summary
- Reference Database

### ES1.3.1 Information Collection and Annotation

#### ES1.3.1.1 Computer Searches and Telephone Contacts, Review of Documents and Citations, and Document Collection

The information collection aspects of the program had two primary goals: (1) to provide literature and data to be considered for inclusion in respective chapters of the manuscript; and (2) to produce an annotated bibliography. Information collection and annotation initially involved the development and review of citation listings, searching for appropriate references for annotation.

In an iterative process involving marine mining experts and MMS technical staff, a series of computer searches were conducted using the Lockheed DIALOG Information Retrieval Service. Thirteen separate databases were searched. Final searches provided a complete entry (i.e., author, title, key words, abstract) for each data source. Key words selected and the specific databases accessed were determined based on professional experience of CSA technical staff and its consultants. Other databases and bibliographies from various government agencies were also reviewed, including a preliminary database on

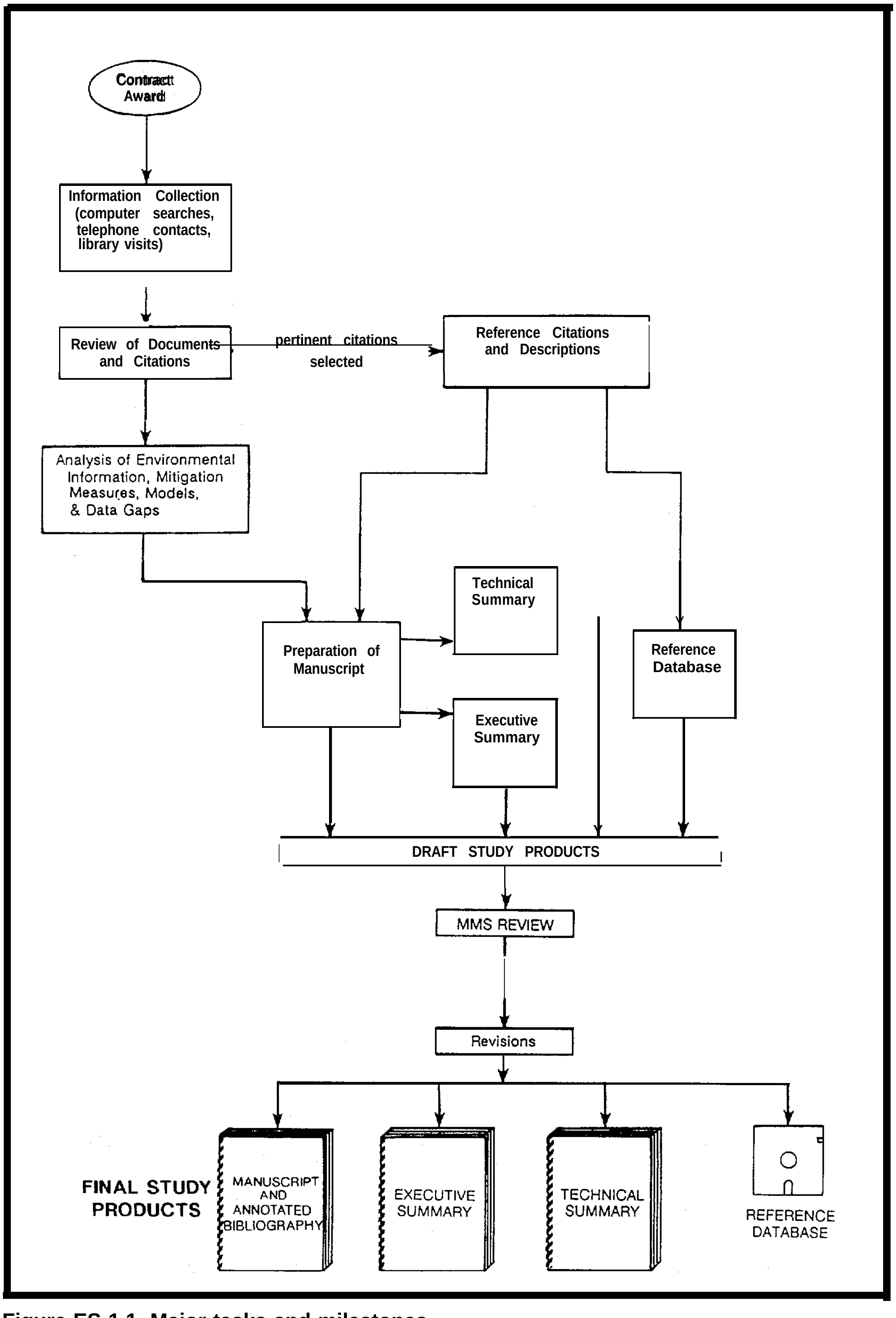


**Figure ES 1.1. Major tasks and milestones**

marine minerals from the U.S. Department of Commerce (USDOC), National Oceanic and Atmospheric Administration (NOAA), National Geophysical Data Center.

To supplement the citation lists developed from searches of the computerized databases and in-house library files, numerous individuals and organizations involved in marine mining were contacted. Requests were made for pertinent references, bibliographies, recent publications, etc. on environmental aspects of marine mining.

Review of potentially salient references led to development of an edited citation list. Listed documents were secured through corporate and consultants' libraries, as well as through library and interlibrary loan.

#### ES1 .3.1.2 Preparation of Annotated Bibliography (Reference Citations and Description Forms)

References to be annotated were selected based upon discussions between CSA and the MMS. References from the master list of documents cited in the manuscript were reviewed and prioritized. Pertinent references concerning potential impacts to various components of the environment were chosen for annotation. In most cases, citations concerning technology, policy, mitigation, and models were not considered as priority items for annotation. Individual annotated citations were assembled into an Annotated Bibliography and included as Appendix A to the main manuscript. Each annotation was completed on a standard reference description form and included (1) a unique entry number; (2) complete citation; (3) type(s) of study; (4) geographic location(s) of study; (5) applicable OCS Planning Area(s); (6) type(s) of environment(s); (7) mineral(s) of interest; (8) type(s) of mining operation(s); (9) environmental resource(s) affected; (10) date(s) of study; (11 ) study technique(s); (12) conclusion(s); and (13) key words. Data from the standard reference description form were entered in dBASE Ill PLUS format to develop the Reference Database.

### ES1.3.2 Information Analyses

#### ES1 .3.2.1 Analysis of Extent of Environmental Information

The purpose of this task was to evaluate the state of knowledge regarding environmental impacts of marine mining. Six basic mineral resource groups were subject to examination, including industrial minerals, mineral sands, phosphorites, metalliferous oxides, hydrothermal deposits, and dissolved minerals.

Discussions of operational methods and technology were separated into four categories, including mining techniques, processing of ores and disposal of waste, transportation, and cycling of materials. Mining techniques included scraping, excavation, tunneling, and fluidizing. Land-and sea-based processing by traditional and non-traditional methods were evaluated. Transportation and cycling of materials within both onshore and offshore environments were considered.

In terms of the affected environment, four separate classifications were used in the analysis, including deep ocean, continental shelf (i.e., beyond the three-mile boundary or beyond the seaward extent of territorial waters), coastal (i.e., estuarine and coastal waters within three miles), and onshore. Each marine-related classification was further subdivided according to respective environmental components, including atmospheric, oceanic or aquatic, geological, biological, and socioeconomic.

### ES1.3.2.2 Analysis of Mitigation Measures and Techniques

An analysis of mitigation measures and techniques was undertaken to identify feasible approaches which could be implemented to lessen, minimize, or avoid environmental impacts attributed to marine mining operations. The summary was grouped according to the resource to which the mitigation measure applies (e.g., air quality, water quality, geological resources, biological resources, social and economic resources). Strengths and weaknesses of each mitigation measure were discussed.

