Planning for Sea-Level Rise in a Coastal Community

Part I and
PART II
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— 1ST PAPER —

Introduction: Environmental impact analyses strive to analyze the effects of some man-made project on the surrounding environment. There are two major types of analyses: those dealing with terrestrial ecosystems and those dealing with aquatic ecosystems. A third type of analysis, dealing with coastal ecosystems is particularly interesting to environmental planners because the impact statements must account for interactions between the aquatic and terrestrial environments. Also, a majority of the American population lives in coastal counties (52%); thus these coastal areas are also very popular areas for new developments (USDOC, 1985). — spell out the first time cited

A common problem faced by planners in coastal areas is the determination of a "safe, but valuable distance" to keep from the water's edge. Developments situated directly at the water's edge have a number of economic benefits. Private houses with a view of the water are highly valued , in comparison to a similar house without the view. Many sewage systems and power plants depend on ~~the~~ water bodies for waste dispersal; therefore these developments place economic value on proximity to the water. Yet at the same time, the developments must be far enough from the water to provide safety from flooding. Generally, the margin of safety must be large enough to account for the "worst-case" scenario. That means that planners must research past patterns of flooding, and predict the maximum flood level which will be reached during the lifespan of the development. The margin of safety must be equal to or greater than the maximum expected rise in water level.

Recently, many scientists have predicted that future flooding problems in marine coastal areas will be augmented (aggravated is perhaps a better word) due to a rise in the ambient

The distance can take into account, however, floodproofing or flood protection design – that is, the structural design can protect functioning even if development is partly under the water level.

level of the world's oceans. The emission of carbon dioxide (CO_2) from the burning of fossil fuels is creating a "greenhouse effect" in which the global temperature is slowly rising over a period of decades. The rise in temperature has apparently caused a sea-level rise of one foot in the past century, and is expected to cause a rise of 3-4 feet in the next century (Eckholm, 1986). This paper considers the possible impact of rising sea-level in the greenhouse effect scenario on the present and future development plans of a coastal community.

Since the research in this area has been limited, there is little data available for the effects on specific coastal communities. Therefore, for the purpose of this analysis, I have created a hypothetical coastal city of approximately two-hundred thousand inhabitants. This city can be considered 'typical' of an Atlantic coastal port in that it has numerous developments built along an estuary, as well as some wetland areas in the nearby bays. It also has several barrier islands, with few man-made developments, guarding a harbor (Fig. 1). In this analysis, I will look at the impact of varying rises in sea-level on this community, if no protective measures were to be taken. Also, I will analyze the impacts of varying rises in sea-level if different methods of protection were implemented.

Assumptions: For the sake of this analysis, I must simplify the problem by making several assumptions. These assumptions are not unreasonable; all of them are backed by substantial scientific research:

1) The concentration of CO_2 in the atmosphere will continue to rise, as per measurements of the last century (Fig. 2).

2) This rise in CO_2 in the atmosphere will cause an increase in the

I don't think you need the "Don't quote or cite" on these figures, as the graphs you are using are from published sources.

greenhouse effect. Thus, global temperature will tend to rise over time (Fig. 3).

3) The increased temperature on a global scale will cause a gradual melting of glaciers in the icecaps of Greenland and Antarctica. This in turn will lead to some amount of rise in sea-level. OK

Defining and Analyzing Human Activities: The human activities in this case can be divided into two major strategies of protecting the community against the rising sea-level. These basic methods are: 1) attempting to maintain the edge of the shoreline with barriers , sand dune refortification, and seawalls, or 2) simply retreating from the endangered zone. Does this mean that floodproofing of structures is not feasible or economical?

The incentive behind maintaining the shoreline with artificial barriers is the protection, and hopefully retention of valuable coastal land. The most commonly used methods of beach protection have been groins and beach nourishment (Barth & Titus, 1984). Groins are long artificial barriers extending out perpendicular from the shore intented to trap sand that is eroding away. Beach nourishment is the actual addition of sand to beaches to replace the sand which has been eroded (Barth & Titus, 1984). In the hypothetical city, groins and beach nourishment would be used primarily on the barrier beaches, and also along some of the coastal recreational areas (Fig. 4).

Other options for protecting the shoreline include bulkheads, sea walls, levees, revetments, and off-shore breakwaters (Barth et al., July 1984). In many coastal communities, such as Galveston, TX, such structures already exist, so the responses might include strengthening existing structures to withstand higher sea-levels (Barth et al., July 1984). Physically, both of these structures would require artificial materials, such as cement and steel, to be placed in the coastal waters several hundred yards from the shore.

The other strategy for dealing with a rise in sea-level is to retreat from the shoreline. The main method used to ensure retreat is the rezoning of coastal lands to ~~allow for some sea-level rise.~~ eliminate or reduce some uses. A similar problem in North Carolina involves the rezoning of seashores endangered by erosion. The state has rezoned coastal land so that most new home construction must be set back from the shore a distance equal to 30 years of erosion (Barth & Titus, 1984). This method is particularly useful immediately after a disaster, before redevelopment can occur. Authorities in Maryland impose a temporary building moratorium after a major storm to determine what redevelopment is appropriate to prevent future disasters (Barth & Titus, 1984). Of course, post-disaster solutions are not effective in terms of saving endangered lives and property; therefore an emphasis is now placed on pre-disaster prediction. Those homeowners with endangered property are subsequently advised not to improve on their homes. Many people may be unwilling to give up their homes, so some communities might choose to offer compensation to these people. In our hypothetical example, the homes located on the barrier island would fall in the latter category. Realizing the potential danger presented to the homes, the community would probably prohibit future building on the islands, and advise residents to move elsewhere.

Rezoning would also include a change in the status of some areas, from saleable real estate to conservancy districts or parkland (Barth et al., 1984). Such a change in status would prevent ill-fated construction as well as preserving valuable land for public benefit.

Another problem faced by communities which choose to retreat from the coast is the relocation of existing storm drains. One approach used by planners is to enhance gravity drainage through the use of larger pipes (Titus et al., 1985). This would require digging up old pipes, and replacing them with the larger ones to accomodate more water flow. However, in areas with extremely low elevations, gravity drainage may not be possible after a rise in sea-level, since the pipes must remain above sea-level to function. Pipes below sea-level must rely on pumps which facilitate 'forced drainage.' To convert the obsolete gravity drainage systems, locks and flap-gates which only allow gravity drainage at low tides can be implemented (Titus et al., 1985). In our hypothetical city, the drainage systems marked A and B would have to be dug up and replaced by larger pipes with locks and flap-gates (Fig. 5).

Residuals and Other Effects: The residuals of each type of strategy must be declared separately, since each strategy would use different means and produce different effects.

