shift to lode deposits. The removal of overburden in open pit mining of lode deposits will be eased greatly by climate warming (Swainbank 1997). Increase in temperatures will decrease costs of fuel, extend the mining season, decrease maintenance costs on equipment, release water for various cooling and washing functions and may possibly reduce the need for and cost of snow removal. Underground placer mining efforts, practiced chiefly in the Russian Far East will be adversely affected by the loss of the stability provided by permafrost (Swainbank 1997). The work season for small-scale placer mining will be increased.

One of the largest future stresses on the production of mineral resources may arise from thawing permafrost and the resulting decay of the support infrastructure. There will be an increasing demand for sand and gravel for the repair of road/trail/railroad systems, and building stone/rip rap to repair and stabilize coastal erosion and river channels and bridges. This will come at a time when the industrial minerals sector will be under increased pressure to support a deteriorating infrastructure in the rest of the Western Arctic. There may be a shift in the present market for industrial minerals, from the private sector (petroleum production, timber roads) to the public sector (repair of roads and airports). Changing patterns of energy consumption induced by climate change may divert interest to the extraction of Alaska's extensive coal deposits. Alaskan coal is considered an untapped national resource whose size probably exceeds 40 percent of the total coal resources in the rest of the United States (Stricker 1991).

Other Pressures on Petroleum, Transportation and Energy Industries

- Loss of infrastructure from natural disaster including storm surges aggravated by sea-level rise.
- Effects of weather variables on buildings and roads conditions.
- Reduced costs of snow and ice removal and reduced frost damage to roads and bridges.
- Sea-level rise may require raising most bridges to ensure sufficient under-clearances.
- Sea-level rise could infiltrate the base of roads & streets necessitating added reconstruction costs and large additional costs to petroleum field and mining facility owners to improve drainage, raise yards and pump sewage.
- Reductions in frost damage to roads, in road maintenance and in road reconstruction.
- High humidity weaken alumina cement, and low humidity and high evaporation rates lead to plastic cracking of concrete
- Increased air pollution may pose threats to metals and other building materials
- Stresses on settlement ponds and containment areas for hazardous wastes from industry production activities.
- Decreased life of vehicles and other metal objects owing to increased use of salt for snow and ice mitigation
- Potential abandonment or relocation of industrial sites may be required as a result of climate change
- Changes in availability of water, may affect the viability of industrial facilities dependent upon that resource.

- Increased need for sea ice location information and ice cover assessment for changing sea routes
- Changed need for plotting hazards to shipping of ice island drift.
- Negative effects on stability of existing oil and gas pipelines.
- Water resource changes could reduce or increase use of barge traffic, thereby changing traffic on competing transport modes such as railways or roads.
- Changes in building design to accommodate to climatic change. These could include road layout affecting the placing of buildings, greater use of new, more weather-tolerant materials.

Stresses On Solid Waste Infrastructure

The solid waste management infrastructure in Alaska will be affected by three stresses of a warming climate change: increased solid waste generation during the period of change, loss of existing solid waste disposal sites, and changes in future solid waste disposal sites.

Flooding/ coastal changes

Rising ocean water levels will flood many existing repositories of solid waste. The area more affected will be in the southwestern part of Alaska in the Kuskokwim and Yukon River lowlands where large areas (and the landfills in them) will be flooded. Many of the villages and cities in the area will be forced to relocate or cease to exist altogether as separate entities. Impacts will go far upstream on many Alaskan Rivers due to their low relief and the fact that communities are located right on the rivers for their primary access.

Similar extensive effects will be seen in areas of the Seward peninsula and around Barrow. Other areas in the South central and Southeast will have more localized impacts but effects could be considerable depending upon the location and elevation of their landfills. The Matanuska/Susitna Valley and the Anchorage areas (with over half the state's population) will be spared from having their current landfills inundated since they are at sufficient altitudes.

Such sites would be especially vulnerable during the period when shorelines are moving and wave action will be eroding a front preceding shoreline advance and exposing currently stable buried waste. Another problem that can occur is leaching of contaminants from landfills that become under water or where the water table rises into the waste zone and leaches contaminants to the surface or other parts of the aquifer. The final impact to the environment from situations such as these could range from insignificant (in areas where non-toxic organics are leached to the ocean or large rivers with strong currents) to serious (where toxins are leached to areas where flow conditions are stagnant in estuaries or marshes or where critical human uses are involved, etc.)