The criteria used to determine the suitability of the various mitigation methods included evaluations of technical and socioeconomic factors. Technical ranking was based on successful actions reported, experience, and theoretical estimates of the success of the method being ranked. Because of extreme variability in environments and mining activities examined, this analysis was necessarily complex. The socioeconomic factors considered related to management techniques and involved the ranking of alternative approaches. Cost factors were a significant factor in the ranking of alternative methods, however the paucity of verifiable data from actual operations imposed severe constraints on these evaluations. The need for flexibility in mitigation management was determined.

### ES1.3.2.3 Analysis of Models

An analysis of computer simulation models applicable to marine mining activities was undertaken. The purpose of this task was to review (1) models that have been used to predict the environmental impacts and fate of discharged particulate matter into the water column as a consequence of mining operations; and (2) models useful in evaluating impacts associated with seabed disturbance resulting from marine mining. The strengths and weaknesses of each model were discussed.

The synthesis effort on models focused primarily on what can be done with existing technologies, rather than on extensive documentation of what has been done with old technologies. The synthesis was organized in four parts. The first part summarized the types of models available and appropriate for the major discharge types expected from marine mining. The second part described the constraints of predictive models. The third part discussed field tools for describing sites and tracking plumes. The fourth part reviewed the status of predictive success obtained to date for actual mining discharges and other discharges similar to those expected from mining operations. This organization permitted a straightfotward assessment of the areas where more data acquisition and technique development are necessary.

### ES1 .3.2.4 Identification of Data Gaps, Research Needs, and Recommendations

In the process of reviewing the environmental information, perceived shortcomings in existing databases were noted. Efforts were made to identify and assess data gaps and information needed to determine potential environmental impacts. Criteria used to describe gaps included such factors as type of technical activity, geographic coverage, environmental characteristics, and resources affected. Findings were summarized, and research projects to fill the data gaps were recommended.

### ES 1.3.3 Manuscript Organization and Additional Study Products

The main manuscript was organized in seven major chapters as follows:

- Chapter 1 Introduction
- Chapter 2 Environmental Considerations
- Chapter 3 Summary of Mitigation Measures and Their Effects
- Chapter 4 Predictive Models
- Chapter 5 Data Gaps, Research Needs, and Recommendations
- Chapter 6 Summary and Conclusions
- Chapter 7 Literature Cited

Chapters 2 through 5 and Chapter 7 were prepared by Drs. Cruickshank and Morgan, with technical editorial input provided by CSA. Chapter 1 was prepared by CSA, while Chapter 6 represents a cooperative effort between CSA and its consultants.

In addition to the main manuscript, several other study products were prepared by CSA under this study effort, including (1) this Executive Summary; (2) an Annotated Bibliography; (3) Technical Summary; and (4) Reference Database. As noted previously, the Annotated Bibliography was incorporated into the main manuscript as Appendix A, creating a complete report deliverable.

A Technical Summary was prepared as a separate deliverable according to MMS criteria. The summary consisted of a three-page description which outlined (1) contractual specifications for the study; (2) report and deliverable specifications; and (3) the study's significant findings (i.e., background, objectives, description, significant conclusions, study results, and study products).

The last deliverable, the Reference Database, is an electronic version of the Annotated Bibliography. The Reference Database was prepared in dBASE III PLUS format and submitted separately to the MMS.

## ES2.0 SUMMARY OF ENVIRONMENTAL CONSIDERATIONS

In Chapter 2 (Environmental Considerations) of the manuscript, the state of knowledge regarding the environmental effects of marine mining was discussed and evaluated. Discussions addressed (1) the potential mineral resource groups or targets (Section 2.1); (2) the operational methods and technology applicable to marine mining (Section 2.2); (3) the environments potentially affected by selected marine mining operations (Section 2.3); (4) a characterization of the literature evaluated (Section 2.4); and (5) a summary of environmental effects by resource affected (Section 2.5). The summary discussion addressed the information on environmental effects under the categories of air quality, water quality, and geological, biological, and socioeconomic resources.

Mineral resources were defined as any mineral deposit found in the marine environment, other than oil and gas but including salt, sulfur, geothermal resources, and precious corals. These resources were classified into six groups, including industrial minerals, mineral sands, phosphorites, metalliferous oxides, hydrothermal deposits, and dissolved minerals. Mineral resources are differentiated largely on the basis of the characteristics of the deposits and the technology required for their mining or recovery. The classification is universal and each class was discussed separately with emphasis on the nature and distribution of the deposits.

The term "mining industry," as applied during this study, generally encompassed companies whose activities are directed towards mineral exploration, development, mining, processing of ores, and marketing of mined materials. The marine mining industry is influenced by a heterogeneous mix of international entrepreneurs, advanced engineering companies, politicians, environmentalists, legal experts, long-time dredge operators, and a few old-line mining companies. Despite setbacks, many aspects of the work done to date have been serious and well founded.

It was concluded that it is still early to generalize about marine mining technology and the environment. Examination of each activity on a "case-by-case" basis remains the most reasonable approach at this time. Despite the fact that every mine is different, there are only four basic methods of mineral extraction on land or at sea, including (1) scraping; (2) excavating; (3) tunneling; and (4) fluidizing (i.e., extracting the mineral through a bore hole or other conduit as a fluid). All mining methods are based on variations of these technologies. The specifics of each mining method have been summarized in Table ES2. 1.

There are three areas in which the processing of marine ores call for special treatment compared to the processing of terrestrial ores. One is the effect of platform motion on separation processes carried out at sea. The second is the effect of complete submergence on beneficiation processes. The third is in the extraction of metals from specific marine ores (e.g., manganese nodules and crusts). Some industrial materials, such as specialty sands, may require washing to remove salt water. For the most part, marine ores do not otherwise differ from those on iand and use conventional methods of treatment.

| Operational Method and Systems | Description | Comments |
|---|---|---|
| **SCRAPING** | | |
| **Conventional Shallow Water Systems:** | | |
| Dragline Dredge | Material recovered by large dredge buckets that scrape it from the surface of the deposit and feed it into barges for transport to shore. | Used in offshore mining, deep seabed sampling, and construction, Use has been advocated for the recovery of deep seabed nodules and slabs of phosphorites. Annual production of phosphorite from an OCS mine could be on the order of 360,000 metric tons, or roughly 138,000 $m^3$ of ore. |
| Trailing Suction Hopper Dredge | Dredge employs a pump to draw a slurry of bottom water and sediment into a riser or pipe leading to a surface mining vessel. | Used primarily for maintaining harbor channels, as well as extensive use in the mining of sand and gravel in water depths of up to 36 m in the North and Baltic Seas. New vessels are designed to extend mining capability to depths of 45 m. Volume of material that may be mined includes the sum of the marketable material, the fraction to be rejected, and the overburden initially stripped away. Use of sand and gravel as construction material requires stringent measures be taken to avoid mining any clay layers due to potential contamination. |
| **Tested Deep Water Systems:** | | |
| Hydraulic Systems | Hydraulic miners use airlift or hydraulic lift with towed or self-propelled collectors. | Towed mining devices (or passive systems) pick up nodules via tines at the front of the miner: nodules are fed into the suction pipe by conveyor belt or by the forward movement of the device. Separation of the fine sediment is accomplished automatically by the screening effect of the tines and use of a screen on the lifting part of the miner. Active or self-propelled miners are more complex and may be fitted with separate propulsion, navigation, nodule pickup, and crushing systems. Important factors include precision of mining track, separation of nodules from sediments, and discharge of suspended solids. |
| Continuous Line Bucket (CLB) System | Original CLB systems used one ship, with empty buckets going down from the stern, and partially filled buckets coming in at the bow. A two-ship system has been designed where the empty buckets go down to the seabed from one ship and are brought to the ocean's surface at a nearby sister ship. | CLB system has been tested for possible future use in recovering manganese nodules and proposed for mining phosphorite nodulea and slabs and cobalt crusts. In a one-ship system, the distance between the downward-moving and the upward-moving parts of the loop of the rope is dependent on the length of the ship. Entanglement can be avoided by achieving an optimum combination of ship speed and the length of the line or by the use of hydrodynamic deflectors. The optimum combination may be disturbed by various other factors, including the nature of the seabed, underwater currents, variations in the ship's course because of weather heading, or bad weather conditions. For Iwo-ship systems, the distance between the descending and ascending parts of the loop and the curve of the loop can be influenced by the relative positioning of the two ships, |

