DEPARTMENT OF THE NAVY

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September 26, 2013

Mr. John Greenewald, Jr.
[redacted]

Dear Mr. Greenewald:

The Department of the Navy Freedom of Information Act (FOIA) Office forwarded your FOIA request of August 29, 2013 to this office for review. This responds to such request in which you seek a copy of a document entitled *Global Climate Change, Implications for the United States Navy* created in May, 1990. Your request was received by this office on September 6, 2013 and assigned file number NAVWARCOL 20130008.

The Naval War College has the document in their records which is responsive to your request. We are releasing the document to you in its entirety.

Since the time for searching and the amount of duplication associated with processing your request fall within the amount not chargeable to "all other requestors" under FOIA, the fees associated with the processing of your request are waived in this instance.

If you have any questions regarding your request, please contact Lieutenant Commander Ellen Sharp, JAGC, USN, Naval War College Staff Judge Advocate, at 401-841-2279 or email your inquiry to ellen.sharp@usnwc.edu .

Sincerely,

E. J. SHARP
Lieutenant Commander
Judge Advocate General's Corps,
U.S. Navy
By direction of the Commander

Enclosure: (1) Information Paper

GLOBAL CLIMATE CHANGE
IMPLICATIONS FOR THE UNITED STATES NAVY

by

Mr. Terry P. Kelley

THE UNITED STATES NAVAL WAR COLLEGE
Newport, RI

May 1990

Abstract of

GLOBAL CLIMATE CHANGE

IMPLICATIONS FOR THE UNITED STATES NAVY

Current scientific data and expert opinion is examined to formulate an overview of the significant implications of climate change for the United States Navy. Two of the principle effects of climate change -- sea level rise and thermal heating of the oceans and atmosphere -- present the possibility of significant effects on the facilities, infrastructures and operations of the Navy. Although no conclusive evidence exists to prove global warming as fact, a large body of circumstantial evidence and expert opinion does exist supporting the existence of the phenomena. The impacts posed by these changes in environment are significant enough to warrant serious examination by the Navy. Nearly all areas of operational effectiveness are threatened by these environmental changes should they occur. Suggestions are made toward having the Navy assist in identifying and interpreting the indicators of climate change so as to better define the problem. The paper concludes by recommending specific areas of tasking for Naval components. These recommended actions will assist the Navy in preparing for the effects of climate change upon Navy planning, facilities, and operations.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

GLOBAL CLIMATE CHANGE

IMPLICATIONS FOR THE UNITED STATES NAVY

CHAPTER I

INTRODUCTION

Naval operations in the coming half century may be drastically affected by the impact of global climate change. For the Navy to be fully prepared for operations in this future climate environment, resources of both mind and money must be committed to the problem. The Navy's research and analysis efforts are required to support the sound planning evolution necessary to insure the Navy's capabilities in this future environment.

There is a growing public perception of a decreasing Soviet threat and improving superpower relations. This perception continues to pressure the Congress for reductions in Defense spending - a peace dividend. Reductions in spending require the services to be, at once, more efficient, cost effective, and oriented toward the long-term, while increasingly more competitive for the dwindling resources. A rising tide of public and, therefore, congressional sentiment over a myriad of public policy problems -- budget and trade deficits, the drug war, homelessness, industrial growth, environment -- further highlight the competitive nature of future federal budgets. Demands on resources wrought by future climate change will be tremendously expensive and stressing for all sectors of our nation. Defense, as a whole, and the Navy, in particular, must insure that the policy formulation, planning, and analysis processes adequately address the impact of global climate change before other sectors take precedence in resource allocation matters and public support. The payoff will be a Navy fully capable of required operations in the new environment through less demanding, planned expenditures over a greater period of time rather than massive, unpopular budget requests once the most drastic effects occur.

This paper presents an overview of the mechanisms of global climate change and their related societal effects and addresses, in broad terms, the impacts upon various areas of naval planning. Global warming, as a major feature and driver of climate change, is a complex issue. However, the presentation of information regarding the causes and predicted global consequences of these phenomena is necessary to enable the reader to attain a clear understanding of the gravity of the problem, the potential seriousness of the impact, and the complex difficulties which will be encountered in attempting to address the Navy's long-range plans.

Assumptions have been made in examination of the problem and in presentation of the materials. First, although most scientists who concentrate in this field now agree that global warming is actually occurring, the rate of temperature increase and the predicted amount and rate of sea level rise are still debated. For the purposes of this examination, figures for temperature increase and sea level rise that are generally agreed upon by most scientists are used. Second, descriptions of climate change mechanisms and their predicted effects are couched in terms for the general layman to facilitate readability. The science involved within these mechanisms is highly complex as is the methodology and mathematics of the models used to predict the global climate modifications. Detailed explanations in either of these concerns is beyond the scope of this thesis.

Chapter II is a brief summary discussion of the elements of global climate change and the anticipated major effects or impacts of that change. Chapter III addresses the specific anticipated impacts of global climate change on the Navy's missions, operations, facilities, and systems. Lastly, Chapter IV will present the specific findings of the research.

CHAPTER II

GLOBAL CLIMATE: CHANGE AND IMPACT

A. CLIMATE CHANGE MECHANISMS.

Global warming is the end result of a naturally occurring phenomenom -- the "greenhouse effect" -- accelerated by external processes. Many climatologists and environmental experts attribute these external acceleration processes to man's industrial and agricultural activities.

Briefly stated, the greenhouse effect is a natural atmospheric process whereby certain greenhouse gases -- carbon dioxide, nitrous oxide, methane, CFCs, and tropospheric ozone -- trap a portion of the earth's emitted heat in the lower atmosphere. This trapped heat increases the average global surface temperture by 33 degrees C (60 degrees F), making life on earth possible. Without this additional heating, the average surface temperature would be -19 degrees C (-3 degrees F),[1] rendering the planet uninhabitable.

When this natural process is accelerated, no matter the cause, the effect appears to be a rapid rise (in relation to geologic time) in global average temperature -- global warming. As concentrations of the greenhouse gases rise in the lower atmosphere, there is an increase in the amount of earth emitted heat trapped within the lower atmosphere. This results in an increase in the average surface temperature. Associated with this warming of the lower atmosphere is a cooling of the stratosphere. This cooling is attributable to the increase in heat energy trapped within the lower atmosphere and, therefore, not available for heating of the upper atmosphere. These effects have been observed within the climate data of the last 100 years.

Historically, small changes in the average global temperature occur over thousands of years. During the past century, however, the global average temperature has increased by 0.5 degree C (1 degree F) and shows correlation to the ongoing increases of greenhouse gases in the lower atmosphere. This fact has lead to a near concensus, among those scientists who specialize in climate study, that global warming is underway and will continue for the next twenty to thirty years (Appendix I contains a more detailed description of the global warming mechanism and related atmospheric processes).

B. IMPACT OF CLIMATE CHANGE.

Although many questions are yet to be answered and new findings are emerging almost daily concerning the causes and rates of global warming, there is near concensus on several points.

- The global average temperature has risen 0.5 degrees C (1 degree F) over the past century.
- The rise in global average temperature correlates well with the rise in levels of atmospheric greenhouse gases.
- Man's activities will continue to increase these gas concentrations in the near term at least.
- Over the next half century, the global average temperature may increase by approximately 4 degrees C.
- Over the next half century, sea level may rise by 1.5 ft.
- Storm frequency, intensity, and distribution is likely to increase, especially in the higher latitudes.
- All nations will be affected.

Appendix II is a broad discussion of climate effects both global and on the United States, given a warmer planet. In summary, nearly every aspect of the world's political, cultural, and economic interests will be affected. Basic human needs, such as water supply and quality, food production, and health conditions, are threatened within the developing nations. In some of these nations, such as, Egypt, India, and Bangladesh, major segments of the populations and significant portions of their agricultural capacities exist in low lying areas or along river basins. As the climate changes, sea level rise may well inundate these areas with salt water (especially during severe storm cycles), producing major damage to the economies, health, and quality of life in nations ill equipped to face the challenge. In some low lying coastal nations, large segments of populations may become environmental refugees, stressing neighboring nations' resources and good will by their forced migration to safer ground.

While developed nations possess far greater resources to deal with adaptive measures required by global warming, the impact upon their societies will form a tremendous hardship, forcing difficult choices. In developed nations, such as the United States, tremendous investments are at risk in the coastal regions. Due to the size of many of these investments, and the business base they represent, these nations will have little choice but to invest in their protection.

In the United States, the necessary adaptive measures for response to the environmental threat will be tremendously taxing. Society, at all levels, will be effected. Climate modification may force alterations in agricultural methods and crop distribution, and threaten water supply and quality, safe regional waste management, urban infrastructure, the viability of commerce and industry in many regions, and stress the energy supply of the nation.

Addressing global climate change issues and effects within the United States, will be both politically uncomfortable as well as terribly expensive. The apportionment of national and state resources for use in programs directed toward climate change effects will necessarily drain off other social programs or force the raising of greater revenue. As currently evidenced, the Defense Department's budget remains a tempting target, especially when expenditure requirements are sufficient to threaten politically popular entitlement programs.

To render some idea of the magnitude of the costs associated with climate change, of the magnitude addressed previously and in Appendix II, consider the following highlights.

- EPA economist, James Titus, estimates ten to fifty billion dollars to replace beaches washed away by rising tides[2]

- Between 1972 and 1985, government and industry spent over $350 billion on water quality and flood control[3]

- Over the past decade, the U.S. lost $3 billion yearly in flood damages[4]

- EPA estimates protection of developed areas, from inundation, will cost $111 billion (cumulative 1985 dollars)[5]

- Elevation of beaches, private homes, land, businesses, and roadways, through year 2100, will cost $75 billion (1985 cumulative dollars)[6]

- For the nation, as a whole, coastal protection will cost as much as $300 billion (funded construction of adaptive engineering and protective devices and methods like bulkheads, seawalls, berms, dikes, sand pumping, etc.)7

- Reforestation of traditional timber stocks forced out by warmer temperatures may exceed $400 million per year8

- The Electric Power Institute estimates that for each 1 degree C rise in temperature, generating capacity requirements would be increased by 20 percent9

- At present energy efficiencies, electricity demand required by projected climate changes will require power utility investments in delivery infrastructure of over $250 billion10

To summarize, the EPA's overall estimate for total national expenditures required to address global climate change exceeds $100 billion each year.[11] Investments of this enormity clearly indicate, that should global warming and climate change become a reality and even approach the projected magnitudes discussed previously, the competing budgetary pressures will focus significant pressures on all sectors of government to assist in the mitigating of societal impacts at the expense of many other interests.