<u>Defending the Shoreline:</u> The use of groins to curtail erosion helps to maintain the shoreline in a particular area by trapping eroding sands. However, groins have adverse effects on the shorelines downshore from the groin. Since groins prevent the movement of sand along the beach, the sand beyond the groin will tend to erode, and replacement sand will be unavailable (Barth & Titus, 1984). In other words, a discontinuity is

formed in sand distribution; with sand accumulating on the groin and eroding from other areas. Potentially, the construction of a groin in our hypothetical city, as in Fig. 6, will cause parts of the barrier island to recede.

Beach nourishment does not adversely affect neighboring areas, but it is probably more expensive, and possibly harmful to the beach dune environment (Barth & Titus, 1984). The cost to raise the beach profile by 1 foot has been estimated at $2-5 million per mile of beach (Barth & Titus, 1984). Also, the dumping of foreign sands on a wetland may have adverse ecological effects. Wetlands are areas of slow, gradual deposition of sediments. A sudden addition of sand would likely destroy a considerable portion of the natural environment, and upset the ecological balance. There also may be some adverse effects on beach dunes, because dune grasses and flowering plants will be buried. Some dune plants, however, show particular resiliency to burying, so the effects on dunes might be less severe than those on wetlands.

Artificial structures such as bulkheads and breakwaters have some value in preventing damage by high waves and tidal surges. In Providence, RI, a hurricane wall was recently constructed, and helped to avert major damage to the harbor during hurricane Gloria. There may be some adverse impact on coastal marine organisms, since they necessarily destroy the benthic (bottom-dwelling) ecosystem directly beneath. However, many organisms respond well to additional settling space provided by the structure. In our hypothetical example, the construction of a seawall to protect the low-lying areas of the harbor would likely help to minimize wave damages (Fig. 6). However, these types of barriers will be of little or no value in minimizing sea-level rise.

Specialized barriers could be used to protect community aquifers from salt-water intrusion. There has been little research done on the feasibility of such a barrier, but its utility in protection of freshwater resources is not in doubt.

Why wouldn't existing structures be permitted to be used in their present use? That's customary when land is rezoned.

Retreat: A retreat from coastal lands would obviously cause a decrease in the amount of coastal real estate available for development. Also, the retreat would necessitate abandoning some endangered structures, and this would mean a loss of property value as well as land value. The rezoning of commercial land would have some benefits as well. Wetland preservation would benefit, since these areas could be set aside as conservancies or parks (Barth & Titus, 1984). The rising sea-level would endanger the ecological balance of the wetland, but by limiting development in the wetland area, the damage would be minimal. Titus et al., note in the National Wetlands Newsletter, "because of substantial development of areas immediately landward of the marshes, these ecosystems may be squeezed (into destruction) by a rising sea-level."

The relocation of storm drains would require digging up the old drains in low-lying areas. However, most older cities replace broken pipes often anyway, so there would be no additional residuals to the surrounding environment (Titus et al., 1984). There would be some cost involved in refitting larger drains with locks and flap gates; that cost would depend on the actual number of drains to be replaced. The relocation of storm drains would produce some benefits as well. Gravity drainage systems which become submerged tend to back up, and flooding in the urban areas

? But replacing a pipe in its existing location is less disruptive than digging a new trench and moving the pipe would result if the drains were not upgraded. Also, stagnated drains can become polluted more easily, reducing aesthetic and health standards.

Effects on Natural Systems and Ambient Environment: The problems created by a rising sea-level are very diverse, because the entire coastal strip of all continents is affected. First, there are serious changes in the ecology of flooded shorelines. The erosion and submergence of barrier islands exposes the coastline to more severe waves and tides. This in turn leads to changes in the ecological balance, since wave stress selects against many native species. In wetlands, the erosion of the peat layer removes the stable environment necessary for most marshland grasses. Thus, the marsh may give way to a new ecosystem.

Salinity stress from the rising waters also has an effect on coastal ecosystems. Particularly vulnerable are estuaries, which depend on specific ranges of salinity. A rise in sea-level would force saline water further inland, contaminating fresh-water ecosystems with saline water. Since aquifers are adjacent to estuaries, these fresh-water reservoirs also would be in jeopardy of pollution (Sea Level Rise in the Delaware Estuary, 1985).

Geologically, the erosion of sands would change the structure of the shoreline. Beaches with less sand lose their resiliency to change. Thus, as erosion increases, the risk of landslides along the coast would also increase.

Physically, the changes would be most severe. The area exposed to a risk of flooding would increase by far more than the rise in sea-level; a one foot water rise would erode most shorelines over 1000 feet (Barth &

? What do you mean? 1000' elevation? 1000' wide?

see corrected section

Titus, 1984.) The risk to a particular area is inversely proportional to the area's elevation above sea level. High elevations are at relatively low risks from flooding, but low elevations are at very high risks. Also, most of the east coast is slowly subsiding, with local values ranging from 2-3 in. (Louisiana) to 22 in. (Galveston) per century (Barth & Titus, 1985.) This causes an increase in the risk to coastal areas which are experiencing substantial land subsidence.

Natural systems models have been used to predict the physical advance of flood waters. In his studies on the Galveston, TX and Charleston, SC areas, Barth used a simple model with categories for low, medium, and high scenarios for sea-level rise. Using a topographic map of the target area, Barth predicted the square footage of land which would be lost for each of these scenarios (Barth et al., 1984). Such a model is helpful for recognizing areas where danger is severe, but the model is incomplete in that only three estimates are made. With only three scenarios, some type of interpolation must be used for any other scenario. In areas with severe topographic discontinuity, more analyses are necessary to predict accurately ~~predict~~ the amount of land in danger. — see corrected section as an addition here

Annotated References

Author not cited, "Peer Review Draft of The Greenhouse Effect, Sea Level Rise, and Salinity in the Delaware Estuary", (Wash, D.C. 1985.)

This reference was useful in prediction of effects on natural systems

Barth, Michael C. et al., "The Economic Impacts of Sea Level Rise on the Galveston, Texas Area". (Wash., D.C., July, 1984)

This reference was useful for its natural systems modeling. Close parallels with the Charleston study were useful in comparisons of site variables

Barth, Michael C. et al., "The Economic Impacts of Sea Level Rise on the Charleston, South Carolina Area". (Wash., D.C., Feb., 1984)

This reference was also useful in analysis of the different strategies used in combatting sea-level rise

Barth, Michael and Titus, James, eds., <u>Greenhouse Effect and Sea Level Rise: A Challenge for This Generation.</u> (Van Nostrand Reinhold, 1984)

Of all of the Barth/Titus articles, this one seemed the most polished, and it was very helpful in getting an overview of the problem as a whole

Eckholm, Erik. "Significant Rise in Sea Level Now Seems Certain", NY Times, (New York, Feb. 18, 1986)

This recent article from the times is an accurate summary of Barth and Titus, and it shows good journalistic accuracy

Noll, Roger C. "Adaptive Approaches to the CO2 Problem". (Cal Tech, 1980+?) *This article was used as a supplement to the research on the greenhouse effect*

Titus, James G., et al. "An Overview of the Possible Impacts of the Expected Greenhouse Warming on Storm Drainage Systems in Coastal Areas" (Wash., D.C. 1985) *This article was very useful for the specific activities and ressiduals involved in storm drainage systems*

Titus, James G., et al. "Sea Level Rise and Wetlands Loss in the United

States" from National Wetlands Newsletter, (Sept.-Oct. 1984) *useful for the natural systems and ecological sections. Good scientific reporting*

US Dept of Commerce, Statistical Abstract of the United States. (US Dept. of Commerce, Wash., D.C., 1985) *provided raw data on coastal communities*

This is a good start, and surveys the major aspects of the problem. The paper is very well written, for which you deserve a lot of credit. There are very few errors and typos. The city is an interesting one.