The opportunities to address the problems of landfill flooding will be seriously hampered because it will happen at the same time that communities are concerned with relocating their homes, schools, businesses, infrastructure, etc. (as explained below or will soon to be abandoned will be competing with needs that are more primary to subsistence, i.e., a family, collectively, a community concerned with moving to another city or the lower 48 states is not going to place high priority on dealing with the waste dump left behind.

Waste Generation

A second and perhaps the largest stress on solid waste during a major climate change will be unprecedented waste generation due to abandonment and rebuilding of communities and infrastructure. As mentioned above, rising waters will cause this in current to future tidewater areas and in the discontinuous permafrost areas south of the Brooks Range.

Information needed to evaluate the magnitude of this increased waste generation is probably in existence and rough estimates could be compiled. It will be necessary to build new structures. The communities needing this rebuilding can be tabulated and the construction industry can estimate wastes generated in this process. Roads, railroads, power distribution systems, sewers, etc. will need to be constructed or reconstructed and factors for waste can be gotten from those involved with such current construction.

Information can also be obtained on structure and infrastructure demolition and salvage to come up with factors on unusable wastes resulting from these efforts and the potential toxicity of these wastes. Uncertainties involve the timing and the specific demolition/ reconstruction sites. Reuse of materials might be possible if relocations are gradual (over a 50 year period) and new site/old site locations are economically close (just uphill).

However, this may not be the way it happens. For the coastal areas at least, the impetus for change will often be those storm events causing swift and unrecyclable damage. Here again, uncertainties will be whether a structure is severely or only partially damaged and whether the person or business decides to rebuild in a totally different community rather than the original inundated site, e.g. in Anchorage rather than Bethel. In the interior, increased frequency of large wildfires may be the deciding damage/reconstruction factor. Permafrost melting will produce large scale damage and rebuilding of the infrastructure, but timing of impacts will be more gradual and predictable, recycling more technically advanced and locations in current or adjacent corridors.

Landfill Site Availability

The availability of landfill sites will gradually increase in interior Alaska as discontinuous permafrost melts, ground settles, and those areas change from permafrost wetlands to something drier. In areas where tidewaters will encroach far inland, current sites will be eliminated (these may be in communities which will need them most). Moving waste materials from areas where sites are being eliminated to areas where sites are being created will be difficult.

Real Estate and Banking Industry

A 1 m sea-level rise if it occurs, is likely to cause major problems on the coastal plains-producing coastline recession of up to several kilometers, displacing coastal infrastructure, villages and depriving many industries and people of their land and resources. The intrusion of saltwater into coastal ground water supplies, erosion of flat land, and storm damage to ports and other coastal facilities will have impacts on government, law, the insurance industry and the availability of capital to accommodate changes.

Although there are few analysis of such impacts, there is every reason to believe that if climate change were to occur at the high end of the projected ranges, the consequences could be serious for many parts of Alaska. A minor sea level rise could cause population displacements in the river delta regions of Alaska as well as in the state's largest city, Anchorage.

Sea level rise and increased run-off in streams and rivers may have a significant, if not devastating, effect upon state, federal, and international banking industries and global financial markets. Loss of property from natural disasters such as the predicted storm surges, an increase in sea levels, and changes to fresh water availability and drainage could result in significant loss of financial value due to the resulting destruction or from population migration (Hertsgaard 1996).

According to some weather models, even a small rise in global temperatures can be devastating to regional and global ecosystems. Increased melt waters from Alaska's vast glacial networks may cause significant river flooding and mud slides, forcing surrounding populations to relocate. Real estate values may plunge in such areas and rise abruptly in areas capable of absorbing such migrating populations.

Coast and river real estate are particularly vulnerable to the effects of global change. Indeed, financial investments in such areas are at risk and the capital markets may be stressed beyond available funds in their ability to make resources available for required clean-up and reconstruction. "... Financiers have come to realize that they have at risk literally trillions of dollars worth of insured property and long-term investments." "Peter Blackman, assistant director of the British Banker's Association, prepared a memo...that warned that more than half of current bank lending is 'affected by environmental factors' and that within the 20 to 40 year 'lifetime of loans granted today, climate change is forecast to have a dramatic impact..."(Hertsgaard 1996).

Governmental and business policies relevant to such matters will need to be developed that protect both lending and real estate institutions as well as corporate interests and the private citizen. Future development in areas particularly vulnerable to the impacts of global change may be in jeopardy in securing sufficient capitalization.