CHAPTER III

IMPACT ON THE UNITED STATES NAVY

Thus far the discussion has established five central points. First, there is near scientific concensus that global warming is occurring and will probably achieve a maximum temperature rise of about 4 degrees C in the first half of the coming century. Second, global warming of this magnitude will promote radical changes in the global climate including sea level rise of about 1.5 ft. by about 2060, redistribution of moisture patterns -- especially in the higher latitudes -- and a large-scale increase in storm energy stores within the oceans. Third, climate change, of the magnitude predicted, will affect all nations in one way or another. Everyone would experience some negative impact. Fourth, within the United States government, budgets are shrinking forcing increased competition. Fifth, within the Department of the Navy (DON), there is a significant requirement to consider the effects of global warming and climate change within their long term policy and plans. What are the possible impacts of global warming and climate change on the Navy?

A. PORTS, BASES, AND FACILITIES.

If there exists one area where the impact of global warming and climate change effects are most easily recognized, it would be the Navy's fixed land structures.

Two of the principal climate change effects previously discussed, oceans warming and sea level rise, become the drivers for some of the key factors in shore protection design. In every

Naval port and coastal facility, the environmental design requirements and constraints are governed by these two climate change characteristics. The historic environmental characteristics of the region are used to guide the engineers in planning, construction, and maintenance of naval facilities and supporting infrastructure. The historic record provides the necessary data on the occurance of storms of various intensities (the ten, twenty,...one hundred year storm), wave height occurance, bottom type, depths, slope, etc., which are required by coastal engineers to design effective protective devices. From this data, the engineer develops designs unique to the geographical situation and its environment.

Ocean warming provides an increase in potential energy for storm generation and growth. A specific structural design developed for a particular storm environment might see that environment radically altered, thus rendering the original design incompetent for the new set of conditions. For example, a breakwater whose toe depth, width at base, height, etc., was designed relative to a 20 year storm intensity could, under projected global heating conditions, see those storm intensities occur every 10 years. The resultant increases in erosion, overtopping and wave shock and vibration forces would exceed the design life criteria much sooner than desired. Effects of this nature will become much more frequent and intense with only a slightly warmer sea.

Major storm systems -- hurricanes and typhoons -- would occur over a longer season, at a higher rate of occurrance, and at increased intensity, especially in the higher latitudes. Coupled with a rise in sea level, surge heights -- the water pushed up ahead of a storm's passage -- will be significantly increased. Under these new storm conditions, the wave action and surge effects will produce significantly higher rates of erosion and scour. (Scour is the removal of the topmost sediment layer by the hydrodynamic forces of the water.) Under the worst projected storm conditions, the much higher wind velocities and the increase in surge heights will hold at risk nearly all existing structures and protective devices.

For Naval facilities, this increases the risk inherent to the design of each facility. At highest risk are those facilities located in coastal flood plains and wetland areas or those at or very near oceanside. Increases in storm surge and general wave energy will increase rates of channel scour and/or fill, thus increasing the frequency of required dredging and channel maintenance activities. Piers, seawalls, berms, revetments, breakwaters and all other hard protective structures will have to be reexamined in terms of new storm parameters. With projected wind velocities increased to over 220 mph for a fully generated storm, the current design criteria for storm design and wind loading will become obsolete. The buildings and structures of every facility will have to be constructed/reinforced to more stringent wind and flood design requirements. (This effort may involve extensive retrofit for structures deemed inadequate or unsafe.)

Sea level rise will cause a gradual inundation of coastal wetlands and other low lying areas. Deeper water depths will reduce the effectiveness of protective structures such as surge barrier gates, seawalls, levees and dikes. Docking facilities will have increased requirements for piling size, depth and load bearing and possibly additional pier height (dependent on ship size and utility).

In some areas, the high water mark could move inland as much as 200 miles. The supporting infrastructures which serve each facility would come under stress. Service and access roadbeds may have to be raised. Bridge heights may have to be modified. Fresh water supply, storm drainage capacity, and sewer treatment handling facilities may need modification or relocation. Railroad beds may need to be raised or modified, and the drainage load capacity will have to be examined for each facility.

For some low-lying coastal facilities, the implications are enormous both in terms of the effects upon the facilities and in the costs of adapting the facilities for effective, safe operations. For facilities, such as King's Bay, Ga., Pascagoula, Ms., New Orleans, La., San Diego, Ca., or Little Creek, Va., climate changes of the projected magnitudes will cause major adaptive stress, and in some instances, consideration of abandonment. Economists at the EPA have estimated that the Port of New Orleans and the lower lying, adjacent areas of the city may have to be abandoned and relocated.[1] This is partially due to initial low-lying conditions, but also attributable to the subsidence of the underlying geologic plate. Some geologists feel that this area of the Gulf coast will be inundated due to subsidence alone, regardless of any global warming.

For other facilities, such as Newport, RI, or Bremerton, Wa., the threat is not as severe. In certain northern latitudes of the United States and Canada, the continental geological plates are still in rebound from the last great ice age, when trillions of tons of ice crushed them down. Now, free of the ice load, they are, and have been, in a state of rebound. This fact, coupled with the physical positioning of the site relative to the harbor structure, topography, and ocean, make them less vulnerable to changes in sea level.

Appendix III is an excerpt from a study conducted by the Army Corp of Engineers and is presented to illustrate the type of analysis (albeit incomplete) required, for each individual site, to anticipate the impact of global climate change. The citation presents a generic case study for the mythical city of Risingsea under threat from climate change effects. The case, while fictional, is appropriate to this paper for three reasons. First, the generic case presents a reasoned, engineering approach for examining the impacts of climate change phenomena on a particular coastal area with specific facilities. As the Army Corp of Engineers are the recognized experts in coastal and hydraulic engineering, examination of their methodology and approach is one of the best resources available. Second, the analysis methodology, demonstrated within the generic case, may be applied effectively to any required naval facility study. The tools used to generate the generic case study, develop the coastal engineering design standards into computer aided design programs. Third, the case demonstrates the range of impacts upon typical port facilities and support infrastructure and lends insight to the kinds of data and modeling required by future planners.

Current facility planning documents exist as individual planning documents, or Master Plans, for each facility. They are limited to the period of the Six Year Development Plan (SYDP) plus some unspecified time period and are of specifically tailored scope. The plan is meant to provide input to the POM process for the individual facility.[2] Currently, **there is not a long range (20 years +) plan which addresses the projected risk and possible adaptive engineering changes to each naval facility required by climate impact.**

Global climate change and its effect is not the only consideration of such a plan. In the restrictive budget climate of the times it makes good business sense for the Navy to address its facility needs in an integrated, long-range, and comprehensive method. This type of plan would systematically address issues such as:

- Identification of facilities whose existence or effectiveness is at great risk (from all factors including climate)
- Criticallity of facility location and function
- Consolidation of facilities and their various functions to optimize their utility
- Requirements for self sufficiency and/or degree of dependancy on the surrounding public and private sector services
- Acceptable levels of vulnerability of the facility and the supporting public infrastructures to external influences including climate modification

Once the long-term plan is established and the grouping of critical facilities identified, individual plans for the facilities should be developed. The facility plans should be larger in scope than the satisfaction of SYDP and POM requirements. Each should address the comprehensive long-term requirements and risks for its facility. Each plan should be developed to produce feedback to the integrated master plan so as to produce a consolidated listing of construction requirements and recommendations, cost data, risk assessment, private/public sector interdependancies, and supporting rationale. Each facility, given its identification as critical and its mission requirements would:

- Translate the facility mission into requirements for structures, dockage, pierage, storage, bunkering, channeling and navigation aids, living quarters, support facilities, maintenance, etc.
- Identify the dependencies of the facility on external support and infrastructure
- Identify the vulnerabilities of both internal structure and external support and infrastructures to environmental influence
- Assess the risk involved and criteria for the facility to mitigate or minimize that risk
- Develop regionally oriented design criteria for the above requirements based on most the likely projected environmental conditions
- Provide cost projections, program and construction schedules, to integrated Facilities Command plan
- Provide for periodic reexamination of environmental projections within the plans and resubmissions to higher authority

The individual plans must be oriented to the specific region of the facility due to the variability of climate effects from region to region. In the future, just as now, the design standards for structures in Florida, California, and Rhode Island will be very different. New information is being uncovered each year and allows for refinement of predictive models. Thus, **the Navy's facility planning should be updated on a regular basis to reflect the changing projections.**

B. OPERATIONS.

Nearly every naval operation is dependent on some aspect of the environment, which either improves or degrades effectiveness. Projected climate changes will lead to modifications of the operational and systems environments across the entire battle volume. Climate change effects on naval operations may be viewed as dependent sets of three change mechanisms -- surface and low atmospheric heating, storm intensity increase, and sea level rise. Each specific projected impact will be attributable to one or more of these three forcing mechanisms. As addressed below, the projected changes in the ocean's physical characteristics, driving mechanisms, and physical coastal and open ocean effects, are derived from one or more of the forcing mechanisms of climate change.

Ocean's Physical Characteristics.

The design and effective operation of many naval systems is based on certain physical characteristics of the ocean volume. A large amount of resources are expended each year to gain a more complete understanding of the interactions of these characteristics, their driving processes, and predictive limitations. All of this is done to enhance the effectiveness of naval warfare systems.

Salinity and temperature, as well as the general ocean chemistry, for a given volume are key factors in acoustic system performance and performance prediction. Modification of these factors alters the performance expectations of the system. In the projected greenhouse world, the general temperature of the oceans may rise by as much as 4 degrees C. This type of general increase in ocean temperature may lead to radically different patterns of ocean surface current generation, changes in biological distribution and production levels, and changes in the sound velocity profile to some degree in nearly all areas of the oceans. Chemistry changes, especially in the amount and distributions of magnesium salts and boric acid -- the principle determinants of acoustic absorption in seawater -- could lead to higher than expected transmission losses (TL).[3] Changes in biological production effect both the antennuation and the ambient noise or background noise levels within the sea.

There are benefits for the Navy in global warming. The projections as to the extent and duration of the Arctic ice cover indicate a radically different operational environment. The northern polar ice sheet may recede extensively leaving much larger areas of clear water, scattered broken ice, and fewer and more shallow ice keels. (Ice masses moving together push pressure ridges both up and down. Beneath the ice cap these ridges are referred to as keels.) Fewer false targets to active sonar prosecution, more effective submarine on submarine engagement expectations, as well as a less hospitable environment for hiding and operating ballistic missile submarines may result.