I think the city needs some more socioeconomic detail – where are poor areas, industry, business districts, etc.?

The only thing the paper seems weak on are the natural systems models. Aren't there fairly sophisticated models mentioned in some of the papers I gave you? Even if not, I'd expect there to be some in other literature on the sea-level rise phenomenon.

Grade: B+

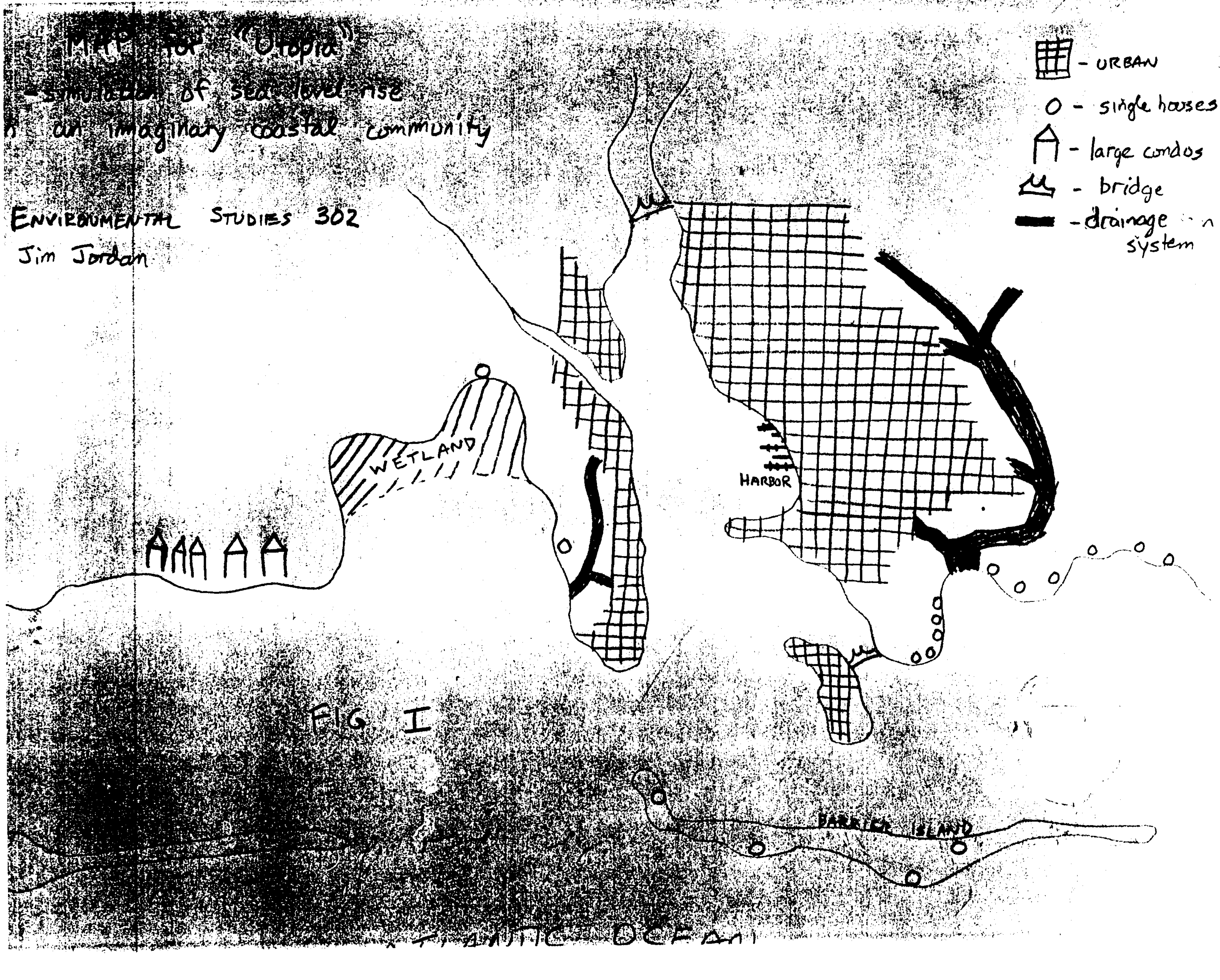
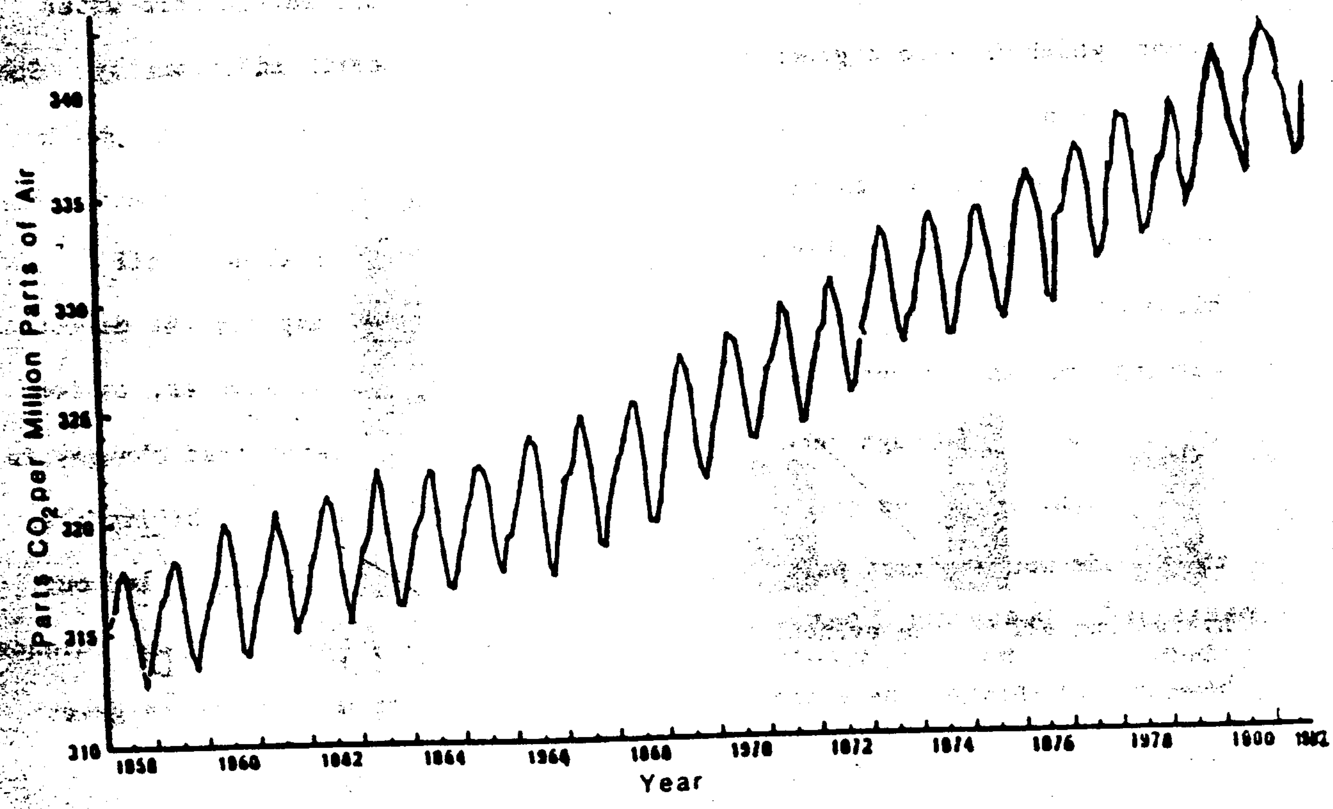