Energy production/ distribution/storage/consumption/markets

Governmental policies initiated in response to climate change may have affects on the structure of energy investment. Response strategies to change may cause some Arctic countries to become more reliant upon nuclear power while others may rely more on renewables. More energy-efficient fossil-fuel technologies, or shifts among types of fossil fuels can affect investment and consumption.

Non-climate-related environmental factors may also act as constraints on the rapidly increased reliance on non-carbon energy systems such as hydroelectric power or nuclear power. A serious constraint on increased reliance on nuclear power will be satisfying public concerns regarding safety and the adequacy of waste disposal. Increased construction of hydroelectric projects may require considerable human resettlement and flooding of important ecological resources. This is a particularly interesting issue as water availability, timing, glacial melt, and precipitation will be affected by global change.

Climate variability and a change in heating/cooling requirements will produce losses or gains depending on the area. Changes in requirements will produce changes in the level of pollution and change the transportation requirements. Storage of fuel in coastal areas may require new design criteria and siting requirements to preserve the safety of the storage facilities.

As Alaska's economy is almost entirely dependent upon the oil industry, any future regulations which limit the extraction, transportation, and subsequent use of these fossil fuels may have a devastating impact on the state's economic stability. Moreover, according to a recent IUCC report, a proposed tax on the carbon content of oil, coal, and gas might discourage the use of and hence exploration for fossil fuels. Such a tax might also curtail or seriously delay the proposed Alaska gas pipeline construction and limit the exploration and overseas export of Alaskan coal products.

Permafrost thaw will also impact the energy industry. In the case of North Slope oil production and transportation, thawing permafrost may cause significant problems for existing pipeline systems throughout the state. A rise in river levels, due to increased precipitation and/or increased glacial melt, would require additional engineering studies and perhaps reconstruction of threatened sections of pipeline and related infrastructure.

Off-shore drilling and production islands may be threatened by changes in ice movement and changes in the pattern and flow of ocean currents, as well as by inundation. The ease of shipping may increase with decreases in average ice thickness, but may be threatened by an increase in the number of free-floating glacier pieces and ice islands. Petroleum exploration and field transportation now conducted over seasonal ice and snow cover may be in jeopardy raising the cost to the environment and increasing the need for new technologies for oil exploration, production and transportation.

The delivery systems for electrical energy throughout Alaska may need significant modification as ground-based high and low-tension distribution poles may become unstable due to thawing permafrost, flooding, and increased erosion in river bottoms. Predicted increases in wind speed, which have already damaged certain stands of Alaska's forests and the potential for increased rime-ice formation, may also require the redesign or more frequent replacement of distribution lines. Regulations and policies which take into account these considerations may be needed to avert these negative impacts. Hydroelectric generation may be a clean and viable option, yet unknown scenarios in glacial melt may make assessment of the alternatives difficult.

Ocean Navigation: Navigation Aids/Charts/Bathymetry

Ocean shipping will be affected by ice cover and timing of break-up, changes in storm frequency, intensity and paths. Weather changes may affect prevailing wind velocities and directions requiring adjustments in sailing directions and coast pilots. Ocean shipping will also be affected by changes in ocean currents, tides and changes in bathymetry requiring perhaps an increase in the frequency of coast line surveys and the replacement and change of navigation aids. The capital costs of changing these public facilities and services will be an additional burden on government.

As precipitation changes & glacial melt occurs, river water levels may be affected greatly and ocean levels will change. River courses will be affected by permafrost thaw and erosion effects of changes in currents and bank collapse Increased river transportation may supplant or complement existing road and rail transportation methods.

Trans-Arctic shipping may become a high priority and a much easier endeavor in a warmer climate with reduced sea ice extent and thickness. The Northwest Passage and more likely the Northeast Passage may have increased use. Extending the shipping season and ports served will require an increased level and extent of navigation aids and ice monitoring.

Water Supply/Quality/Distribution/Sewage Disposal/Floods

Changes in the availability and location of potable water supplies due to changes in weather patterns could alter population distribution and jeopardize industrial facilities dependent on these supplies. Changes in water levels throughout Alaska's river system could reduce or increase the conduct of barge traffic, thereby changing traffic on competing modes such as aircraft, roads, and railways. Flooding rivers may require relocation of many rural and native Alaskan communities, fish camps, and other settlements leading to a breakdown of the community's infrastructure and thus the existing social and cultural frameworks.