At the present time, there is no general agreement as to the projected rate or amount of change in ocean chemistry or biological production and distribution due to climate change. Some changes in ocean chemistry can be anticipated in the far northern and far southern latitudes based on climate conditions projected for these areas. A large scale retreat of the northern icepack is anticipated. This, coupled with atmospheric warming, would increase the glacial melt and runoff as well as melt from the icepack. This would seem to lead to a large regional influx of freshwater in the far northern areas. The surface freshwater layer may occur deeper and over a larger expanse of the northern area seas.

Coupled with more extensive mixing, the freshwater influx in the high northern latitudes may result in altered sonar performance expectations. This would be especially true in areas where the mixed layer does not reach bottom and/or additional thermal layers exist. All of the above effects imply a strong need for real time linkage of sonar systems processors to highly accurate environmental measurement devices. **Systems employment and search doctrine may need modification to compensate for areas where radically different water layers may exist.**

Ocean Mechanisms.

Heating of the oceans and the atmosphere should lead to changes in the location, distribution and circulation patterns of the ocean's surface currents. The surface currents derive their character from the surface winds and land masses. With the southern polar ice cap increasing in size, the northern cap decreasing, and general atmospheric and ocean warming trends increasing the wind velocity capacity, shifting of the ocean surface and geostrophic currents would be expected. The resultant ocean surface current speed is only one to two percent of the wind speed acting on the surface.[4] If wind velocities, in general, increase, a corresponding increase in the surface current speed can be anticipated. This speed increase will tend to intensify the turbulent flow environment of the currents thus intensifying eddy generation effects.

The creation of stronger mixing and intensified eddy generation is worth something in tactical utility. Submarines today use natural boundaries or differences in the water volume as barriers to prevent prosecution. In a more energetic and turbulent ocean environment, **it may be possible to acheive significant tactical advantage, especially in ocean and area transit, by precisely tracking on the edge of these turbulent phenomena.** Again, this will require precise water column sensing tools and real time linkage of data to the submarine's navigation capability.

An increase in general storm intensity, frequency, and duration will produce another set of operational limitations. In this environment, changes in the mixing layer depth can be anticipated. Currently the surface mixed layer extends to around 200 meters at midlatitude winter and very near to bottom in the arctic winter. The predominant driver for mixing is the wind. Therefore, increased wind activity due to warming should lead to a deeper mixed layer in the oceans. The extent of these changes will be dependent on wind velocity, fetch distance and duration, changes in ice formation cycles, and changes in ocean circulation patterns.

Storm intensity modification of the ocean's surface layer will also raise the ambient or background noise. This particular form of noise is derived partially from the wave turbulant impact at the surface, partially from wind flow generation over the rough sea surface, and partially from cavitation (the collapse of air bubbles caused by turbulent wave action). Increases in levels of this nuisance noise source would be consistent with a more turbulent and energetic ocean. Ambient noise sources degrade passive sensor performance over much of the frequency spectrum.[5]

As storm energies increase, they will pose serious implications for both naval vessels and their associated equipments. All equipment, intended for use at sea, is designed to account for the oceans' vibratory and shock environment. The design criteria for systems exposed to the splash zone, seawater immersion, environmental shock, fatigue stresses, and vibratory ocillilation, attempts to account for the stresses placed on systems operated in an ocean environment.

Projected climate conditions not only anticipate a much more energetic sea throughout the year but major storm intensities which may be capable of producing winds of 220 mph or better. Depending on pressures, fetch distance, duration, etc., the generated seas, waveheights and winds could exceed system design parameters.

Significant changes in frequency, duration, and intensity in the ocean ocillatory environment would increase environmental design requirements of both the ship's exposed equipment and of the vessel itself. To appreciate the scope of the design problem, consider that current equipments are designed for a certain life cycle of environmental stress. If the sea is projected to be, in general, 40 to 50 percent more energetic, then most equipment would exceed life cycle stress standards sooner than expected. Mean Time Between Failure would also be expected to decrease causing more frequent down time and repair support. **The development and maintenance of a new miltary specification (MIL-SPEC) for environmental design will be required to keep pace with climate change.**

Corrosion control problems for all marine structures should increase in this type of environment. In a marine environment, the chief elements of structural corrosion are seawater (the electrolyte) and oxygen. A piece of steel, totally immersed, below the mixed layer will have a lower corrosion rate than the same material at a location at or very near mean water level. This difference is due to the amount of oxygen available to the surface being exposed to seawater. This area of a marine structure is known as the splash zone -- that area of a structure which is exposed to fairly continuous wetting in an oxygen rich environment. The splash zone is the most critical area of protection because of alternate submergence and aeration. The splash zone area usually extends vertically down into the mixed surface layer and upward above the mean water level for some distance, dependent on local tidal conditions and nominal waveheight. A more energetic sea would increase the size of the splash zone or wetted area, thus, increasing corrosion control design requirements.

Corrosion control impacts every marine structure. **The potential corrosion control problems may require new classes of coatings and coating applications techniques.** Active and passive cathodic protection as well as new materials technologies are all possibilities in compensating for corrosion. For the Navy, there are obvious areas of concern -- ship's and ship's systems, anchor chains, buoy design, etc. Other areas of concern would be any structure which depends on ferris components for design strength and integrity (piers, docks/drydocks, cargo handling facilities and equipment, etc.).

In certain areas of the world, the impact of rough water on operational effectiveness and safety is already being experienced. In a fairly recent NATO fleet exercise, five ships were severely damaged and removed from participation through collision and grounding incidents. These losses were directly attributable to the attempted execution of amphibious support operations in rough waters. **Safe and effective performance of naval vessels in rough water will become increasingly necessary in the future, if climate change is realized.** As the energy of the oceans and the duration of storm seasons increase, naval forces will encounter rough water conditions throughout a much longer period of the year and over a larger portion of the ocean.

Sea Level Rise

Rapid sea level rise provides another set of operational risks. The increase in sea level is due, in part, to the thermal expansion of the oceans from heating (about 25 percent) and to the glacial and northern icepack melt and runoff. An increase of this magnitude may not seem significant, however; for many coastal nations, large areas of their territory are below 3 feet. In the case of Bangledesh, 80 percent of the nation is below 3 ft. and a 1.5 - 2 ft. rise in sea level could inundate almost one-half of their territory. Several island nations, such as the Maldives and the Marshalls, are in jeopardy of being submerged completely. In the United States, significant portions of territory would be subject to inundation. The topography and bathemetry of the planet's coastal areas will undergo dramatic change in a relatively short period of time.

Changes in coastal topography and features will greatly increase the workload of mapping agencies. If the rate of change becomes as rapid as predicted by climatologists, inundation will quickly (50 - 80 yrs) and continually modify the coastal contours of the world. This rapid change will create a tremendous challenge to the various mapping agencies to keep pace with change and deliver quality products.

The effects on naval operations from this inundation apply primarily to the targeting of effected operations areas. As the coastal plains of target nations are inundated, large expanses of very shallow water (from 36 ft. of depth to the high water mark) are created. For a considerable amount of time, any inundated forest or mangrove area will become an area of partially submerged beach obstacles with perhaps large areas of water up to 1 ft. in depth behind them.

As time goes on, the increased energies of the ocean, coupled with the rise in water level will increase erosion rates. Transport of erosion materials may create significant sediment bar deposits offshore using the transported erosion material. This situation also effects harbor facilities which are bounded by transportable sediments and sand beaches. As the oceans energy and the mean sea level increases, the littoral drift of this material (down beach transport of material due to edge wave phenomena) will increase, posing channel and route maintenance problems for the effected harbor.

The increase in wave energy and sea level will tend to increase the beach's slope angle up to the high water mark. This type of erosion tends to scoop out the sand from the waterside of the beach and deposit it offshore in a bar deposit. As time goes on the angle of the beach slope may exceed the design slope of some vehicles such as the Landing Craft Air-Cushion (LCAC).

The erosion effects generally will increase the water depth from the surf zone to the first bar. This change in bathymetry creates several problems for naval forces. For an assault force, the face slope of the beach above high water may exceed the design flight envelope of the LCAC requiring rerouting or other disruptions in the assault. The deeper water between the surf zone and the bar allows more enemy flexibility in mine field planning, thus complicating attack planning. The existence of the bar(s) would have an impact on target beach selection since the transport of the follow-on and sustaining echelons need to be placed on the beach via larger vessels.

Lastly, the inundation of more protected areas where assault might be considered may create natural beach obstacles as described before. These obstacles would take valuable time to destroy. Time is a limited commodity in the modern over-the-horizon assault concept. In many areas, even though only a foot to a foot and one half of water covers the target area, the beach may not be trafficable. Many of these areas, prior to inundation, tend to exist as peat bogs or heavy humus which turns to a thick mire when immersed and thus, are not easily trafficable.

One final operational consideration is the effects of changes in atmospheric temperature and chemistry on communications. The addition of higher levels of ionizing gases and particles at different atmospheric intervals coupled with an increase in the temperature difference between lower atmospheric heating and upper atmospheric cooling will change the nature of the propagation medium for frequencies in the upper low frequency, medium frequency, and high frequency bands. The range performance of these systems is particularly susceptable to ionization effects while other bands are far less vulnerable.

CHAPTER VI

CONCLUSIONS/RECOMMENDATIONS

Global climate change poses a multifaceted challenge to the Navy over the next half-century. This challenge will impact naval operations, facilities, and systems, and effect resource allocations.

Recent estimates have put the total yearly expenditures for global climate change adaptations at well over $100 billion (not considering large investment amounts from the private sector). The level of required funding and the basic quality of life issues involved would pressure Congress to further favor internal public policy issues over defense. It is, therefore, essential for the Navy to assess the impact of climate change on its own resource requirements and then determine the required "bottom line" allocation needs to guarantee a successful long-term investment strategy in light of that impact.

CONCLUSION: There is no single irrefutable statement that confirms global warming as fact or demonstrates linkage between man and global warming. There is however, a proponderance of scientific data which shows that a warming trend is occurring. That it is occurring at a record rate and shows correlation with historic warming trends and greenhouse concentrations, is evidence enough to warrant serious concern.

CONCLUSION: Currently, there is a concensus amoung leading climatologists that global warming is occurring, and will continue due to man's contributions to the greenhouse gases. Further concensus indicates a warming of oceans and atmosphere of around 4 degree C and a sea level rise of about 1.5 feet. The seriousness of the impacts of these changes, should they occur, warrant Navy management concern and oversight.