MAP for "Utopia"
- simulation of sea level rise
in an imaginary coastal community
ENVIRONMENTAL STUDIES 302
Jim Jordan
- URBAN
o - single houses
- large condos
- bridge
- drainage system
WETLAND
HARBOR
BARRIER ISLAND
FIG I

Fig. 1

FIGURE 2

MEASUREMENTS OF ATMOSPHERIC CARBON-DIOXIDE ABUNDANCE OVER TIME: 1958 to 1982 (parts CO_2 per milligram of air)



Source: Keeling, C.D., R.B. Bacastow, and T.P. Whorf, 1982. Measurements of the Concentration of Carbon Dioxide at Mauna Loa, Hawaii. Carbon Dioxide Review 1982, edited by W. Clark. New York: Oxford University Press, 377-382.

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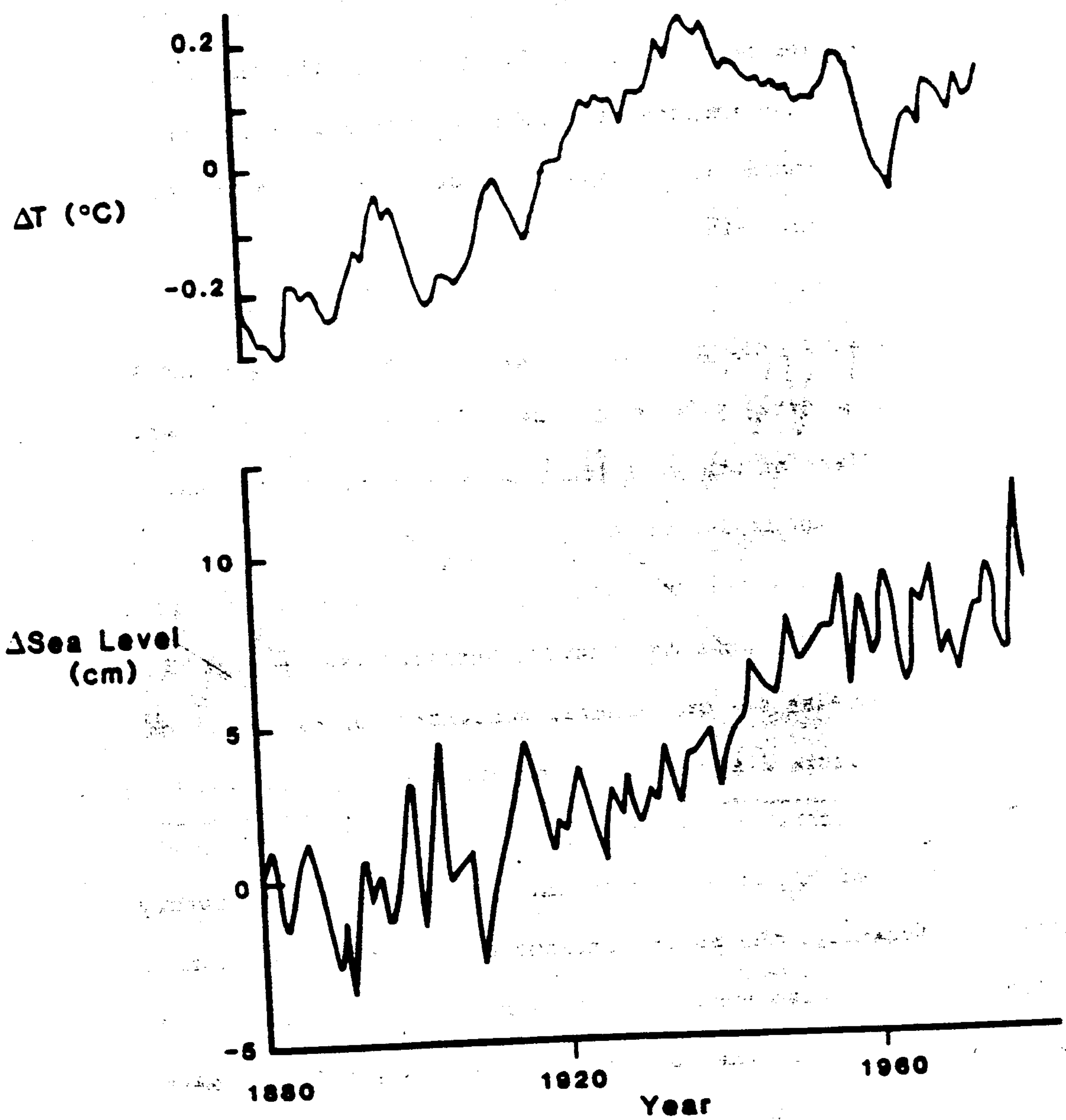
FIGURE 3

COMPARISON OF RECENT HISTORICAL TRENDS IN GLOBAL TEMPERATURE AND SEA LEVEL



Sources: Temperature curve after: Hansen, J.E., D. Johnson, A. Lacis, S. Lebedeff, D. Rind, and G. Russell, 1981. Climate Impact of Increasing Atmospheric Carbon Dioxide, Science 213:957-966. Sea level curve adapted from Gornitz, V., S. Lebedeff, and J. Hansen, 1982. Global Sea Level Trend in the Past Century. Science 215:1611-1614.