Predicted rapid population growth will by itself tax the world's fresh water supply well into the next century. The predicted growth in the Western Arctic's population in the same period will also place increasing demands on the water resources. Increased warming in winter and increased evaporation may have a profound effect on the water cycle.

Rising sea levels may cause leaching and intrusion of salt water into coastal community fresh ground water reserves making them unfit for human consumption. Communities may have to reduce pumping of water to prevent aquifers from being refilled with sea-water. Concentration of salts from run-off and reduced levels of water supply in drier areas may both impair the quality of available drinking water. The associated costs of protecting coastal communities from such disasters and preventing constant land erosion would be enormous and place cultural and historic sites, potentially valuable tourist attractions, and fishing centers at risk. On the other hand, shipping in some localities, such as shallow ports on the Bering Sea, would benefit from a higher sea-level. Additional investments would be needed to adapt existing sewage and water supply systems to accommodate increased demands placed upon these infrastructures.

Changes in the timing of water cycles and the volume of precipitation may directly and adversely affect human health. Increases in flooding and storm surges associated with sea-level rise may increase the pollution of water supplies from incursions into solid waste and sewage systems. Melting permafrost may also increase the incidence of water-borne disease by leaching of disposed wastes into ground water supply systems. If water quality were to diminish, public health services would have to address outbreaks of several existing Northern diseases. A reduction in quality might engender the incidence of opportunistic diseases not now normally found in the North. Wide-scale disruption of communities could include psychological stresses on environmental refugees and place enormous pressure on existing public health facilities and workers. The economic impact of such scenarios would place additional financial demands on the insurance and banking industries.

11.4 Uncertainties

The spatial distribution of the effects of a changing climate are too poorly known to make conclusive plans for dealing with the site-specific effects of the changes. Changes in precipitation will be positive for some areas of the state and negative for others. Rates of permafrost melting will vary greatly, depending on local terrain, temperatures, snowpacks, vegetation cover and other factors. Current monitoring stations for ground water, surface water and water quality are too sparse to enable researchers to detect changes that probably are already occurring.

A principal difficulty in constructing studies of the likely impact of climate change on human habitat in the Western Arctic is the fact that many other factors largely independent of climate change, e.g. demographic trends, technological innovation, evolving cultural tastes, employment opportunities and transportation modes, may significantly shape where and how people will choose to live and work in the future. Changes in the requirements for resources will determine many of the eventual affects in the North. With climate unfortunately the only thing we can be sure of is that all other things will not remain equal.

One can reliably predict that certain Northern societies will be more vulnerable to climate changes than the highly industrialized areas because they are already at the limits of their capacity to cope with climatic events.

Significance of rates of change

If the rate of change in climate is rapid, it could overwhelm our ability to adapt and modify our technologies, laws, financial and human support structures. This impact could cause human migration and would lead to conflict over resources. Capital equipment, buildings, industrial plants all are designed with set lifetimes and then one normally replaces them. If the rate of change is so rapid and severe to require abandoning structures and facilities before the end of the a normal lifetime, much greater costs may be incurred and the society's ability to respond may fail. The potential seriousness of the affects are beginning to receive notice even from those who may have to bear the cost of mitigation such as James Browne, the President of British Petroleum, who stated that "It would be unwise and potentially dangerous to ignore the mounting concern." (San Jose Mercury News 1997)

11.5 Additional Research Needed

Careful analysis of the economic issues related to climate change is a high priority for further research leading to identifying the economic and social stakeholders, development of effective strategies to mitigate the effects and appropriate decision making by the stakeholders. Research and development related to energy efficiency technologies and non-fossil energy options also offer high potential value. In addition, there is also a need for research on the development of sustainable consumption patterns.

The information needed to refine the magnitude of climate change impacts on solid waste sites are the location, size, and elevation of the existing landfills throughout the state. This information should exist for operating landfills and could be put together. More difficult is assembling this information for inactive landfills especially ones containing hazardous wastes (both public and private agricultural, hatchery, mining, industrial, military, etc.) chemical or radioactive wastes.

Substantive research concerning the specific impacts on Alaska's non-renewable resources is needed. This paper merely skims the surface of potential impacts and suggests areas of concern. An action plan representing the interests of the state and federal governments as well as industry needs to evolve as a result of shared concerns and ongoing partnerships.Finally, a survey of the vulnerability and resiliency of water basins is needed to support water-use planning in the event that climate change has its predicted impacts.

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