RECOMMENDATION: The Navy should place itself at the lead for DOD in supporting research and analysis of the suspected problem. The impact upon the Navy's operations and assets will be far greater than any other segment of DOD. The Navy's oceanographic assets should be tasked to assist in a coordinated federal program to:

o Define the critical indicators in the oceanic and atmospheric environment that will provide a definitive answer as to whether global warming is occurring, the rate of occurrance, and the end points of the process.

o Provide coordinated access to oceanographic and meteorologic data bases available at Fleet Numerical Center.

o Assist civilian research agencies in defining the ocean processes in terms of global circulation and recurrent phenomena for input to the supercomputer modeling effort.

o Assist with collection of needed data as concurrent part of force mission on not to interfere basis.

CONCLUSION: The current projected climate change poses significant risk to navy facilities. Until such time as definitive evidence is available, however, reaction should be limited to steps which make equally good business sense. Current facility plans are focused on the SYDP and are not concerned with far-term outlooks. There is an existing need to articulate in one plan the issues of base criticality, vulnerability, mission requirements, public interaction, etc., under a single span of control. In the current base closure and budget trimming environment a single, consolidated, long-range plan is needed.

RECOMMENDATION: The Navy, coordinating with DOD, should examine the criticality of its facilities, both at home and abroad, to develop a ranked priority listing of those facilities by their strategic and operational importance. Concurrently, DOD should be urged to apply every pressure necessary to gain full control over defense facilities and streamline them to those of true military and strategic importance. Finally, the Navy should strive to reduce its facilities and infrastructure to the essential units required to fulfill Navy tasking. All methods -- shared Joint facilities, where applicable, consolidation of activities, expansion of current essential sites to house an enlarged scope of functions -- should be examined in order to produce a cost effective, minimum essential listing.

RECOMMENDATION: Once the critical "must survive" bases are identified, the Naval Facilities Engineering Command should develop a 20 year plus integrated facilities master plan to consolidate and plan for effective investment and technology strategies. As detailed within Chapter III, the plan would pull together the individual facility's needs and optimize allocation of resources to meet those needs. The focus should be on a top-down planning approach to ensure the maximum effectiveness of the force in accomplishing its mission.

RECOMMENDATION: All future base construction should consider the threat posed by climate change in the design considerations of new facilities. The concensus data, as derived via the Global Circulation Models, could be used as the conservative baseline or as input to derive the safety factor of the design.

RECOMMENDATION: The Office of Naval Research, through its foreign evaluation teams should be tasked to gather information and lessons from some of the more innovative adaptive techniques used in ongoing projects in the Netherlands.

CONCLUSION: ASW sensor performance and employment doctrine may be modified by climate change phenomena. In the far northern latitudes, changes in salinity and temperature would modify the SVP, increase transmission losses, and shorten ranges. Increases in ambient noise may cause significant interference with passive prosecution methods. The under ice submarine scenario, while being very tough in the beginning, would eventually yield an environment not unlike other areas of the world once the ice cap has receded. Until that time, ambient noise from wave slap, ice scrape and ice melt void popping would be detrimental.

RECOMMENDATION: Once definitive evidence is uncovered, the systems commands should define the extent of impacts from climate change predictions on ASW sensor performance. From this effort, plans can be developed to maintain capabilities in the face of rapid climate change and accompanying modification of the ocean environment. The push to link ocean environmental data to real time operations, should be continued and modified as the emerging data dictates.

CONCLUSION: Current ship designs use historic sea condition data to describe environmental limitations on the designs. The predicted environmental conditions of global warming will stress or exceed the current designs.

RECOMMENDATION: The Naval Sea Systems command should investigate required environmental design standards to insure all future ship designs consider the predicted environmental conditions within their specifications, should definitive evidence emerge. These new specifications must extend to all essential equipment and must translate the predicted ocean characteristics changes into definitive environmental design requirements for shock, vibration, and thermal conditions. Modifications to the existing preventative maintenance requirements should also be anticipated.

CONCLUSION: All supporting combat systems will be effected by the predicted climate changes. All weathered equipment will be subject to shock, vibration, spray, and immersion conditions which may exceed their design requirements. Certain top heavy and/or large cross-section equipment may encounter conditions which exceed their design requirements.

RECOMMENDATION: Systems commands must ensure that projected environmental conditions are accounted for in the designs of new equipment. In cases where the predicted conditions could arrive before the expected end of equipment life cycle, engineering changes should be instituted to ensure the equipment's combat readiness throughout its lifecycle.

CONCLUSION: Rapid rise in sea level will greatly expand the very shallow water regions of the worlds coastal areas. These new areas will consist of inundated wetlands, mangroves, and low-lying, sometimes forested, coastal areas. These expanded regions of coastal shallow water will extend some target beaches 100 km inland. There is no current method for remote determination of the viability of prospective assault beaches.(use of SEALS for this mission poses risk in loss of surprise and exposure) There are no mapping data or products of sufficient resolution -- three feet or less -- for topographic assault determination. The data used in the construction of maps and charts exists in varying formats and media and is not readily usable to produce merged products.

RECOMMENDATION: The Defense Mapping Agency should be allocated sufficient assets to produce high resolution products direct to the user. On-line systems should be considered as well as optical database products compatible with emerging tactical computer decision aides.

RECOMMENDATION: Once global warming is confirmed and sufficient data exists to better determine rates and end effects, the Naval Coastal Systems Center should be tasked, to direct a survey and support program for the determination of viable assault beaches. Such a survey would entail prioritizing a listing of probable target countries, conducting mission analysis efforts to determine possible assault beaches, and then applying an inexpensive and rapid methodology to determine if the subject beach is viable for assault.

RECOMMENDATION: Doctrine for the amphibious assault must be reexamined in light of global climate change. Assumptions as to the required parameters for both the first wave and follow-on forces will be challenged by the new environmental conditions. Some target beaches may be fronted by many kilometers of very shallow water, limiting the size and type of vessels approaching close to shore. Required lengths of causeways and support structures for debarking heavy armor and support equipment may change.

CONCLUSION: Atmospheric characteristics will change dramatically over the next fifty years. Changes may include modifications to atmospheric chemistry sufficient to effect ionization layering and intensity. This could degrade several types of long-haul communications.

RECOMMENDATION: Support operations, such as C3I, depend heavily on certain environmental characteristics for optimal operation. Studies should be developed to determine the effects on the various atmospherically dependent support operations. These should fully address both tactical and strategic support operations.

Approximately 2500 years ago, the ancient Mesopotamians were faced with their own environmental crisis. For years, their agricultural land had utilized the salty waters of the Euprates and Tigris rivers to irrigate their lands. Over the years, the land became poisoned as the salt content increased. When faced with this threat, these people simply abandoned their land and moved to another spot. They abandoned Babylon as being a cost effective solution to their problem.

Today, the coastal regions and cities are again under threat by the seas. The countries and cities of today, however, are much less able to just move inland than in past centuries or even recent decades. The investments and basis of the culture is much broader and more directly linked to the geographic location than before. Today, however, there exists the ability to see the indicators and better recognize them for what they are. We also have the scientific and engineering talents to find adaptive solutions.

The Navy must take advantage of these gifts and ready itself to enter the next century. The security of the nation and its influence abroad depend on a strong Navy and the ability to use that force when and where necessary. That ability is under threat from the very environment which spawned it.

APPENDIX I

ELEMENTS OF CLIMATE CHANGE

A. THE MECHANISM.

Global climate is the result of complex interactions among the many elements of the planetary climate system. The oceans, atmosphere, land, water bodies, ice and snow cover, and both marine and land biota are all connected via complex systems of feedbacks and dependencies. Normally, changes of even small magnitude occur over thousands or tens of thousands of years. This, heretofore, slow rate of change is the key concern for scientists who voice alarm over rapid warming of the earth's atmosphere. Warming of about 0.5 degree C (1 degree F) has occurred over the past century. This change would naturally occur over a span of hundreds to thousands of years.[1] Dr. John S. Hoffman, the Director of the Environmental Protection Agency's Global Atmospheric Program, put it best for the New York Times, when he said, "...we may be moving through an entire geological epoch in a single century."[2]

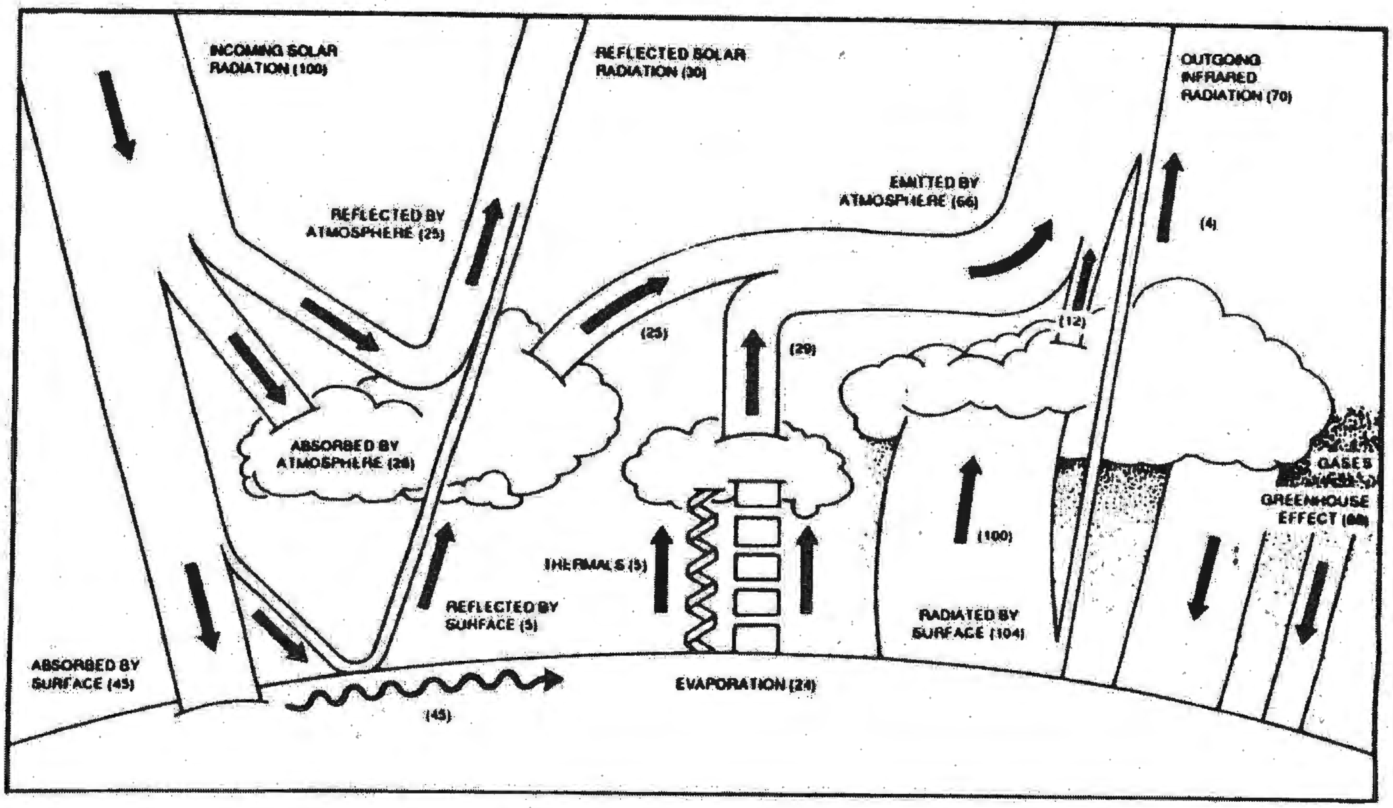
The greenhouse effect has become the popular phrase used to describe the gradual heating of the planet's atmosphere due to increases in heat-trapping gases such as carbon dioxide and methane. These gases and other trace elements allow the lower atmosphere to act much as the glass panels on a greenhouse, allowing heat to enter but preventing some of it from returning to space. In fact, the greenhouse effect is a naturally occuring function of the atmosphere that allows for the existence of life on earth. Without this natural process, the planet would become a frozen ball of ice.