Table ES2. 1. Summary of various marine mining technologies.

| Operational Method and Systems | Description | Comments |
| --- | --- | --- |
| **Speculative Deep Water Systems:** | | |
| Modular Mining System | An autonomous collector vehicle would be launched with ballast material such that the weight in water of the ballast is equal to the weight in water of the nodules to be collected. | The collector is designed to have sufficient buoyancy so that the vehicle is weightless in water. Thus, in descent, thrusters propel the unit down steadily against hydrodynamic resistance alone. On the bottom, the collector is propelled over the bottom, and as collection proceeds, ballast material is simultaneously ejected on an equal weight-in-water basis. In this manner, a small net weight in water of the collector is maintained. Mining is terminated shortly before ballast material ejection. Ballast material ejection is continued until the weight of the vehicle is zero or slightly negative. Finally, the vehicle is propelled by thrusters to the surface, docked with the surface ship, unloaded, serviced, and re-ballasted for a new mining cycle. In theory, very little onboard power is required to collect the nodules because the major source of energy is the potential energy of the ballast material. The operating principle of this system is illustrated in United Nations (19S4). Processed tailings have been suggested for use as ballast. Advantage might be taken of ambient currents to propel the vehicle similarly to a sailplane or glider. |
| Crust Miner | Proposed systems would be capable of breaking and removing the thin manganese oxide crusts from the underlying rock and feeding it to a hydraulic lift system through hydrocyclones to separate entrapped substrate. | Recent interest in manganese oxide crusts containing relatively high values of cobalt and platinum has led to proposals to develop the deposits. The manganese crusts vary in thickness from mere stains to layers as much as 40 cm thick, and covers variety of substrate rocks ranging from hard basalt to weak hyaloclastite. The physical properties of the crusts are similar to a hard coal, and they occur extensively in the Pacific on seamounts and submarine ridges at depths between 800 and 2,400 m. Mining systems proposed for this work include a vessel equipped with hydraulic lift systems and active bottom miners (Halkyard and Felix 1987; USDOI, MMS and HI, DEED 1990). The roughly cleaned ore would be pumped to the surface vessel for further cleaning and transport to shore, The mining machine would provide its own propulsion and travel at a speed of approximately 20 cm/s. The miner would have articulating cutting devices which would allow the crust to be fragmented while minimizing the amount of substrate collected. Behind the cutter heads, a series of parallel pickup devices would be positioned, consisting of either articulated hydraulic suction heads or a mechanical scraper/rake device. Approximately 95% of the fragmented material would be picked up and processed through a gravity separator prior to lifting. Under normal operations, the mining ship and the miner would follow a coordinated track following bottom contour fines. System speed and/or pipe length would have to be altered to accommodate changes in depth over approximately 100 m. Steering of the miner would be used to maneuver around obstacles, over areas of particularly high abundance, or around a previously mined swath. |

Table ES2.1. (Continued).

| Operational Method and Systems | Description | Comments |
|---|---|---|
| **EXCAVATING** | | |
| Conventional: | | |
| Clamshell Bucket | Clamshell buckets are mechanically actuated to bite into the seabed and remove material. | Clamshell buckets have been used offshore to mine sand and gravel in Japan and tin in Thailand, andtosample phosphorite off New Zealand. The need for multiple cables to actuate the grabs can cause complications, particularly in heavy seas where wave compensating devices may also be needed. The clamshell is beet suited for excavation of large-size granular material where accuracy of positioning and cleanup is not important; this system is inefficient in clearing bedrock of fine materials. The size of buckets may range from a few cubic meters to as much as 7.6 m’, |
| Bucket Ladder Dredge | The bucket ladder consists of a chain of closely connected digging buckets mounted over a heavy supporting arm or ladder, | The bucket ladder dredge is most efficient for excavation of deposits containing boulders, clay, and/or tree stumps and weathered bedrock. Dredges of this type have been used successfully all over the world for mining gold, tin, and platinum placers and diamond deposits: offshore use has been limited to gold and tin. They are frequently used for clearing harbors because of their capability for digging into broken rock and coral. This system delivers a virtually water-free product to the mineral dressing plant onboard the dredge. Discharge of water from shipboard operations is limited to that needed to concentrate valuable constituents (i.e., use of flowing water to remove the leas dense materials). In the case of gold, the bulk of concentrate recovered is only a few parts per million; virtually all the material removed from the deposit is returnad to the seabed. Turbulence accompanies these operations, which may involve the annual movement of up to 4.9 million $m^3$. Bucket ladder dredges are limited to 45 m water depths, rarely operating at depths over 20 m. |
| Bucket Wheel Suction Dredge | Bucket wheel dredges use a small-diameter bucket wheel mounted on the suction ladder to excavate material, combining the best aspects of the bucket ladder and suction dredges. | Advantages of this system include very high torque or digging power available for application to the wheel, delivering the excavated material directly into the mouth of a suction pipe for transport to the surface. Digging capability is equal to that of the bucket ladder dredge with respect to ease of digging and bucket capacity; the depth capability using submerged pumps is nearly unlimited. A combination of concurrent digging and suction at the seabed allows for vessel treatment or transport to shore. |

Table ES2.1. (Continued).

| Operational Method and Systems | Description | Comments |
|---|---|---|
| Stationary Suction Dredge | Operates under similar principles as other suction dredgea. | Anchored suction dredges are widely used in Japan (i.e., mining sand and gravel) at depths leas than 30 m. Current designs will extend depth limits to 200 m (Tsurusaki et al. 1988), An anchored suction dredge has also been teeted for mining metalliferous muds at a depth of 2,000 m in the Red Sea (Fletcher and Mustaffi 1980). Stationary, or anchored, suction dredges are used extensively in Britain, although most vessels built since 1980 are trailing suction dredges. Anchored suction dredges leave deep pits in the seabed. |
| Cutterhead Suction Dredge | This method uses a rotating butterhead which is usually comprised of an open basket with hardened teeth or cutting edges. The end of the suction pipe is normally located within the basket. | Typically, cutterhead suction dredges are used to excavate fairly compacted, granular materials in water less than 30 m deep, In standard practice, the dredge is swung back and forth in an arc pivoted from a large post or spud attached to the stern. The dredge cufferhead cuts downward a short distance with each swing. Because the cutter rotates in one direction only, the bite is much stronger on one swing than the other. In mining for heavy mineral sands, the action of the cutter tends to disintegrate the material, allowing heavy minerals to separate, fall below the cut, and be left on the seabed. Cutter suction dredges have been used successfully for mining cassiterite (fin placers). Suction dredges circulate large quantities of slurry, creating a significant discharge of water containing fine particulate materials. Treatment of the decanted solids may be unnecessary for construction sands and gravel but may be required for heavy minerals. The valuable constituent or concentrate from these orea will rarely amount to more than a few percent of the materials mined. The butterhead suction dredge may also be equippad with a multi-blade ripper to cut into moderately consolidated rock. Present use is limited to the excavation of soft rock, such as coal and shale. However, advances in rapid tunneling technology suggest that rock cutterheads could be designed for medium strength rocks, such as sandstone and limestone (Hignett and Banks 19S4). |
| Drilling and Blasting | Involves the use of explosives to fracture a formation: subsequent retrievaf of the mineral resource requires one of the methods notad above. | Blasting operations are designed to expend as much force as possible on fragmenting the ore so water column effects are much lower than those for equivalent, unconfined explosions from which most available data have been derived. With respect to the possibility of mining deep seabed deposits that require fragmentation, many more aspects need to be examined. Technically acceptable means of drilling and fragmenting hard rock in deep water have not yet been developed. However, methods of gathering and tiffing the fragmented material may be assumed to be similar to the methods developed for deep seabed nodule mining. |