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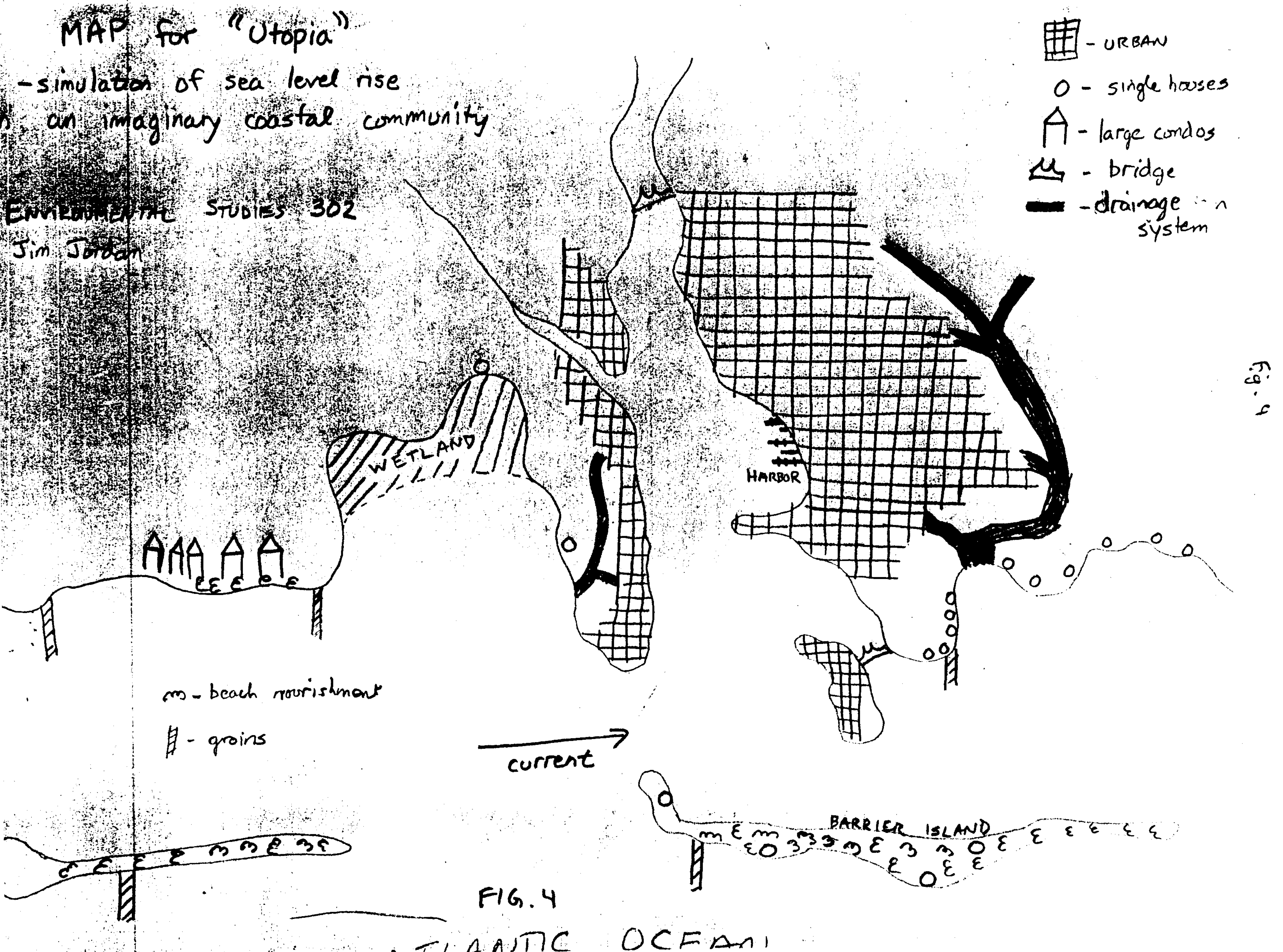

MAP for "Utopia"
-simulation of sea level rise
an imaginary coastal community
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Jim Jordan
- URBAN
o - single houses
- large condos
- bridge
- drainage system
WETLAND
HARBOR
m - beach nourishment
- groins
current
BARRIER ISLAND
ATLANTIC OCEAN
Fig. 4