The earth's climate is driven by the sun. Therefore, the greenhouse effect is primarily an effect of solar radiation balance. The sun constantly bathes the Earth in multispectral energies, mostly in the spectrum of ultraviolet, visible, and near-ultraviolet wavelengths. This short wavelength radiation delivers about 1,370 watts of radiant power to the earth's atmosphere. This value is known as the solar constant. (actually this value is not a constant but varies some tenths of a percent over the eleven year solar fluctuation period or sunspot cycle.) The earth is not a flat disk of fixed diameter and area. It is, instead, a rotating sphere of roughly four times that surface area. Therefore, the energy available for delivery to the earth's surface is one-fourth of the solar constant or approximately 340 watts per square meter. This arrival energy is 100 percent of the arrival energy depicted in Figure 1. (The numbers in parentheses are percentages of the total incoming energy and not watts per square meter.)

As this energy travels through the upper atmosphere, the ozone content filters out only the shortest wavelength ultraviolet radiation. Due to the chemical properties of the gases in the atmosphere and the short wavelength characteristics of the arrival energy, the majority of solar radiation passes through the atmosphere. Of the total solar energy arriving at the earth's atmospheric margin, about 25 percent is reflected back to space by atmospheric properties -- for the most part, clouds. The atmospheric gases and particles absorb another 25 percent, while approximately 5 percent is reflected by various surface features such as deserts and ice fields. The remaining 45 percent of the incoming energy is absorbed by the surface of

FIGURE 1

GLOBAL ENERGY BALANCE



Source: Schnieder, Stephen; <u>Global Warming: Are We Entering The Greenhouse Century?</u>; Sierra Club Books.

the planet.

Like all bodies whose temperatures are above absolute zero, the earth radiates its heat to the near absolute zero of space. However, radiation wavelength is inversely proportional to the temperature of the body. (That is, the colder the body, less energy per unit area is given off and the longer the wavelength of the resultant radiation.) The short-wavelength energy heats the surface and is then re-radiated as long-wave infrared energy. However, the lower atmosphere is no longer transparent to this long-wave radiation. In the lower atmosphere, there exists a few trace gases which, while composing only a few percent of the total makeup of the atmosphere, possess a significant ability to absorb long-wave infrared energy.

Referring to Figure 1, the radiation emission from the planet to space is different than that of the incoming radiation to the earth due to both a change in the properties of the outgoing radiation and the way the atmospheric trace gases act upon the outgoing energy. Dr. Veerabhadran Ramanathan, of the University of Chicago, has measured the outgoing infrared radiation as seen from space by sensors on orbiting satellites.[3] His team measured energy equivalent to 240 watts per square meter being radiated up from the planet, or approximately the 340 watts of solar constant radiation minus the 30 percent of solar reflected radiation. This shows that the earth is in an approximate energy equilibrium and confirms why temperature change is relatively slow.

As mentioned before, all bodies not at absolute zero radiate energy to their surroundings. If the average equivalent temperature of the earth is calculated, based on the emitted 240 watts per square meter over the 500 trillion square meters of the planet's surface, the resultant temperature would be representative of a body whose temperature is -19 degrees C (-3 degrees F). However, if we compute an average temperature based on surface measurement, corrected for measurement and instrument placement error, we find the observed temperature to be 14 degrees C (57 degrees F). This difference of 33 degrees C (60 degrees F) is due to the greenhouse effect.[4]

The solar heat absorbed by the earth's surface is given back to the atmosphere through the evaporation of water, convective heating of the air by the warm surface (thermals), and by the emission of 104 units of infrared energy (see Figure 1). However, the greenhouse gases and particles (mostly suspended water droplets) absorb infrared energy, trapping most of this heat before it escapes. The major greenhouse gases -- water vapor, carbon dioxide, methane, and chlorofluorocarbons -- are composed of molecules having more than two atoms and, like all gases having more than two atoms in their molecule, have an inherent capability to absorb infrared radiation. These gases and particles also re-radiate this trapped heat in all directions, some upwards (about 12 percent) and the rest back toward the planet. This re-radiation toward the planet provides the additional 33 degrees C (60 degrees F) needed to balance the observational data and make earth habitable.[5]

That this greenhouse effect is occurring is not a matter of debate. It is fact supported by millions of measurements over many years. The greenhouse effect is understood and accepted by all informed scientists. The cause of debate is to what extent man's activities have altered the atmospheric chemistry, the effects of those alterations on the climate, and at what rate these alterations and effects might occur.

B. GREENHOUSE GASES AND CLIMATE CHANGE.

In 1896, the Swedish physicist and chemist, August Arrhenius, published his calculations on the relationship between atmospheric carbon dioxide and global increases in temperature. Arrhenius calculated that a doubling of atmospheric carbon dioxide would lead to a rise in the global average temperature of about 4 degrees C.[6] More recently, research of both short-term and long-term atmospheric carbon dioxide levels have revealed a significant link between the amount of carbon dioxide in the atmosphere and the average global temperature.

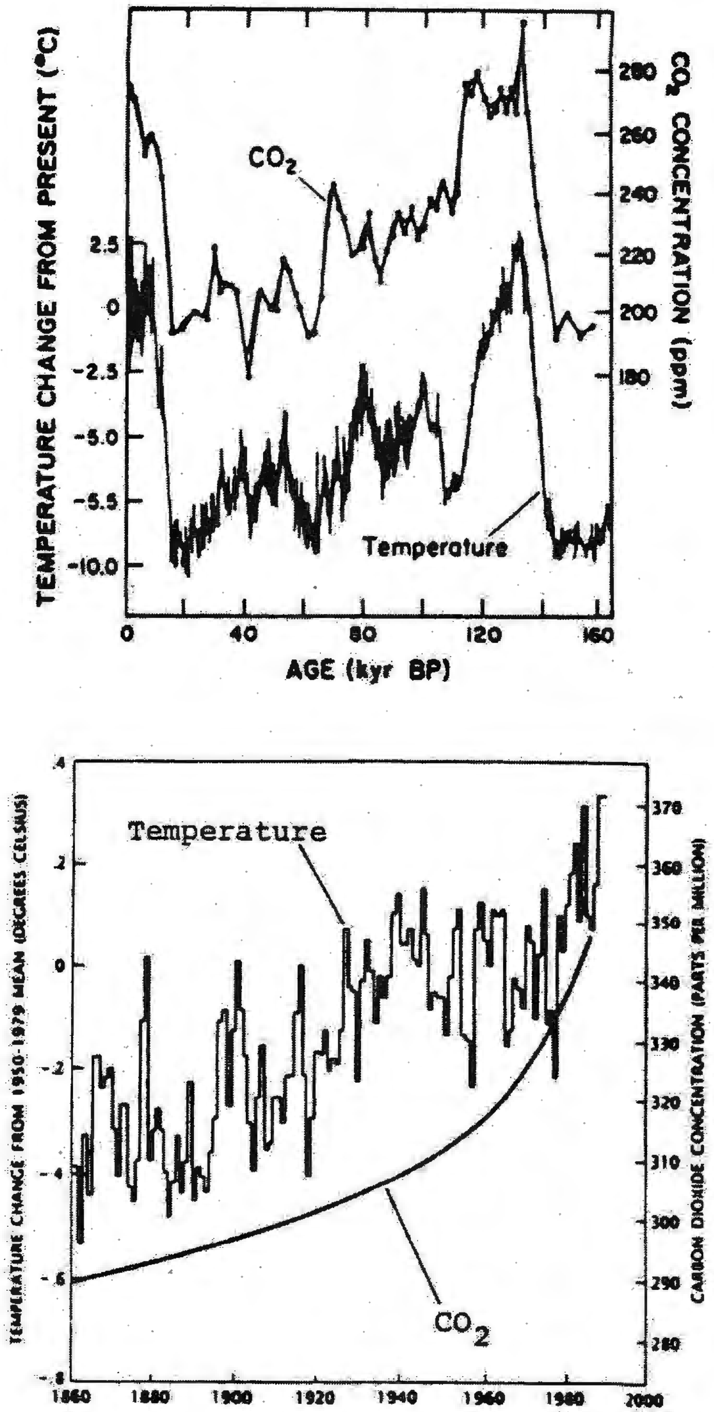
In the short-term study, Dr. Charles D. Keeling at the Scripps Institute of Oceanography, set up continuous measurement of atmospheric carbon dioxide at the observatory atop the extinct volcano Mauna Loa in Hawaii in 1958. The site is built upon a bed of frozen black lava and was chosen because the site would induce no error into the measurements. The level has been monitored 24 hours a day for over 30 years and forms the most complete short-term record to date.

The long-term studies were conducted by analyzing air bubbles trapped within ice cores obtained in deep core drilling projects in the Antarctica. Year after year, new snowfall is laid down, compacted, and turned to ice. When snow turns to ice, it traps about 10 percent of its volume of air. Thus, when a core is obtained from these immensely thick ice sheets, the climate history of the region is obtained. According to Dr. Richard B. Alley at Penn State University, ice core data is the only known method for obtaining information on the atmospheric chemistry for time periods prior to 1940.[7] To date, the richest study, in terms of data, is the Vostok drill hole in east Antarctica. In 1985, the Soviet group extracted an ice core of more than two kilometers, representing 160,000 years of climate history.