Table ES2. 1. (Continued).

| Operational Method and Systems | Description | Comments |
|---|---|---|
| TUNNELING | Conventional underground mining methods involve tunneling from a surface entrance or a shaft and working the mine in an unpressurized environment, | Sub-seabed deposits of bedded coal, ironstone, potash, and veins of copper, lead, and tin have been mined by conventional underground methods. Entry to these mines is either from the shore or from natural or artificial islands in shallow waters. The location of the mines in the seabed only slightly adds to conventional problems of access, safe overhead cover, and ventilation. The effect on the environment is similar to that for any shoreside mine. The possibility of developing underground access through seabed airlocks has been considered for special cases (Austin 1967). |
| FLUIDIZING | | |
| Fluidizing (Slurries) | This mining methods entails drilling of a borehole to the base of the ore, then applying a means through the borehole to granulate or fluidize the resource. The slurry is recovered through the borehole, creating a waterfilled cavity which may be backfilled with waste material. | Under proper conditions, certain types of unconsolidated or marginally consolidated mineral deposits may be mined as a fluid slurry through drillholes penetrating the seabad (e.g., sand, phosphorite). Sub-seabed sand was mined in this way in shallow waters offshore Japan in 1974 (Padan 1983), and recent onshore experiments in Florida proved the capability of this approach in recovering phosphate from beneath thick overburden (Savanick 1985). This system was determined to be cheaper than conventional land mining systems if the overburden is at least 45 m thick (Hrabik and Godesky 1985). Similar experiments conducted off Georgia (Drucker et al. 1991) from an anchored barge confirmed the potential for borehole mining for phosphorite as an economically and environmentally attractive alternative to dredging. In the recovery of sulfur, super-heated water is pumped into the deposit to melt the sulfur so that it may be removed as a fluid (Cummins and Given 1973). |
| Fluidizing (Solutions) | Using this method, hard rock deposits (and associated ores) amenable to hydrometallurgical treatment are extracted by dissolving the valuable constituent in place and removing the pregnant solution through a borehole. | Major unsolved problems are noted in dealing with toxic or corrosive solvents used in enlarging fractures to provide a flow path for the solvent through the deposit end selectively extracting the desired metals in complex ores. Effects of accidental solvent spills would depend on the nature of the solvents and the sites affected. If the solvent is water soluble, effects should be localized because of rapid dilution and the buffering capacity of seawater. |

Table ES2. 1. (Continued).

Materials handling in the marine environment is complicated by the motions of the platform and the need in most cases for closed-cycle systems and stringent controls to avoid spillage or contamination. These issues are normally addressed in environmental analyses that are a part of the planning process. In the case of marine mining, the problems would be addressed on a case-by-case basis.

The nature of the various environments (e.g., deep ocean, continental shelf, coastal zone, onshore) in which marine mining may take place and the anticipated effects of mining operations on those environments are discussed in Section 2.3. Where possible, real examples of operations were cited and discussed, rather than speculative methods. The geographic extent of the environments under consideration in this analysis was global, even if the U.S. Exclusive Economic Zone (EEZ) was the only region for which a particular mining operation or environmental effect was documented. The descriptive material was directed to areas selected by the authors as being representative of possible future mine sites. Examples from areas outside of the U.S. were commonly used, including southeast Asia, Europe, and the Pacific Basin.

The nature of the available and salient literature acquired during this study was discussed in Section 2.4. The general nature of its content was analyzed in a qualitative manner. Thirteen major documents exist that together address the state of knowledge at the time of compilation. These volumes alone contain more than 5,000 references selected for their relevance to the subject matter addressed, many of which pertain to environmental effects of mining. During the present analysis, more than 3,570 references were scanned, over 1,100 selected titles were categorized, and approximately 350 sources were used as references. Analysis of the documents categorized indicated that 54°A were not country specific; of those that were, 66% pertained to North America. More than half of the literature sources did not specify to which environment they pertained; of those that did, 75% were coastal and only 3% of the total referred to the OCS. Only 17% of the documents reviewed pertained specifically to mineral deposits; of those, 80% applied to deep ocean oxides and hydrothermal deposits. Nearly 50% of the sources reviewed were office studies, while nearly 30% were based directly on field work, and 10% were based on laboratory studies. More than 20% of the sources evaluated did not specify which resource was affected; of those that did, three resource categories were prevalent, including biology (41 %), water quality (35%), and geology (18%). Socioeconomic and air quality were identified in only 5°A and < 1% of the resource-specific citations, respectively. The bulk of the work appears to have centered on North American coastal biology.

Based on limited information available from actual operations, a general approach was used in Section 2.5 in summarizing the environmental effects of marine mining in the deep ocean, continental shelf, coastal region, and where appropriate, onshore. Marine mining operations affect both natural resources (e.g., atmosphere, land, sea surface, water column, seabed, and all living things therein) and artificial resources which have been developed to suit human social needs (e.g., governance, commercial activities, technology, economics, and aesthetics). The direct or primary effects of marine mining on the environment may include (1) removal of the mined material; (2) introduction of new materials as processing wastes, tailings, and discharges, or of energy as heat, light, or seismic and acoustic waves; (3) perturbation or mixing at the seafloor due to the mining operation; and (4) subsequent replacement of mined material as waste, tailings, or discharges. These primary effects result in physical, chemical, and biological changes such as alteration of the shape or character of the seabed; changes in the quality of the air and water in the vicinity of the operation; and impacts on biological and other resources.

The key environmental concerns expressed in the literature have focused on air quality, water quality, seabed perturbation, biological resources, and socioeconomic resources (including commercial and recreational fisheries). These aspects form the basis of the summary discussion, but it was stressed that a reliable analysis of effects, or environmental impacts, of any mining operation must be based on commodity-specific, site-specific, and technology-specific information. A synopsis of findings for each resource affected has been presented in Table ES2.2.