FIG. 4

simulation of sea level rise
in an imaginary coastal community

ENVIRONMENTAL STUDIES 302

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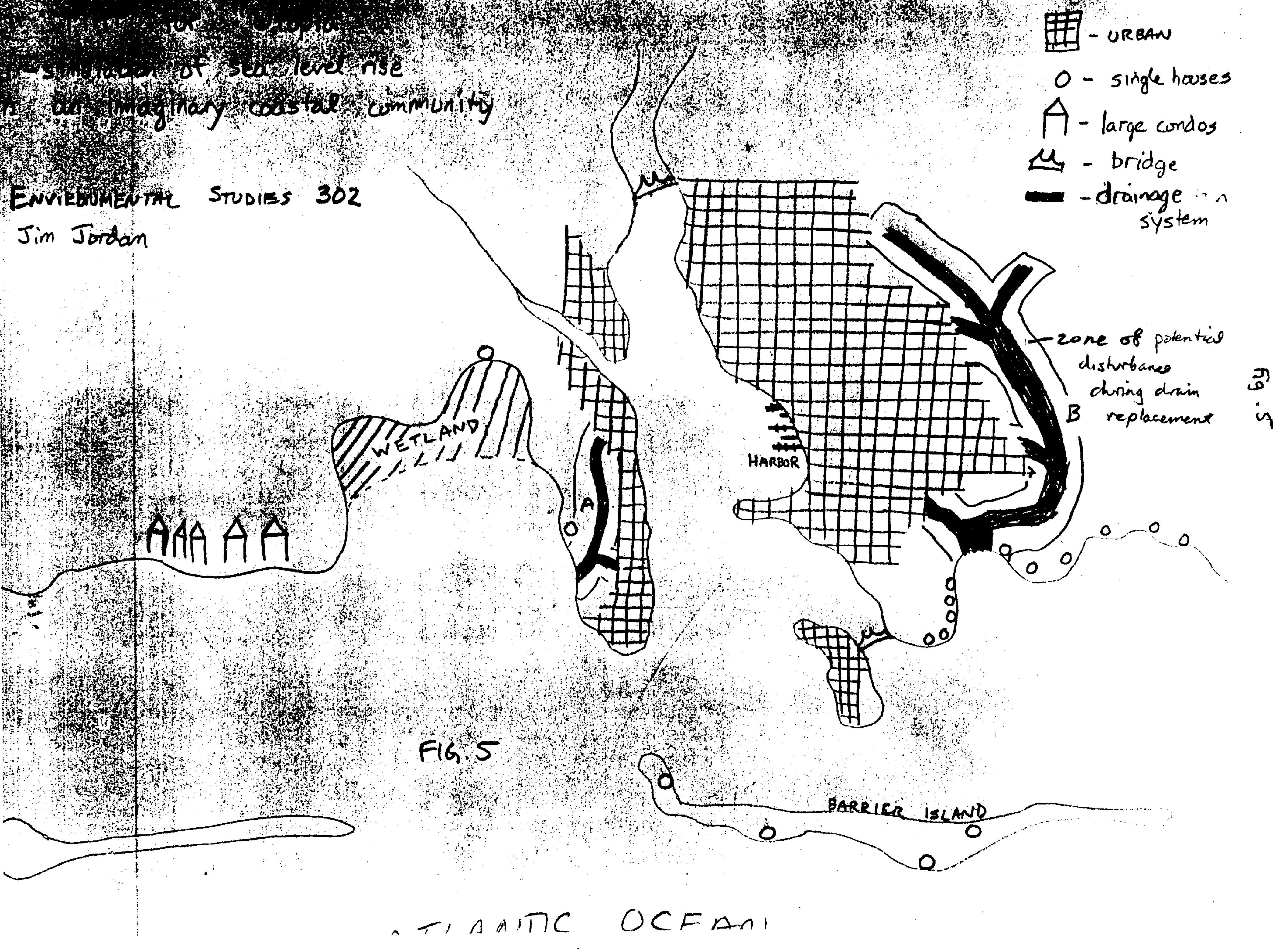
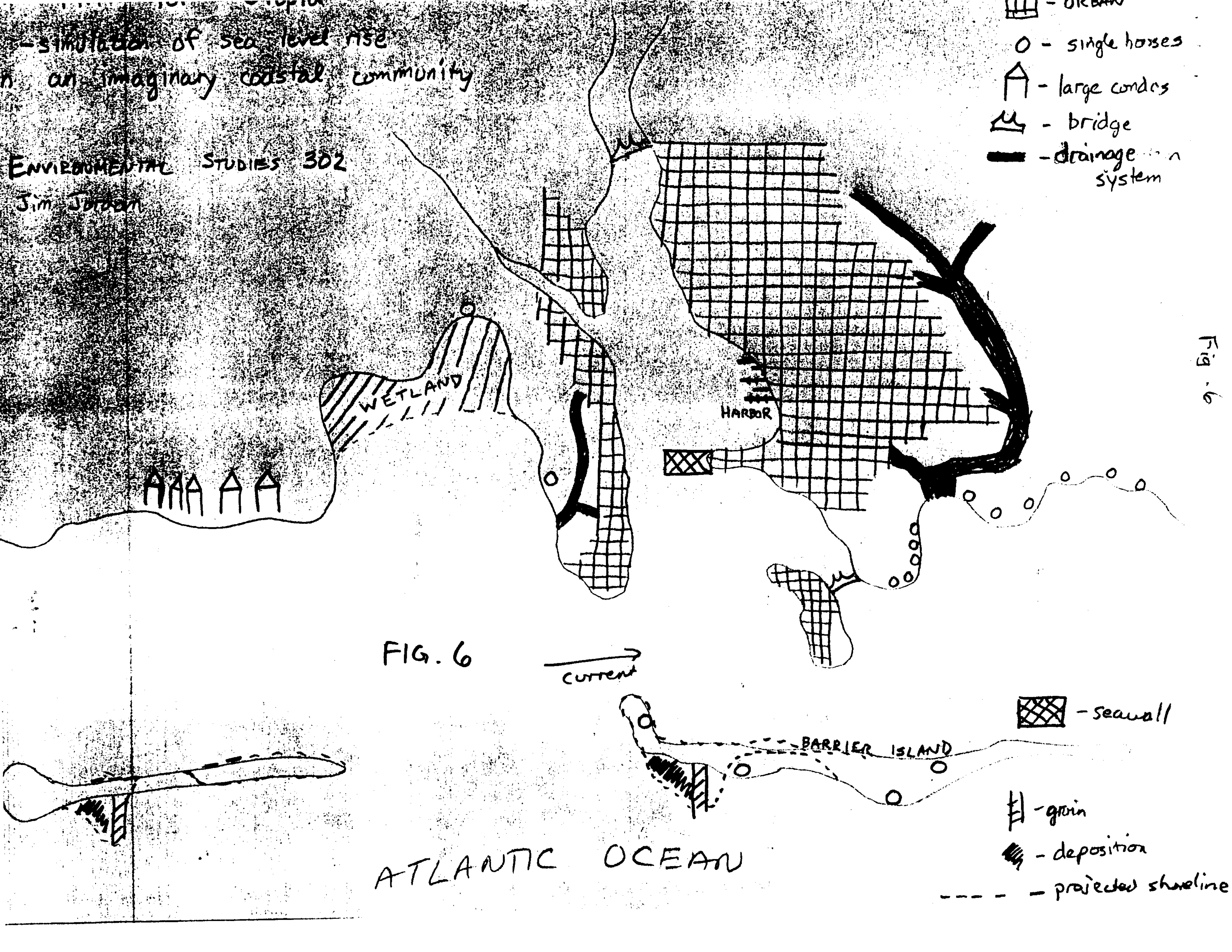


FIG. 5

Fig. 5



-simulation of sea level rise
n an imaginary coastal community
ENVIRONMENTAL STUDIES 302
Jim Jordan
- URBAN
O - single houses
- large condos
- bridge
- drainage system
Fig. 6
WETLAND
HARBOR
current
BARRIER ISLAND
- seawall
- groin
- deposition
- projected shoreline
ATLANTIC OCEAN

FIG. 6

Part II

Corrections from first paper: p. 9: The risk to a particular area is inversely proportional to the area's elevation above sea-level. Areas which are located at high elevations are most likely to be flooded, since the water level will rise at most several feet. However, low-lying areas are at the highest risk, since a rise of a few feet in sea-level will inundate all areas in which the elevation is less than the height of sea-level rise. In some areas with very gentle slopes to the water, this poses a severe problem. In this city, the most endangered area happens to be a very poor section of the city, since more wealthy inhabitants prefer the views afforded by higher elevations. The combination of a serious flood threat and a low-income neighborhood will create special problems for decision-makers. These problems will be discussed later in the paper.

p. 9: Barth used another natural systems model to predict the effects of sea-level rise on salinity changes in the Delaware River Estuary. In this system, the greatest concern is of increased chlorinity at the head of the estuary. Increased chlorinity would affect the ecology of the system, as well as affecting some anthropocentric uses such as contaminating some freshwater aquifers and decreasing oyster production (Effects of Rising Salinity in the Delaware Estuary,1985). Barth used a model developed by Thatcher and Harleman which relates freshwater inflows, tides, and ocean salinities to chloride distribution in the estuary. The model can project salinities over time, and also can predict effects for a variety of low, medium, or high scenarios. A typical simulation will predict the maximum and minimum chlorinity readings at key locations for each tidal cycle over a period of a year or more (Thatcher & Harleman, 1981).