The two studies, represented in Figure 2, make apparent the close correlation of temperature change and atmospheric carbon dioxide levels over the past 160,000 years. Since the mid 1800's, carbon dioxide levels have been increasing at an exponential rate. The Mauna Loa data shows that atmospheric carbon dioxide increased from 315 parts per million (ppm), in 1958 to its present value of nearly 355 ppm. By examining ice core data, we can see a low of less that 200 ppm atmospheric carbon dioxide at the end of the last ice age -- some 18,000 years ago. By extrapolating the curve of atmospheric carbon dioxide through the year 2000, we can visualize the temperature/carbon dioxide picture in 2030, when some scientists estimate the carbon dioxide level in the atmosphere will have reached 600 ppm, or approximately double the 1900 level. One of

FIGURE 2

TEMPERATURE/CARBON DIOXIDE CORRELATION



Source: Schnieder, Stephen; "The Changing Climate". Scientific American, Sept. 89.

the most worrisome features of this analysis of carbon dioxide trends is best vocalized by Ralph Cicerone of the National Center for Atmospheric Research (NCAR). "Now this is the point: In all of recorded history, in the sense that we have real data going back 160,000 years, the carbon dioxide level has never been as high as it is now. Not even close. We're at about double what it has been in glacial periods and about twenty-five percent higher than carbon dioxide has been in warm times before. So we're moving into uncharted territory."[8]

C. **GREENHOUSE GASES -- SOURCES AND EFFECTS.**

The major sources for carbon dioxide are the burning of fossil fuels and global fires. More than five billion tons of carbon were released from the burning of fossil fuels in 1988, the United States being responsible for one-fifth of this amount.[9]

According to Joel S. Levine, at NASA's Langley Research Center, global fires may cover as much as five percent of the earth's land areas. "Global fires may produce as much as fifty to seventy-five percent as much carbon dioxide as the burning of fossil fuels, once believed to be the only significant source of carbon dioxide."[10] To make matters worse, continuing increases in the greenhouse gases are inevitable. According to Dr. Michael McElroy, chairman of the department of Earth and Planetary Sciences at Harvard University, "Approximately half the carbon since the Industrial Revolution persists in the atmosphere today. . . ."[11]

The trend toward continually rising levels is not limited to carbon dioxide. While not as plentiful, by volume, atmospheric methane, nitrous oxide and CFC's surpass carbon dioxide's thermal capacity. Like carbon dioxide, methane and nitrous oxide levels also track closely with the fluctuations in temperature.

Methane is the second most important greenhouse gas being added to the atmosphere, after carbon dioxide. While the concentration of methane in the atmosphere is now about 1.7 ppm -- about twice as high as it has ever been before -- its molecule is 25 times more efficient at infrared absorption, and it persists in the atmosphere for about ten years. The sources of methane are varied and sometimes most unexpected. The burning of biomass, emmissions from solid waste dumps, coal mining, and natural gas leaks are all contributors. One surprisingly large contributor is the digestive tract of cows and other ruminant animals. The average cow belches up to 400 liters of methane a day and, given the number of cattle on earth, the annual yield of methane is about 100 million tons. This does not account for additional contributions from sheep, horses, camels, water buffalo and bison. There also are contributions from the approximately 50 percent of humans who are methane producers. The other unusal source is from termites. In 1982, a report completed by Patrick Zimmerman of NCAR stated that termites could be responsible for releasing some 150 million tons of methane each year, which would amount to from one-third to one-half of the total atmospheric increase.[12]

Nitrous oxides are trace gases in the extreme -- only about 350 parts per billion (ppb). Nitrous oxide molecules, however, are 250 times more efficient at absorbing infrared radiation than carbon dioxide molecules. Further, nitrous oxide persists in the atmosphere for 250 years. Sources for nitrous oxides appear to mainly be the abundant use of artificial nitrogen fertilizers and the burning of fuels that contain nitrogen. Current estimates put nitrous oxide emmissions at about five million tons per year.[13]

CFCs make up an even smaller trace gas, about 200-400 parts per trillion (ppt). Each molecule, however, is 10,000 times more efficient for heat absorption than carbon dioxide and persists for 60 to 120 years. The present rate of increase for this gas is currently five percent per year.[14] This chemical is totally man-made and, therefore, one which man can control. Its chief effect is the destruction of stratospheric ozone which filters out quantities of short-wave ultraviolet. This destruction not only leads to increases in the amount of ultraviolet solar radiation that impacts and warms the earth, it also directly increases the incidence of certain types of skin cancers.

The final greenhouse gas discussed herein is tropospheric ozone. Ozone emissions into the lower atmosphere are mostly produced by complex photochemical reactions between the sun and fossil fuel combustion products in the lower atmosphere. In urban areas, large scale production of these combustion products is found mainly in automobile emissions. This gas may have increased by 25 percent since the start of the industrial revolution.[15]

D. CLIMATE PREDICTIONS.

Although precise predictions concerning long-term global climate are still not possible, average global conditions and trends can be forecast by combining the results of large scale General Circulation Models (GCM), past climate history, and application of the laws of atmospheric chemistry and physics. Over the past years, research has amassed a proponderance of circumstantial evidence confirming that global warming is occuring, that man has made a significant contribution to the change already in evidence, and that man is hastening further change. Dr. James Hansen, Director of NASA's Goddard Institute for Space Studies, brought this issue to the forefront in his testimony before Congress. "Current climate patterns are consistent with the projections of the greenhouse effect in several respects in addition to the rise in temperature. For example, the rise in temperature is greater in higher latitudes than in low, is greater over continents than oceans, and there is cooling in the upper atmosphere as the lower atmosphere warms up."[16] The projections he referred to are produced by large supercomputers running the GCMs. These models use mathematical representations of chemical and physical processes and attempt to represent the composite climate machine of the planet. The key to using their output, as with any model, is to realize the limitations and assumptions inherent in the model. Models are limited by the complexities of the process to be represented, the computational power required to resolve those complexities, the assumptions made to either simplify a representation or to represent what is not clearly understood, and in their application towards problems for which they are not well suited.

After examination of much of the current literature, it would appear that there is near concensus that global warming is occurring and that the planet will continue to heat. Even Dr. Richard Lindzen, of the Massachusetts Institute of Technology, one of the most outspoken critics of global warming, conceded that warming of the planet will continue. In December of 1989, the University of Chicago reported making the first direct measurements of the heat amplification effect of water vapor in the atmosphere. This is one of only a few measurements which directly confirm the increase in greenhouse effect processes.[17]

A near concensus exists that the earth will warm by about 4 degrees C over the next century, as the greenhouse gas levels increase. In writing for Science magazine, Dr. R. Kerr stated "...None of the committees that have criticized the quantitative details of these climatic-trend plots has challenged the conclusion of a century-long global warming trend of a half degree C or so; only the detailed values have been questioned."[18] Dr. Mark Meier, of the Institute of Artic and Alpine Research, sites one other major feature of warming. "...the concensus now is sea level will rise by about a foot in the next century...".[19]

What we now know is significant. It is agreed that carbon dioxide and other gases have increased over the last 100 years to levels never before encountered by the planet. The accumulation is attributed primarily to the burning of fossil fuels and biomass destruction which release the stored greenhouse gas elements to the atmosphere. The basic phenomena of the greenhouse effect are agreed upon, having been measured and verified in operation.

What are the effects of the concensus beliefs stated above? NCAR's Warren Washington has been running one of the better GCMs for several years. In a recently produced graphic simulation of climate change over twenty years, supercomputer applications were used to graphically represent what the climate might look like through a 20 year period as the atmospheric carbon dioxide doubled. Although regional predictions cannot be reliably produced from these models, trends from current patterns of weather production and movement can be made. From these, the computer models can extrapolate reasonable expectations of climate conditions in highly generalized regions. As greenhouse gases continue to build, the planet, as a whole, will continue to heat. The higher latitudes will heat to a greater extent than the lower latitudes. As the heat is trapped in the lower atmosphere, the stratosphere will become much cooler -- due to less earth emitted radiation reaching the upper atmosphere. Since the oceans possess such large heat capacities, indications of significant heating and the attainment of an new equilibrium state may lag the atmosphere by as much as three decades.[20]

It is now estimated that wet tropical areas will become wetter and slightly warmer. In the higher latitudes, dry to drought conditions will increase in both frequency and intensity. Likewise, due to ocean warming, the stores of storm energies will be much greater than in the past. The frequency, intensity, and distribution of major storms and hurricanes will increase.

Maximum hurricane strength will increase with winds of 225 mph accompanied by higher storm surges. These storms will occur with more frequency and the hurricane season will probably cover a larger part of the year.

Large portions of the high latitude glacial fields may melt. The arctic ice cover will recede far to the north. Ocean circulation patterns, fresh water influx, front and eddy generation, and the major ocean currents are subject to modification.

Unfortunately, these trends do seem inevitable. Now that the warming has begun, its momentum will be self sustaining. Even if all greenhouse gas emissions were halted immediately, the planet would continue to heat due to the length of time required for the oceans and atmosphere to reach a new, higher temperature equilibrium.

The unknown is the rate of change. How much time will there be to confirm the amount of change and then to act? Most climatologists agree that, within the next two decades, we will have enough definitive data to state the warming extent and make fairly hard predictions on the global effects. However, many believe that we will have waited too long to avoid major dislocation, hardship, and conflict -- on a scale not as yet seen by man.

APPENDIX II

CLIMATE CHANGE IMPACTS

Changes in the average global temperature, of just a few degrees, would produce tremendous impacts on society. During the last ice age, when most of the northern hemisphere was blanketed by ice and snow and the glacial sheets extended over a large portion of the United States, the global average temperature was only five degrees cooler than at present. Sea levels were 330 feet lower than at present, due to the huge amounts of water frozen into the glacial ice sheets. During the coming century, the climate may warm by about 4 degrees C. What follows is a composite of anticipated impacts derived from numerous sources. All are within the bounds of the atmospheric changes and temperature increases discussed previously. Most are supported directly by GCM predictions of probable climate futures, the rest by individual research, study, and expert opinion.

A. WATER RESOURCES.

Large-scale changes in rainfall distribution and drought conditions will occur, given an increase in global temperature of four degrees C. Worldwide, evaporation will increase; however, the deposition of rain and snow will increase in the lower latitudes. In the higher latitudes, the GCMs lead climatologists to anticipate that places already prone to drought will become even drier and there will be increased incidents of very dry years in existing temperate agricultural areas. Wet tropical locations in the lower latitudes will become even wetter. Snowfall and ice laydowns over the Antarctic will increase. The northern ice pack, however, will retreat as snowfall decreases, the seas warm, and longer, warmer melt seasons occur.