| Resource and Environment | Significant Findings | Salient References' |
|---|---|---|
| AIR QUALITY | Emissions of gaseous or particulate metter to the atmosphere are of greatest potential concern. Principle emissions are nitrous oxides and residual (reactive) organic compounds. During exploration and test mining, emissions are expected to have little effect on onshore air quality except offshore California where high background pollution already exista. Emissions from marine mining sources are expected to be qualitatively and quantitatively similar to oil and gas related sources. In the deep ocean, some gases might be released from seawater brought to the surface from the seabed vie hydraulic dredging; information cmthis effect is sparae. Noise from non-explosive seismic exploration activity ia generally dismissed as insignificant. In terms of global or regional effects of marina mining, there is only limited literature on this subject. Effects are generally examined on a site-specific level. No significant problems or priority areas for research are noted. | USDOI, MMS (1988b)<br>OTEC publications |
| WATER QUALITY | | |
| Natural Effects | In general, the natural effects of environmental change are easily recognized. Phenomena such as rsd tides, mega-plumes resulting from seabed hydrothermal activity, and storm- or earthquake-induced slides may result in significant but temporary changes in water quality. | |
| Induced Effects | Induced effects (e.g.. turbidity, nutrient or trace metal enrichment) may result in secondary effects throughout the trophic web. | |
| Deep Ocean and OCS | Impacts are difficult to assess. The capacity for assimilation of plumes increases in deep water, however ofher factors (e.g., presence of a thermocline, low velocity benthic currents) may prolong the effects of plumes compared to shallow coastal waters. Effects should be examined on a site-specific baais. Dilution of a discharge to low concentrations is rapid (i.e., reduced to 1,000 ppm within 2 min of discharge; to 10 ppm within 1 h). The affected zone typically extends 1,000 to 2,000 m down current. Field studies of drilling muds and other discharges indicate that pollutants are rapidly reduced to background levels. Long-term, chronic effects of these discharges have not been observed. Mining discharges are subject to the same settling and dilution factors es oil end gas related discharges. Turbidity from resuspended sediments may be detected down current over many km: direct effects and indirect effects (e.g., nutrient or trace metal enrichment, increased biological or chemical oxygen demand) are limited to the immediate area of operations. Petroleum spills from marine mining activities would be limited to fuels (during transfer) and tanker loss. | Aurand and Mamontov (1982)<br>Cruickshank et al. (! 987)<br>de Groot (197Sb)<br>Drinnan and Bliss (1986)<br>ECOMAR (1 983)<br>Evans et al. (1982)<br>Gillie and Kirk (1980)<br>Hirsch et al. (1978)<br>Middleditch (1981)<br>Neff (1981, 1985)<br>U.S. Congress, Office of Technol. Assess. (1 987)<br>Zippin (t 9SS) |
| Coastal and Onshore | Marine mining would affect water circulation and water quality proportionally to the level of activity. Large stockpiles of marine minerals or mining wastes could be usefully maintained or disposed of at convenient sites near to shore; impacts from these activities can only be assessed by analysis of site-specific conditions. The shallow and confined nature of many coastal waters makes them susceptible to perturbation or pollutants. Turbidity is generally not considered a problem (e.g.. sand and gravel mining operations are discontinuous; deposits rarely contain large amounts of silt-sized material). Good management practices are critical to eliminate potential impacts. A very low potential exists for release of chemicals normally associated with harbor and channel dredging (e.g., PCBs, Irate metals). | U.S. Congress, Office of Technol. Assess. (1 987) |

**Table ES2.2. Summary of environmental effects of marine mining by resources affected.**

| Resource and Environment | Significant Findings | Salient References* |
| --- | --- | --- |
| Terrestrial Sites | Impacts on water quality at shoreside facilities are attributed to gaseous, liquid, or solid weste emissions, Potentially serious problems include the dumping of mined failings end processing wastea into adjacent waterways. The nature of the effect will be influenced by the characteristics of the dumped material, the nature of the waterway, end its ecosystem. | Ellis (1987, 1988, 19S9)<br>Ellis end Hoover (1990) |
| GEOLOGICAL RESOURCES | The primary effect is the removal of the ore; additional secondary effects may include alteration of the value of remaining mineral resources (grade depletion) and alteration of the seabed. | |
| Mineral | Mineral deposits removed by mining result in en irretrievable transfer of the mineral from a resource base to a consumptive use. | |
| Other | Major geologic impacts of marine mining result from activities in the coastal zone where wave energy is a prime factor. The effects of large excavations or shoaling resulting, for example, from the mining of mineral sends will depend on location. Changes in wave or current patterns induced by altered conditions can cause changes in shoreline equilibrium. causing erosion or deposition. Possible effects from sub-seabed fracturing using conventional or other type explosives are not well discussed in the literature; additional study end observation (i.e., in offshore areas susceptible to slumping, in deep water) was suggested. Coral reef growth may be severely affected by siltation, altering the supply of cord sands to adjacent beaches. | Chansang (1988) |
| BIOLOGICAL RESOURCES | Most biological impacts ere secondary, attributed to some alteration in existing physical, chemical, or trophic equilibria. Impacts in the coastal zone have a greater tendency to be significant because of higher energy levels, Physical changes which may induce biological effects include changes in temperature. current patterns, amount of particulates present, nature of the substrate, and introduction of new habitats. Significant chemical changes include changes in the presence of nutrients, trace elements, or toxics. Trophic changes include removal or alteration of indigenous species. Biological impacts are the major enigma of impact assessment. Criteria upon which significant biological changes are based are typically arbitrary. Generalizations rarefy allow meaningful prediction of the effects of specific mining operations. Biological studies should be directed on a case-by-case basis to respond to specific needs. Effects of turbidity, sedimentation, explosives, light, and noise on marine biota heve bean reviewed. Other date sources were noted from deep seabed mining, OCS oil and gas, and academic research. | Cruickshank et et. (1987) |
| Birds | Large oil spills which have the potential to kill numerous sea birds and shore birds ere not anticipated from marine mining operations. Effects of smell spills tend to be lodized and short.fried. | USDOI, MMS (1983b, 1991) |
| Mammals | Effects of aperations may include loss of feeding areas, uptake of heavy metals, end noise. Oil spills era not considered significant because of the low risk. Mining activities located away from known migratory pathways and calving or feeding grounds are unlikely to adversely affect marina mammal populations although individual transient animals near mining sites may be startled or show avoidance behavior. Limited research suggests habituation to low-level noise. | Gales (1962)<br>Geraci end St. Aubin (19S0)<br>USDOC, NOAA (1981)<br>USDOI, MMS (1983a,b) |

Table ES2.2. (Continued).

| Resource and Environment | Significant Findings | Salient References' |
|---|---|---|
| Marine and Aquatic Fauna | Both adverse and beneficial impacts have bsan noted. Beneficial impacts include the attraction of fish to offshore structures; enhancement of substrate habitats by alteration of the texture; enhancement of substrate habitats by the presentation of new surface nutrients by mixing and replacement of the benthos; thermal stimulation of growth; and introduction of nutrients by mixing of water masses and enhancement of phytoplankton growth. Adverse effects include direct lethal toxic effects (e.g., abnormal growth, reduced adult fecundity, behavioral changes, etc.) and disruption of community and ecosystem structure (e.g., changes in diversity and abundance via feed web disruption, changes in predator-prey relationships, etc.). Analyses of potential impacts requires a knowledge of the pm-operating populations and their natural cycles, allowing a differentiation between natured fluctuations and impact response, Adequate knowledge ofpre-operating conditions (baseline) is debatable. Difficulties arise in the selection of indicator species. Effects ofmarine mining operations occur from turbidity, smothering, and pollutant (from mined formations). Turbidityeffects may not be a concern if dilution rates are high arrd sensitive communities ore not proximal to the mining site. Numerous studies have beenconducted regarding the effects of turbidity on indigenous fauna, especially fishes. The exposure of free-floating organisms (e.g., plankton) to high turbidity concentrations will be limited. Turbidity impacts from aggregate dredging operations on sensitivebenthic organisms will be far less than placer mining. Smothering of bottom dwelling organisms is due to the settlement of suspended sediments end associated depletion of oxygen in surrounding waters. Coral reek and seagrass beds are particularly sensitive. Smothering is perceived as being of greatest concern in placer mining operations, Pollutants may affect growth and reproductive rates. The affects of pollutants on the physiology of marine fauna has received only limited study, Effects on marine phytoplankton are observed in response to decreased illumination in the laboratory, but these shading effects are not expected to be a problem in open waters. In the benthos, some species will likely be more affected than others because of feeding mode (filter feeders), life habit (surface dwellers), degree of mobility (tube dwellers), or sensitivity of life stage (larvae). Areas that may not be able to withstand slight increases in sediment deposition includecoral reefs and areas used by bottom spawning fish, In cases where a majority of the benthic community hea been adversely affected, recolonization will occur from populations outside the disturbed area, Benthic organisms may serve as indicators of pollutants and the structure of thebenthic community may be indicative of a stressed or disturbed environment, | Aurand and Mamontov (i 982)<br>Bigham et al. (1 982)<br>Blaxter (19S0)<br>California Department of Fish and Game (1977)<br>Chan and Anderson (1981)<br>Clark (19r?8)<br>Cressard (1981)<br>Cressard and Augris (1982)<br>Cruickshank (1974a,b; 1987)<br>Dawson (1984)<br>de Groot (1979a,b)<br>Drinnan and Bliss (1988)<br>Ellis and Hoover (1 990)<br>Gillie and Kirk (1980)<br>Glasby (1985)<br>Hanson et af. (19S2)<br>Hirota (1981)<br>Hu (1981)<br>ICES (1979)<br>Kawamura and Hara (1 980)<br>Levin (t 984)<br>Lunz et al. (1984)<br>Matsumoto (1 S84)<br>NRC (1985)<br>Pfitzenmeyer (1970)<br>U.S. Army Engineer District (1974)<br>U.S. Congress, Office of Technol. Assess. (19S7)<br>United Nations (1981)<br>USDOC, NOAA (1981)<br>USDOI, MMS (1988b) |
| Flora | Effects on flora are not regarded as a major concern, | |
| Sensitive Habitats | In sensitive areas (e.g., Arctic waters), particularly in shallow water, or in the deep seabeds, slow regrowth of affected communities is expected Areas of hydrothermal venting along mid-ocean ridge crests support unusual benthic colonies. Draft regulations have provided for avoidance of such environments. | Dunton et al. (1982)<br>USDOC, NOAA (1981)<br>USDOI, MMS (1983a) |