In this model, the estuary was simplified to an extent by dividing it into a core section, which represents the current estuary, and a storage section which represents potential shallow, inundated regions (Effects of Rising Salinity in the Delaware Estuary, 1985). This is a much more complicated model than Barth's Galveston model, yet it does not directly address the problem of coastal planning. It might be feasible and worthwhile to modify this model, so that it could estimate maximum and minimum water levels over time in a coastal community. This type of model, however, would be extremely useful in solving the planning problem.

Effects on Receptors: The major receptors in this problem are the residents of the coastal areas. Obviously, the residents living in low-lying areas or highly exposed coastal strips are more threatened than other residents of the community, since the probability of a flood or storm surge is much greater in these areas. The city could be divided into high risk, medium risk, and low-risk areas. The high risk areas represent a high potential social cost, and the low risk areas represent a low potential social cost. These concepts will be addressed later in an application of McHarg's land-suitability analysis.

The receptors not only differ in the level of risk that they face, but they also differ in socio-economic status, in their perception of the potential risk, and in their concern for environmental quality. There are certainly many other grounds on which the receptors may differ, but I will only analyze these three variables.

The socio-economic status is important, because it reflects the ability of the receptor to move out of an endangered home. A family with a very low socio-economic status is less likely to be able to afford a major move. Also, this type of family will have greater difficulty recovering from losses after a large flood. Therefore, the social cost will be higher if flooding occurs in a low-income area. For this reason, the land-suitability analysis which appears later in the paper will also include a socio-economic map.

The receptors also differ in their perception of the risk which they face. Many people are not likely to believe that sea-level rise will affect them, and thus they will be unwilling to voluntarily move from endangered areas. The receptors will have to be informed of the problem, and convinced that there is a real risk. This is potentially a major obstacle for the planners to overcome, because the residents of the community may be adamant in their opposition to any solution which uses their tax dollars for a problem perceived as a minimal threat.

Finally, receptors will differ in their concern for environmental quality. Some receptors may prefer the construction of bulkheads and groins, despite their detrimental effects to the environment. In fact, they may choose to construct their own barriers against rising waters. For this reason, the planners should account for the effects of the various solutions on environmental quality in their assessment.

Values: To account for the value of environmental quality, some negative value must be assessed to those solutions which require disruption of the environment. For the most part, the solution of "protecting the shoreline" involves the most environmental damage, from beach nourishment, groins, and bulkheads. Thus, the costs of this solution should include consideration of the cost of this damage. Rising sea-level will have serious effects on wetland communities, but none of the proposed solutions will minimize these losses. Therefore, these effects can be considered constant to the decision-maker. This does not imply that the wetland loss is unimportant, but simply that it is not relevant to this problem.

Another important value to be considered in the decision is concern for future generations as opposed to the welfare of the current generation. It would be easy for the town to put off the decision indefinitely, since the effects are only detrimental in the long term. However, passing the problem along is not the correct solution. It may take a long time to mobilize the resources for a viable solution, and delaying the decision only shortens the time available. Also, the planners may decide on gradual implementation of a solution, which would require a fairly long period of time. In summary, there must be some desire to obtain a solution to benefit the future generation.

There will likely be some inequities in the distribution of benefits and costs after a solution is reached. Assuming the solution is effective in protecting coastal residents (as one would hope!), the benefits are distributed primarily among those coastal residents in high risk areas. Some smaller benefits may accrue to those living in moderate risk areas, and certainly very few benefits will accrue to those living in areas of little or no risk. There is no way to disperse the benefits among citizens in this problem, because the major benefit is the elimination of a danger which is not faced by most of the community. However, it might be reasonable to disperse some of the cost among those coastal residents who will receive the benefits.

As mentioned before, the planners must consider the extent to which residents will perceive the potential risk of sea-level rise. If residents underestimate the risk, as they are likely to do, there will be an increased cost associated with the "no-action" or "optional relocation" type of plans.

Valuation of Effects: The valuation of effects for this particular problem could be done in a number of ways. In this section I will discuss the four methods which seem most relevant to the problem: decision analysis, cost-benefit analysis, planning balance sheet, and land suitability analysis.

The method of decision analysis seems well suited for application to planning in the city, since there is some uncertainty about the exact amount by which the sea will rise. One possible decision tree shown in Fig. 1 includes three possible solutions to the problem: 1) the city does not prepare at all; 2) the city installs groins, levees, and other structures to defend the shoreline but does not retreat; and 3) the city retreats from threatened areas by rezoning those lands in flood zones. This simplified decision tree allows for four levels of sea-rise, as adapted from the Galveston study of Barth et al. (1984). The probabilities listed in the tree reflect general opinions of most researchers; that is, no rise in sea-level in the next 50 years is highly unlikely, and both the low and high scenarios are fairly unlikely (Barth et al, 1984, p. 5).

Economic impacts of the rising sea-level for the decision tree were also obtained from Barth's Galveston study. In the case where the city does not prepare, full damages are assessed, discounted at 3%. For the second case, full damages are assessed in the area lost due to shoreline movement, since defending the shoreline does not reduce this loss. However, only half-damage was assessed for the floodplain areas, since seawalls, groins and beach nourishment tend to reduce damage from storm surges and high waves. In the final case, no damage from rising water was assessed, because it is assumed that the retreat has removed structures in the area of a potential flood. The damage values listed in Fig. 1 have no value in themselves, but if the costs of retreat and protection could be measured, the damage values could be used comparatively to find the lowest expected cost solution.

If a decision-analysis method were used, we might expect the people of the city to be risk-preferring rather than risk-averting. This is due to a psychological phenomenon in which people prefer a risky choice to avert a potential loss, but prefer a sure choice to obtain a certain gain. Since losses are involved here, we would expect that there would be an incentive in society to risk the possibility of sea level rise and thus do nothing.

Cost-benefit analysis is more difficult to apply in this problem since there are no monetary values involved. To make cost-benefit analysis into a viable alternative, more research would have to be done on the cost of implementation for each method, and the potential costs incurred if sea-level were to rise. Also, if cost-benefit were to be used, the future could not be discounted since many of the damage costs will be accruing in the future.

An alternative to cost-benefit analysis would be the planning balance sheet method, since this does not require specific monetary values. Also, planning-balance sheets are very useful for hypothetical or planned developments. The city discussed here definitely falls into that category.

The planning balance sheet shown in Fig. 2 is an example of a possible way in which to apply this method. In this case, it is difficult to break down the various costs for each separate solution, but it is fairly easy to compare the relative benefits and costs for each separate solution. The retreat solution definitely minimizes relative costs to environment and society, but the unknown implementation cost may be inordinately large. Many ~~separate~~ costs to the environment are listed for the solution of defending the shoreline, but again the exact costs of implementation are unknown.