The impacts on societies will be severe with redistribution of water resources causing the most tension. In many areas, the decreased rainfall means less runoff and collection for surface waters and less replenishment to groundwaters. There could be large scale changes in the sediment transport and deposition cycles which maintain many agricultural societies and maintain the levels of many wetlands and marshes. The decrease in runoff impacts heavily on those countries that depend on crop irrigation for food production. Less runoff means less stored reserves, more competition from urban water users, and less water available to dilute pollutants in transported sediments and streams. In some areas, competition for water resources will increase between industrial uptake, food producing agri-business and the daily domestic needs of the average citizen.

The real problem is not that the aggregate amount of water available will be insufficient for all uses, rather it is the mismatch between location of the global populace and the distribution of future water resources. According to the EPA, a future cause of international tensions will be water availability and distribution, especially where the mass populations have grown up around the great river basins. "For example, more than 75 percent of the total land area of nearly fifty countries on four continents falls within international river basins, while globally, about 47 percent of all land area falls within international river basins. ...The problem with water resources then, is not the total amount of fresh water that falls on earth but rather the lack of uniformity in the distribution of human settlements, population centers, and national boundaries -- and water resources -- around the world.[1]

International boundary tensions may become severe, in light of the interdependencies of water runoff. For example, the Danube River drains through 12 separate nations and many of the nations furthest downstream are already experiencing pollutant problems of massive proportions; the Nile drains 9 nations, the Amazon basin serves seven nations, the Mekong serves six, and the Elbe and Ganges-Bramaputra both drain portions of five nations.[2] In these areas, some regional basin water management plans will have to be worked out. Countries upstream would be ill advised to build dams and seek to solve their own internal water problems at the expense of others downstream. As some rivers flows are reduced, and salt water intrusion eases further into the coastal areas, water supply and quality, and population displacement become critical issues. It will be essential for stability and human survival, that equitable plans exist for water management.

B. OCEANS HEATING AND SEA LEVEL RISE.

Warming of the atmosphere will be accompanied by a 2 - 4 degrees C warming of the oceans. As a consequence of this ocean heating, two dramatic things will occur. First, given the physical properties of water, the ocean bodies will expand, thus raising sea levels. Drs. W.R. Peltier and A.M. Tushingham, of the University of Toronto, recently reported in Science magazine that they have calculated an average sea level rise of 2.4 millimeters a year over the last century, or about a tenth of an inch per year.[3] Sea level around the world has risen by about one foot over the past century, about half as a result of the warming, that has expanded the oceans, and about half from a subsidence of the land.[4] To make matters worse, the rate of sea level rise seems to be increasing. Currently, the concensus seems to be that sea level will rise by .5 - 1 meter (1.5 - 3 feet) by about 2060. Second, the increase in ocean temperature means a far larger quantity of energy available for storm generation. Storms will be more frequent, more violent, and more probable over a greater span of continental shoreline, especially at higher latitudes.[5]

Sea level rise and an increase of storm energies lead to a myriad of problems for coastal areas the world over. For much of the protected coastal regions and cities, the design conditions of the existing protective works will be exceeded. Larger waves and higher storm surges will reach coastal structures and shoreline. Any new structure must be more stringently designed due to this environment and thus more expensive to construct.

Populations that have congregated along shorelines and river basins will also be affected. For some island nations and many countries who have large areas of lowlands, the rise in sea level and the threat of inundation or excessive tidal erosion threatens their very existence. The Netherlands has already begun to construct reinforced coastal structures designed for a dramatic increase in sea level due to global warming. Huge areas of the globe will have to be remapped and major relocations of populations will be a consideration in many regions. Increases in tidal heights and energies threaten the water quality in some areas and the actual supply in others. In coastal eas, lower levels of freshwater within the aquifers reduc the osmotic pressure (the weight difference between fresh and saltwater which creates an equilibrium barrier) within the supplying aquifer (water holding geologic substrate) and allows saltwater to intrude, destroying any drilled well fields.

Coastal marshes and wetlands, when they exist as stable, fibrant ecosystems, provide the first step in support of strong, healthy fish stocks. They act as shallow, warm water nurseries for the small to the microscopic. Additionally, they provide stability to the coastal inland waters and act as buffer areas for bays and inland waters against propagating wave action. Nature requires these marshes and wetlands to be just slightly above sea level.

In an environment undergoing natural sea level fluctuations, the ecological systems have time to adjust. Wetlands collect sediment and produce peat, which enable them to maintain their height above sea level. River delta areas depend on the deposit of sediment transport down the major rivers. A rapid rise in sea level does not allow time for these natural events to occur and thus threatens the life of the wetlands and all associated ecosystems.

Such destructive threats follow up the ecological chain affecting industries dependent upon the sea: fishing, tourism, boating, hotels and the like. In developed countries, these industries exist to such an extent that entire cities derive their economic basis from them. In other less developed nations, recreational industries are being looked to as anticipated sources of foreign business and money. In summary, the loss of large areas of coastal wetlands could be catastropic.[6]

C. UNITED STATES REGIONAL IMPACTS.

The United States represents a microcosm of the global effects. As a highly developed nation, the United States relies on integration and interdependence of its industries, communications, global commerce, and most importantly, on its abundant natural resources and production abilities to remain a world leader. For these reasons, we have a tremendous investment at risk from climate change. The problem for the United States then becomes one of increased challenges to the way we manage limited resources against competing and ever increasing requirements. The following paragraphs address these issues on a regional basis.

The Pacific Northwest region is growing rapidly with associated demand increases for power, water, and land for development, while trying to maintain industries, fisheries habitat, and traditional standard of living expectations. The region's primary concerns, in relation to climate change, are the risks of increased flooding, the reliability of hydroelectric power production, increased demand for irrigation support, and the maintenance of fisheries habitat. Prediction of current trends would seem to indicate that this area is not as vulnerable to climate impact as other regions of the country. Reduced runoff due to a small reduction in upriver rainfall could be met by enlarged storage capacities. Production of hydroelectric power to meet increasing demands is a moderate problem for the region. Maintenance of the fisheries habitats will not be as difficult in this region as in other parts of the nation due to a more protected and stable wetlands structure. Heating of the ocean would change the basic character of the ecosystems. However, it is not possible, at this time, to predict what effect Pacific Ocean warming might have on the movement and generation of ocean currents.[7]

California is much more vulnerable to climate change than the Pacific Northwest. The population is located almost exclusively in coastal areas with high concentrations of industry, people and agriculture attempting to coexist. Air quality in many locations is already stressed despite stringent controls on emissions. The climate of central and northern California is Mediterranean in nature with seasonal snow, rainfall, and melt supplying water. In Southern California and in the agricultural regions, rainfall is not as plentiful or reliable and much is supplied from the Colorado basin via aqueduct. Much of California's coastline is vulnerable to either inundation or high rates of erosion and subsidence. As one of the primary suppliers of fruits and vegatables, the demand for water to support irrigation is already in conflict with other regional uses. A warming of 2 - 4 degrees C would have the effect of shifting the time of the snow melt and compressing the period over which it occurred. This would result in competing priorities for either flood control or storage for future supply.

In the Great Lakes region, a different sort of phenomenom would occur. Due to less rainfall, run-off, and warmer summers, the level of the lakes could drop by 2 - 8 feet. Over the past century, runoff from major industrialized areas has poured tons of toxic sediments into the lakes. While on one hand, a subsidence of the lakes may uncover valuable beachfront property, that property may be too toxic for habitation. Lower lake levels would cause an upheaval in shipping and commerce on the lakes unless major capital is invested in the deepening and widening of channels and modification to the St. Lawrence Seaway. This might be offset somewhat by a longer ice-free shipping season. Outflow and intake pipes would have to be relocated and extended and much of the Illinois coastline would require construction and dredging for channels, docking facilities and other port facilities.

In the Northeast, the main threats are posed by the region's lack of fresh water storage, changes in rain supply patterns, and sea level rise. Several major cities would have large percentages of their infrastructure threatened by rising seas. Around Boston, New York, and Long Island, millions of people and billions of dollars of investment would limit adaptive options to protective hard structures. New York already has problems with salt water migration within the Hudson River's basin and Long Island is examining the kinds of construction required by the threat of major hurricanes coming ashore across Long Island. Most of the structures along the New York/Long Island coast do not meet stringent storm design requirements.[8]

The Gulf Coast and Florida, in particular, are most intensely effected by sea level rise and oceans warming. Large portions of the Gulf Coast are considered wetlands and subject to inundation for miles inland. Because a process of subsidence (the sinking of a geologic plate due to plate tectonics), hundreds of thousands of acres in the Louisiana lowland would certainly be inundated by sea level rise of as little as one foot.[9] This region is already subject to high intensity storms and is located in an area of storm amplification from the existing warm waters of the Gulf of Mexico.

One graphic presentation developed by the United Nations Environmental Program depicted Florida after a sea level rise of three feet. With existing protective structures, beachfront property was located just south of Orlando. Most of the coastline of the state would have to be re-engineered for a sea level rise of 1.5 feet. Bridges, revetments, seawalls, and other hard structures would need to be raised and strengthened for increased storm surges and tide levels. Water resources in southern Florida, already under strain, would be severely effected. This area, which is most threatened, is one of the fastest developing areas in the nation, undergoing tremendous pressure from surging population growth.[10]

In the heartland, hotter, dryer summers and even drought conditions in some areas will force a redistribution of crops. Many crops now grown in the midwest would migrate farther to the north, some possibly to Canada. Water for irrigation would come under increasing competitive pressure from the population. The central Great Basin would experience drastic reductions in water runoff which, in turn, reduces sediment transport and nutrient supply to farmlands, as well as causing reduction of river channel depths.

Providing for increased power demands will be one of the most stressing problems for all regions of the nation. For the Southeast and New York alone, a one degree C rise in temperature would require a 20 percent increase in power production to support increased air conditioning/environmental control requirements. Power production, to supply much higher demand rates will have to be carefully planned so as not to increase levels of greenhouse gases. The use of fossil fuels will only intensify the problem.

Other concerns and interests will compete for resources given the degree of projected warming and climatic changes. Human health will be affected by everything from air quality to water quality to toxic exposure. Forested lands, which employ some two million Americans, would be hard pressed to adapt or migrate when faced by rapidly decreased moisture, increased carbon dioxide, and temperature increases of 4 degrees C.