**Table ES2.2. (Continued).**

| Resource and Environment | Significant Findings | Salient References* |
| --- | --- | --- |
| Threatened and Endangered Species | Impacts were discussed under respective biotic resource categories. Impacts are associated with noise (marine mammals, birds), accidental oil or fuel spills, and increased turbidity. | |
| SOCIAL AND ECONOMIC RESOURCES | Most actions resulting in environmental query are triggered on the basis of some social or economic need, Such aspects are built into the scoping process for respective environmental documents. The literature is voluminous and scattered. | |
| Human Resources | Effects on human resources include health, employment, end infrastructural needs. For processing plants and mining operations conducted from platforms or seabad mining operations carried out in the hard rock, extend ad periods of relative isolation create impacts on mining personnel. The social environment is extremely variable and widely described, but not specifically for marine mining, Disturbances must be weighed against benefits. The ranking of multiple uses is potentially highly subjective. From a legal perspective, national laws are not adequate for many minerals and international laws regarding the mining of the seafloor are still not well-defined. In many instances, national and international laws have lagged behind rapid social change. Several aspects have a significant effect on planning and conduct of operations, including the exhaustible nature of mineral resources, resource conservation, arrd multiple uses of mineralized areas. | USDOI, MMS (1988a,b) |
| Commercial and Recreational Fisheries | Literature from Europe is more extensive on this subject than in the U.S. Modern European prospecting operations cause little disturbance to the marine environment and do not interfere with other activities at sea; no formal government consultations procedure exists for a prospectinglicense, however, the permitting process is substantive. As a resource, standing fishery stocks are affected by various factors (e.g., turbidity, pollutant loading, physical disturbance). Direct effects of oil or turbidity are limited due to the mobility of fish. Indirect effects include damage to eggs, larvae, and juveniles; sublethal uptake of hydrocarbons and pollutants: loss of prey: leas of habitat; and reduced reproductive success. Marine mineral activities may interfere with fishing activities and compete for space at sea and in port. Space use conflicts between fishermen end vessel operators have occurred with entanglement or severing of net and trap lines. Coordination efforta between the two industries have helped avoid most vessel conflicts. Recent research interest has included assessment of the potential for marine geophysical surveys to reduce catchability of fish and darnage to fish eggs and larvae. Long duration, spatially concentrated use of seismic energy sources can disturb the spatial distribution of fish in the water column and reduce catchability. It is expected that there has bean some loss of individual income through lost catch opportunity or gear loss end increased cost of port space. | Nunny and Chillingworth (19S6)<br>Pasho (19ss)<br>Zippin (i 9SS) |
| Regional Economies | Impacts from resource disturbance will be measurable on the economy. The extent of the economic impact resulting from a given action is affected by various factors. A determination of a prospect's feasibility must consider the net rate of return cm the investment. | Sorensen and Mead (1969) |
| Local Economies | Local economies are site-specific, driven by many factors. | |

Table ES2.2. (Continued).

| Resource and Environment | Significant Findings | Salient References' |
|---|---|---|
| Cultural Resources | Effects are particularly difficult 10 quantify because intangible cultural systems are subject to the historical and contemporary changes induced by all human activities. A comparison of alternatives using semi-quantitative methods of factor analysis mght be valid. Archeological resources may be significant end should be protected. | Cruickshank (1 974a) |
| Technical Resources | Major impacts on technology eppear in the form of disturbances to the system due to materials failure primarily effected by motion, pressure, corrosion. and biological fouling. Impacts cm the environment are relatively small. | |

•- Salient references indicate key sources; several reference listings (e.g., Marine and Aquatic Fauna) have been pared, given tabular space constraints.

Table ES2.2. (Continued).

## ES3.0 SUMMARY OF MITIGATION MEASURES AND THEIR EFFECTS

Chapter 3 summarizes viable mitigation measures and their effects. Mitigation with respect to marine mining is potentially a subjective concept. For purposes of this analysis, mitigation was defined as actions taken to make the effects of marine mining as harmless to the environment as possible. Council on Environmental Quality (CEQ) Regulations (40 CFR 1508.20) define mitigation to include (1) avoiding the impact all together by not taking a certain action or parts of an action; (2) minimizing impacts by limiting the degree or magnitude of the action and its implementation; (3) rectifying the impact by repairing, rehabilitating, or restoring the affected environment; (4) reducing or eliminating the impact over time by preservation and maintenance operations during the lifetime of the action; and/or (5) compensating for the impact by replacing or providing substitute resources or environments (U.S. Council on Environmental Quality 1978).

For the U. S., the mineral resources of the marine environment are managed in territorial waters by the adjacent States. In OCS waters, mineral resources are managed by the USDOI, MMS. In the seabeds beyond national jurisdiction, the USDOC, NOAA retains primary management responsibility within the U.S. Federal government. In OCS waters, the USDOI operates under the sometimes conflicting authority of 35 Federal laws, 24 of which are applicable to operations for minerals other than oil and gas. Environmental issues have been an important and contentious element in OCS leasing policy since the time of the Santa Barbara oil spill in 1969. Even for minerals other than oil and gas, this air of controversy has affected the stance of policy makers for marine minerals development at the State, national, and international levels. In attempting to institutionalize the management needs for marine minerals, however, the assignment of specific weights to environmental risks is extremely difficult, particularly for an industry in the early stages of development.

To deal with these factors in a productive way, the USDOI has assigned regulatory controls to be applied on a case-by-case basis. The type of risk that might be applicable to mining development includes effects on air and water quality; interference with natural shoreline processes; alteration of habitats and species distributions; and conflicts with fishing, recreation, or other commercial activities. The mitigation of these risks or effects by the application of optimal engineering design, generally referred to as internal costs, can be reasonably calculated. However, if the effect is imposed on others such as fishermen, recreational boaters, or other categorical opponents, with or without compensation of some kind, the cost becomes an external cost and is difficult to assess.

This analysis has focused on one of the most important mitigation measures possible, the acquisition and promulgation of facts concerning the marine minerals environment and the effects of mining. Whereas mitigation itself is specific to specific operations in specific environments, the form of the mitigation is strongly influenced by institutional procedures and perceptions. These “institutional” aspects of mitigation are discussed at some length in Section 3.1, while Section 3.2 outlines some of the important aspects of actual mitigation measures which have been proposed or implemented.

A summary of potential mitigation measures is presentedin Table ES3.1 on the basis of resources affected.

| Resource and Environment | Significant Findings |
|---|---|
| AIR QUALITY | Air quality issues tend to be site-specific. Available environmental assessments of marine mining conclude that air quality effects are not expected to be significant except offshore California, Major exceptions to this conclusion are related to power generation and pyrometallurgical processing. With respect to power generation, the recovery and processing of both marine and terrestrial ores is considered very similar, Primary recovery in a marine setting might require more combustion energy than recovery of terrestrial ores, however, subsequent marine transportation can be expected to be significantly more efficient and less polluting than over-land transportation. In metallurgical processing, the type of ore being recovered is much more important than whether or not the ore is recovered from a marine or terrestrial deposit. Oxide ores can be expected to require more energy to process than sulfide ores; processing of sulfides may also produce acid rain, whereas oxides will not. Air quality effects for marine mining activities in the deep oceans and OCS are not expected to be significant or to require any special mitigation. The site-specific nature of coastal activities precludes the reasonable evaluation of mitigation options, particularly for air quality effects. The available environmental assessments of marine mining proposals (USDOC, NOAA 1981: USDOI, MMS 1983a,b; USDOI, MMS and HI, DBED 1990; USDOI, MMS 1991) universally conclude that offshore activities in coastal areas are not expected to cause significant effects on air quality and would not require mitigation beyond existing regulatory controls. Because the bulk of the power consumption and air emissions for marine mining will be caused by metallurgical processing, and because all currently proposed marine mining ventures would require onshore processing, air quality effects can be expected to be most acute in this region. |
| WATER QUALITY | In environmental assessments of deep seabed mining (USDOC, NOAA 1981; USDOI, MMS and HI, DBED 1990), the potential for mitigation of effects from mine ship discharges have been considered in detail. Subsurface discharge of deep sea or OCS mine tailings is a cost-effective means of eliminating potential effects on the habitate in the surface photic zone. Turbulence and high oxygen levels in surface waters would ensure rapid dispersal and stabilization of discharges; plankton play a role in encapsulation and sedimentation of fine-grained materials. Significant efforts have bean made, particularly in Europe and Japan, to develop coastal mining systems with minimum generation of turbidity and generally minimum impacts on water quality. The area affected by plume sedimentation can be reduced by subsurface discharge or other techniques that force the particulate material to settle close to its source; this approach also creates a heavier accumulation of discharge material in a smaller area. Appropriate sedimentation pattern and appropriate disposal methods will depend upon the characteristics of the site, including the biota. Other mitigation methods include (1) a system to return turbid water overflow from the dredge hopper to the dredge intake; (2) use of silt curtains to contain the plume within a specified area; (3) return of overflow waste to the seafloor (i.e., shunting); (4) closing the upper side of the bucket ladder on a bucket ladder dredge, reducing the mid-water and surface turbidity plume; (5) enclosing individual dredge buckets; (6) application of an anti-turbidity overflow system (ATOS), removing air bubbles from the overflow of a hopper dredge: (7) selection of the most appropriate dredging system for the site; (8) imposition of daily or annual limits on the quantity of dredged material; (9) limiting the number of vessels or operations in given areas: and (1 O) prohibitions on overboard disposal of equipment. |
| GEOLOGICAL RESOURCES | Geological resources affected include the mined material and the seabad from which the mined material is removal. In the case of high value materials (i.e., gold or platinum), the volume of material removed is insignificant., Local hydrodynamic conditions and the type of deposit being mined must be taken into account when establishing a minimum water depth for dredging in order to avoid the possibility of coastal erosion. Large excavations can also lead to coastal erosion if the wave patterns and sediment movements are sufficiently changed nearshore. U.S. regulations are being developed. In Britain, coastal dredging reportedly causes no problems in water depths greater than half the normal wave length or more than one-fifth the length of extreme waves. The use of marine mining for sand and gravel production eliminates the scarring of onshore environments due to quarrying. Further, unsightly and unsafe operations with major dust, noise, and traffic problems are alleviated (Fischer 1968). |

Table ES3. 1. Summary of marine mining mitigation measures by resources affected.

| Resource and Environment | Significant Findings |
|---|---|
| BIOLOGICAL REsOURCES | |
| Birds | Significant effects of marine mining activities on birds have not been identified in the available literature. No mitigation measures were identified. |
| Marine Mammals | Collisions with marine mammals and alteration of migratory patterns (via noise in the water column) have bean identified as potential effects. Collision could be eliminated or significantly minimized by requiring or encouraging reduced boat speeds in areas of known or suspected concentrations of marine mammals or sightings. Reduction of noise of the primary recovery and ore-lift operations could be considered to mitigate the second type of effect if quantitative information about the actual sensitivities of the marine mammals involved could be determined. |
| Marine and Aquatic Fauna | Effects on neuston, phytoplankton, zooplankton, fish, and other water column organisms are directly dependent upon water quality. Consideration of mitigation options for effects on these populations is reduced to the mitigation of water quality effects. In the development of deep seabed sulfide deposits end manganese nodule and crust deposits. several mitigation options are possible to minimize the effects of mining on benthic habitats. Mitigation methods include (1) maximizing the dispersed of suspended particles to minimize benthic smothering; (2) mining in a discontinuous fashion, leaving small patches within mine sites unmined; and (3) exclusion of large areas which contain potentially unique populations (e.g., hydrothermal vent communities). For coastal mines, many opportunistic species can colonize tailings: colonization is variable from year to year and encompasses a range of different species, most of which are deposit feeders. Problems with ongoing bottom fisheries can be avoidad through management practices that do not allow the use of stationary dredges in areas where bottom trawling, bottom scallop dragging, or clam raking is normally practiced. In situations where exposure of silts and clays is a concern, it may be necessary to require that the bottom portion of the layer being mined be left in place to minimize such change. Some form of seabad fertilization by organic sludge could facilitate reclamation of undersea tailings beds. |
| Sensitive Habitats | For water column habitats in general, the rapid and effective dispersive processes virtually eliminate the possibility ospecial, sensitive habitats. Possible exceptions include neuston layers, where significant populations of sensitive larvae can congregate. and confined straits end other waterways which form migratory pathways. Mitigation of possible effects on these habitats will generally consist of avoidance (through restriction of the activities) or through modification of the activities, such as subsurface discharges. Probably the most serious limitation on the evacuation and mitigation of effects on sensitive habitats in deep seabed environments is a general lack of knowledge regarding the deep sea benthos. In nearshore environments, materials in the water column can be transported downstream, affecting coastal benthic communities. Coral reefs, mating and spawning shoals and beaches. and sensitive estuarine habitats are particularly sensitive; mitigation measures. if feasible, must be developed on a she-specific basis. |
| Threatened and Endangered Species | Within available environmental impact statements for proposal mining (USDOC, NOAA t 981; USDOI, MMS 1983a,b; USDOI, MMS and H1. DEED 1990; USDOI, MMS 1991), regulatory agencies have undertaken extensive examination of effects to threatenad and endangered species. Specific areas have been removed from consideration where possibly significant effects could result. No other forms of mitigation which specifically address threatened and endangered species have been identified. |

Table ES3.1. (Continued).