APPENDIX III

EXCERPT FROM U. S. ARMY CORPS OF ENGINEERS REPORT:

COASTAL ENGINEERING OPTIONS FOR ADAPTING TO GLOBAL CLIMATE CHANGE

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EXAMPLE OF IMPACTS; THE SCENARIO OF RISINGSEA

There are many international examples of the variety of impacts we can expect Global Climate Change to cause the world's coastal areas. Although caused by other factors, such lessons as the subsidence of Venice and the Louisiana coastal plain, the dramatic erosion of the Nile delta, the land reclamation efforts in the Netherlands and Germany, the fifteen year high water level cycle in the Great Lakes (1972 - 1986), and the recent occurrence of a Class 4 hurricane (HUGO) in South Carolina all contribute to our understanding of what sea level rise and severe tropical storm activity can mean.

Many great and established cities are at risk from Global Climate Change. However, in order to illustrate the quantitative level of impact which many real communities are likely to experience we will use a fictional coastal area and the town of Risingsea (Figure 1). The possible level of impacts to this coastal community were computed for a sea level rise or increased storm surges of 0.3, 0.6, and 0.9 meter (m)(Table 1). A rubble mound breakwater protects boats moored in the harbor. The harbor shore is a narrow beach backed by a revetment which protects the town from flooding. West of the revetment is the city dock and a bridge over the west end of a tidal marsh. The bridge leads to a resort community protected by a seawall. On the east side of the inlet is a natural beach and dune area. Calculations concerning the effect of sea level rise on the Risingsea area were done using the Automated Coastal Engineering System (ACES) package of computer programs developed at the Coastal Engineering Research Center (Leenknecht and Szuwalski, in press) and analytic methods presented in the Shore Protection Manual (SPM, 1984).

The breakwater was designed to afford adequate protection for a stillwater depth of 4.6 m at the toe of the breakwater. The breakwater is a typical multiple-layer stone rubble mound structure. Armor stone was sized assuming waves impacting it were depth limited to 3.6 m by the 4.6 m water depth at the toe. The calculated stable armor size is 7.6 metric ton (m-ton) stone. When impacted by the 3.6 m, 9-second period waves the breakwater transmits 0.8 m waves to the harbor.

The 0.8 m waves propagate across the harbor towar the revetment inflicting minimal damage to the moored fleet. The 305 m long revetment is 1.8 m from toe to crest and has a toe buried 0.6 m below grade. The 0.5 m depth limited breaking wave requires a computed stone size of 18 kg. However, to prevent pedestrian damage the revetment is made of 45 kg stone. Calculations indicate there will be no overtopping but undoubtedly the winds accompanying a design storm will blow considerable spray into the town. But drainage systems easily handle this water. The city docks are 0.9 m above design sea level and waves pass under them without damage.

A 0.3 m sea level rise will result in 4.9 m of water at the breakwater toe. A depth limited wave of 3.8 m will now impact the breakwater. Stable armor stone size requirements are now 9.1 m-ton. Rubble mound structure loss reduces the structure height as armor stone is displaced. If the breakwater does not loose crest elevation the transmitted wave will be 1.1 m, but if it fails by just 0.2 m, the transmitteed wave becomes 1.3 m. The 1.3 m wave increases damage to the moored fleet. The revetment now has 0.9 m of water on it and is subjected to a 0.7 m breaking wave which requires 61 kg rock. Assuming the structure survives with no major damage 0.0024 cu m/sec-m of water is delivered to the town center by overtopping. For the 305 m waterfront this is 0.27 hectare m per hour which may tax the existing drainage system. Wave crests are about even with the pier deck and start to cause damage. The moment about the mudline on the dock pilings as calculated using stream function wave theory as presented in the SPM approaches the design value which used a factor of safety of two.

For the 0.6 and 0.9 m of sea level rise the situation becomes progressively worse. With a 0.9 m rise there is 5.5 m of water on the breakwater toe and a proper design would require 13.2 m-ton stone for the resulting 4.3 m breaking wave. The 7.6 m-ton stone used in the original construction is only a little over half the required weight and will be easily dislodged. An estimated 0.6 m of crest loss or 20 % damage to the breakwater may be optimistic. Boats would no longer be safe at their moorings in the resultant 2 m seas. Since wave energy is proportional to the height squared, the 2 m wave would have almost 5.5 times the energy of the 0.8 m wave. If given notice, the fleet would head for a safer port. In these situations people often leave too late resulting in loss of lives and boats. The revetment which is constructed of 45 kg stone would be severely under-designed with the 1.2 m breaking wave requiring a 282 kg stone. In the unlikely event the revetment did not fail, the town would receive 15.5 hectare m of water per hour which would result in extensive flooding. If the revetment failed the flooding would be worse. The docks would most likely be destroyed by wave crests over 1.5 m above the pier decks and excessive forces on the pilings. Depth limited wave forces on the seawall as calculated by the Minikin formula would be over twice what they would be febore the 0.9 m of sea level rise. Flooding near the seawall will be severe.

The marsh south of the bridge was 150 m by 300 m before sea level rise. If the land adjacent to the marsh slopes upward at 1:30 on the north and south sides and 1:100 on the west side the surface and thus the tidal prism will increase as sea level rises. This can result in increased current velocities and sediment movement. In this case, the channel under the bridge is 4.6 m wide and 1.8 m deep before sea level rise. The rise in sea level will increase the cross-sectional area of the channel as the tidal prism increases. With the expected 16% increase in cross sectional area, there will probably not be any significant scour around the bridge pilings for this bridge located in the back of the estuary. Considering all the calamities afflicting Risingsea, the citizens needed something to feel grateful for.

Table 1: Effect of Sea Level Rise on RisingSea

Sea Level Rise	0	+0.3	+0.6	+0.9 m
BREAKWATER				
Depth Limit Wave	3.57	3.78	4.02	4.27 m
Armor Stone Size	7.62	9.07	10.98	13.15 m-ton
Transmitted Wave	0.85	1.10	1.34.	1.71 m
Settlement		0.15	0.30	0.61 m
Transmitted Wave After Settlement		1.28	1.59	1.95 m
REVETMENT				
Depth Limit Wave	0.49	0.70	0.94	1.19 m
Armor Stone Size	18	61	145	282 kg
Overtopping				
cu m/m-sec	0.0	0.0024	0.035	0.14
hectare m/hr /303 m revetment	0.0	0.27	3.91	15.54
DOCKS				
Wave Crest Height	0.61	1.16	1.77	2.47 m
Moment on Piles	1660	3581	5720	8854 N-m
TIDAL PRISM				
Upriver of Bridge	70792	82544	95145	108595 cu/m
SEAWALL				
Wave Impact Force	429	617	846	1083 N/m

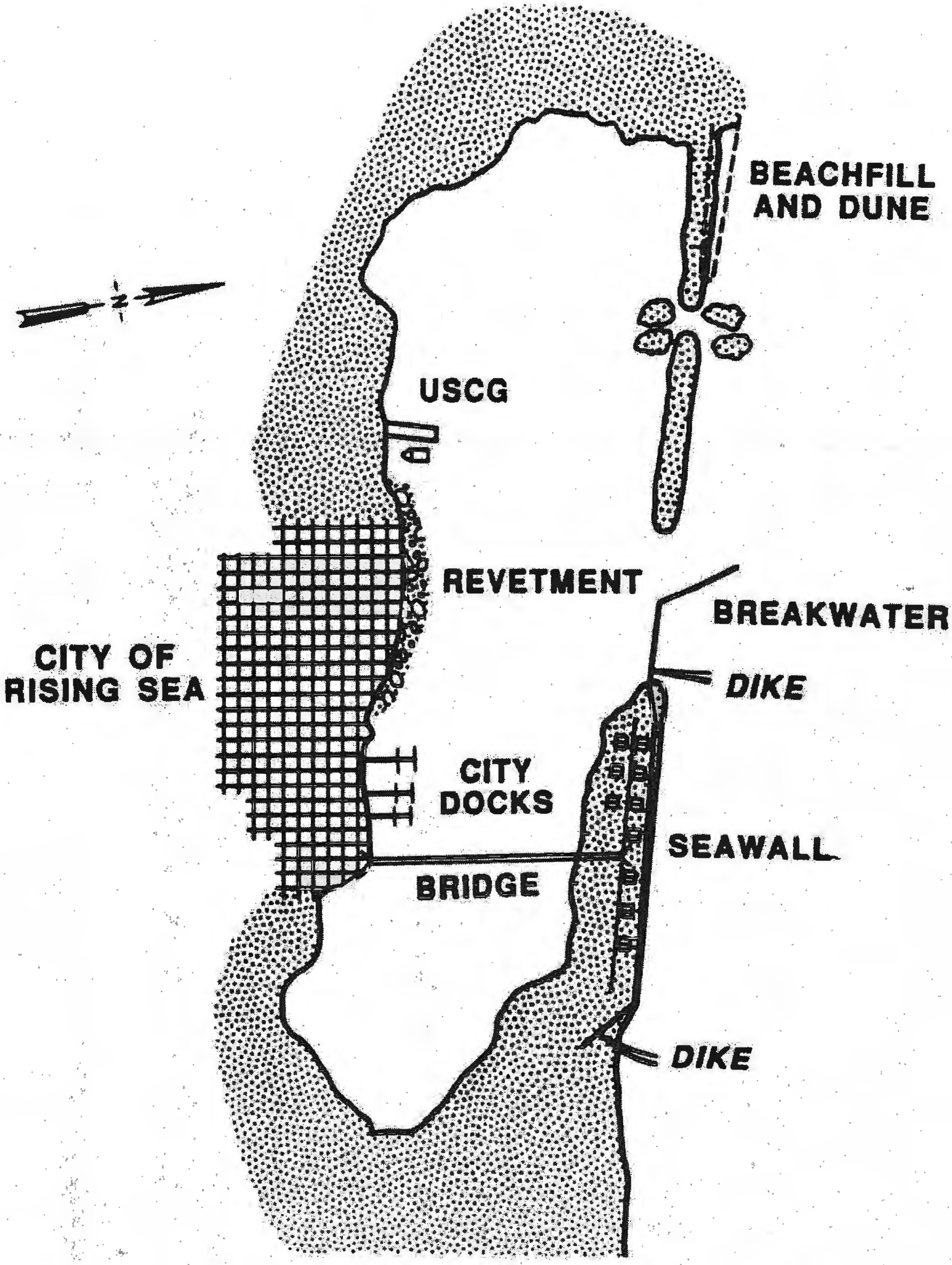

Figure 1. Fictional coastal setting and City Risingsea.

NOTES

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