| Resource and Environment | Significant Findings |
| --- | --- |
| SOCIAL AND ECONOMIC RESOURCES | |
| Human Resources | Effects in this category are confined to issues which deal with human health and safety. Most issues are too site-specific for a rational discussion of general mitigation options. Safety is an important issue in every aspect of the operation, while health issues are focused on perceived or actual threats to public health through effects on air or water quality or through the generation of excessive noise. Mitigation of sir and water quality effects has been discussed previously. In bucket ladder dredging operations, it has been suggested that noise can be reduced by hanging rubber mats over the ladder wellway. |
| Commercial and Recreational Fisheries | Most of the potential problems related to social and economic environments would be site-specific end concerned with onshore processing facilities, A key area of possible conflict is related to commercial and recreational fisheries. Most current development strategies are biased toward the development of sustainable end renewable resources rather than non-renewable resources, end marine mining interests must be prepared to avoid any potential conflicts with fishing interests in operational areas or prove that such operations will not jeopardize ongoing or anticipated fishing activities. Mitigation measures include (1) active solicitation of inputs from the pertinent fishing industry representatives early in the planning process for marine mineral development (2) possible use of abutting dredging tracks to obtain an unobstructed seabed and minimize creation of mounds, trenches, end pits: end (3) use of trailing, rather then anchored, suction dredges in bottom fishery areas. |
| Regional and Local Economies | Marine mining ventures have the potential to affect regional end local economies, both positively and negatively. General strategies to mitigate the negative effects include (1) job discrimination in favor of local residents and associated training populations to implement such discrimination; (2) process plant location in areas with maximum development to avoid large influxes of new residents in predominantly rural areas (as well as to take advantage of existing infrastructure); end (3) local requirements for the establishment of infrastructure when necessary. Such measures have been implemented with varying degrees of success. Eventual success depends on thorough planning and detailed interfacing with existing authorities end public interest groups. |
| Cultural Considerations | Land-based operations devoted to the development of marine minerals must be implemented with particular consideration given to the unique mores and traditions of the local population. For operations in presentty underdeveloped or undeveloped areas, careful accommodation must be made to permit the introduction of what may be perceived es a radical changes in lifestyle. Local cultures and attitudes are of primary importance in the consideration of land-based operations sites. Further, extensive public education end outreach efforts, though necessary, may not be sufficient to overcome potentially fatal opposition to development. |

Table ES3.1. (Continued).

## ES4.0 SUMMARY OF PREDICTIVE MODELS

Chapter 4 addresses the state-of-the-art and use of mathematical models to predict impacts resulting from marine mining activities. Models for the portrayal of natural dynamic functions have been widely used in forecasting and predicting events and effects. The advent of powerful desktop computers has made these previously expensive tools available to a wide range of users. For the purposes of this analysis, the use of models in marine mining environmental analyses was limited to the study of physical dispersion through the water column and sedimentation on the seabed; air emission, chemical transformation, and demographic processes were considered too site-specific to warrant useful consideration in this analysis. Although numerous sedimenttransport and dispersion models have been devised in recent years, most testing has been via computer simulation. Useful field testing of dispersion models has been limited to less than a dozen separate efforts. Despite these efforts, the predictive capabilities of the present generation of dispersion models is still limited, due to insufficient testing/tuning and the inability to include enough important parameters in sufficient detail to afford accurate predictive results. Typically, the effects of unusual bathymetry cannot be accounted for; only relatively simple flow fields can be accommodated; and the influences of complex shorelines can only crudely be considered. The effects of turbulence on various length scales further complicates the modeling process. The use of eddy diffusivity coefficients which crudely describe complex flows does not provide good near-field predictive capability. Finite element models, with their variable gridding capabilities, are expected to play a greater modeling role in future efforts.

Near-field predictive capability is relatively good in close proximity to a discharge or sediment dump location (i.e., before the full effects of the turbulent flow field occur). Within even a few hundred meters of a discharge, the ability to predict concentrations within an order of magnitude at any particular location becomes limited. If, however, average concentrations are considered within bounded regions increasing in size with increasing distance from the discharge, predictive capability is improved.

Testing of far-field predictive capabilities of dispersion models has been hampered by numerous difficulties, including the need for large numbers of measurements over large spatial and temporal scales. Plumes of suspended material originating from human activity have not been effectively generated on large scales for the purposes of testing dispersion models. The effects of large-scale natural phenomena (e.g., continental rivers, oceanic rivers such as the Gulf Stream, and other mixing processes) have been extensively studied, and provide better source material for empirical far-field studies. Far-field predictive capabilities of sediment transport models are rather poor, with predictive capability degrading with increasing distance from the source. What is considered far-field depends on the context. For typical regional water quality concerns, distances exceeding 15 km are clearly considered far-field. At such distances, with present day models, prediction of concentrations within one to two orders of magnitude is difficult at any chosen location. The development and refinement of water quality criteria and standards for distances greater than 15 km from a discharge will have to be undertaken with considerable caution if reasonable expectations for measurement and compliance are to be met.

The continued development and testing of mathematical models, especially those predicting suspended sediment and dispersion characteristics through the use of finite-difference and finite-element modeling methods, will improve predictive capabilities. Based on the present analysis, it is feasible that reasonable predictions can be made in the near future for certain classes of materials at scales of regional concern.

## ES5.0 SUMMARY OF DATA GAPS, RESEARCH NEEDS, AND RECOMMENDATIONS

Chapter 5 addresses data gaps, research needs, and recommendations in those areas where environmental studies have been described in the literature or of which the authors have a personal knowledge. Discussion focuses on the gaps still apparent in the data and information available from the published literature, and presents recommendations for further work including field studies. There are significant data gaps in the U.S. knowledge base, as indicated by the literature, in the areas of (1) water quality modeling (i.e., the generation and dispersion of particulate and dissolved materials in the water column based on, or at least confirmed by, empirical data acquired from marine mining operations); (2) effects of significant alterations of the seabed on adjacent coastlines; (3) understanding of the characteristics, behavior, and recolonization response of organisms in various mine site areas (e.g., deep seabed, seamounts, guyots, OCS, and coastal) under the stress of production operations; (4) impacts of processing discharges from onshore mines on coastal biota; and (5) understanding the realities of mining in perspective with other natural processes and man-induced activities. Other less significant areas of concern that may not yet have been adequately addressed by research activities have been presented under the respective headings of air quality, water quality, geological resources, biological resources, and socioeconomic concerns.

Substantive principles for resolving marine use conflicts have not been developed by the courts under the public trust doctrine. Related judicial approaches legally separating exploration rights from development rights aids the resolution of marine use management conflicts significantly. These legal approaches to mitigation are of concern to the MMS and should be considered appropriately.

Extensive mathematical and computer programming efforts have been made to predict the dispersive behavior of discharged materials in marine environments. Adequate mathematical and computer-based tools are available. Unfortunately at this time, sufficient field efforts have not been completed to confirm these tools and to adequately discriminate among them.

Priorities for individual research needs at the project level are very subjective. In the long term, however, the authors believe that two major data gaps should be addressed concurrently as a first priority, including (1) the verification of very extensive models that have been developed for plume dispersion; and (2) the opportunity to utilize ongoing operations in areas outside of the U.S. to verify existing models and to develop a database on other environmental needs determined from actual mining operations.

A considerable amount of useful data are available with regard to the environmental effects of marine mining. An adequate collation of these data, particularly in the foreign grey literature has not been possible within the constraints of the present study. At present, there is no global database directed to address these matters. New data are needed to address many specific aspects of concern. In many cases, such data could be acquired at low cost in cooperation with foreign governments and operators. Economic decisions on marine minerals development may be based on the perceived cost of overcoming implied environmental effects which are defined on the basis of supposition rather than measurement. The acquisition of data and information to verify such conceptual models is of the highest importance.

## ES6.0 SUMMARY AND CONCLUSIONS

The primary objective of the study, to examine and analyze the existing literature regarding the environmental impacts of marine mining, has resulted in the disclosure of considerably more written material on this subject than initially expected. At least 10,000 documents are in the public domain, many in the areas of grey literature, and it was suggested that many more would be disclosed, given simpler access to foreign sources. The second objective of the study, to summarize the literature in a single, monograph-style manuscript, was met with the development of the manuscript. The manuscript addressed the literature from several points of view, including environmental considerations, viable mitigation measures, predictive models, and data gaps, research needs, and recommendations.

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