A final valuation method which might be useful in this problem is McHarg's land suitability analysis. However, this method would only be useful in identifying areas which would have the highest social cost after flooding due to rising sea-level. That is, a large scale analysis of the whole community would not be applicable, since this particular problem is localized to the coastal region. However, establishing a hierarchy of problem intensity in coastal areas would help planners to find solutions first for those areas in which a solution is most urgent. Overlays for this type of analysis should definitely include the elevation above sea-level, socio-economic status, population density, exposure to storm surge and high waves, and any other variables deemed to be important in a particular area. For the hypothetical city, I have drawn maps for each of the preceding variables, as an example of how land-suitability analysis might be applied.

Overlaying the maps shows that the small island outside the main harbor will have the highest social cost if flooding were to occur. This is because it has a low socio-economic status (Fig. 3), high population density (Fig. 4), high exposure to storms (Fig. 5), and moderate elevation (Fig. 6). It is evident that this method can be used to assess the total social cost of potential flooding in any particular area.

Conclusion: Because the decision involves planning for future environmental problems, many communities decide on a solution which delays action until the effects seem inevitable. However, I believe that this is a foolish way to treat the situation, because that approach considerably lessens the possible economic benefits. During the period of delay, new structures will be built and more money will be invested in existing structures in the endangered areas. Then, when the decision is finally made to defend or retreat, the money spent on development has been lost.

The solution of defending the shoreline does not seem feasible to me because it does not protect structures against ambient rises in sea-level. Rather, it defends against occasional damages resulting from storm surge and high waves. Even so, the structures which would be built would only be effective for a limited period of time. On a small scale, this method could be used in the areas most threatened by storms, but on a large scale, this solution simply does not solve most of the problems of a constant rise in sea-level.

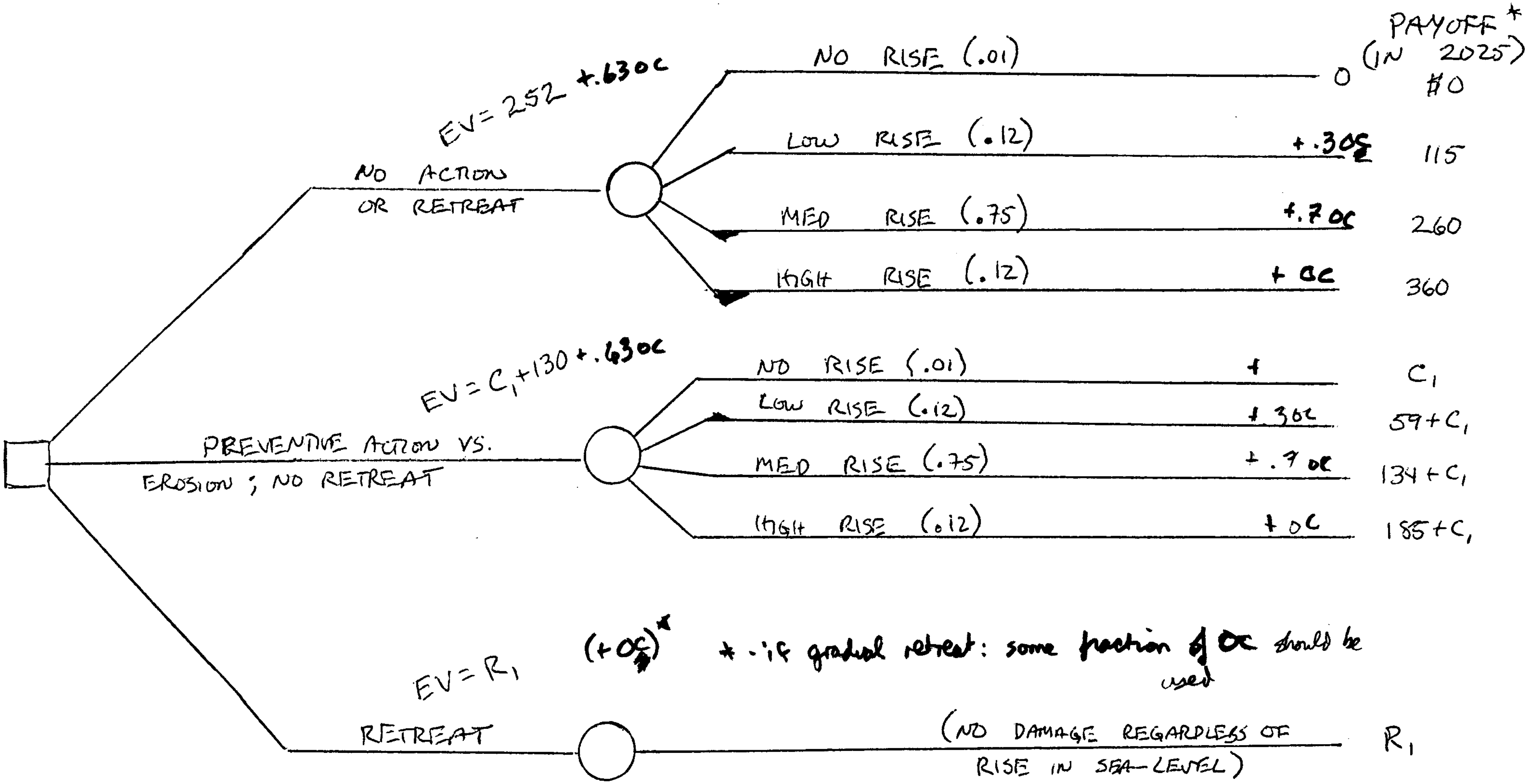
I would advocate a gradual pattern of retreat from the shoreline, since this would allow planners to both assess the severity of the risk and to conserve economic benefits. The planners can assess the severity of the risk directly, since they will observe during the next 25-50 years the actual pattern of sea-level rise. Also, during this time, economic benefits will be conserved as long as the retreat is sufficient to protect structures from flood damage.

Specifically, I would suggest that the planners determine the highest level of expected sea-level rise for the next 20-year period and they label that as the "risk-zone". Then, they should rezone existing coastal land to disallow improvements or developments in the risk zone beginning immediately. After the 20-year period, the planners should repeat this procedure, with a new assessment of the 20-year risk zone, as long as new parcels of land fall into this zone. The project should be financed through city and state taxes.

This solution seems to be the most feasible, since it includes a gradual reassessment of the problem. It would be less feasible to rezone the land all at once, because there could be a reversal or an aggravation in the rising trend. The solution of continued reappraisal allows for change in the rising trend, and as well allows for maximum conservation of social and environmental benefits.

FIG. 1: POTENTIAL USE OF A DECISION-TREE

(r = 3% discount)



C_1 - cost of defending shoreline implementation

R_1 - cost of retreat from shoreline implementation

* (Probabilities) Adapted from Titus, Scenarios for Galveston Sea Level Rise

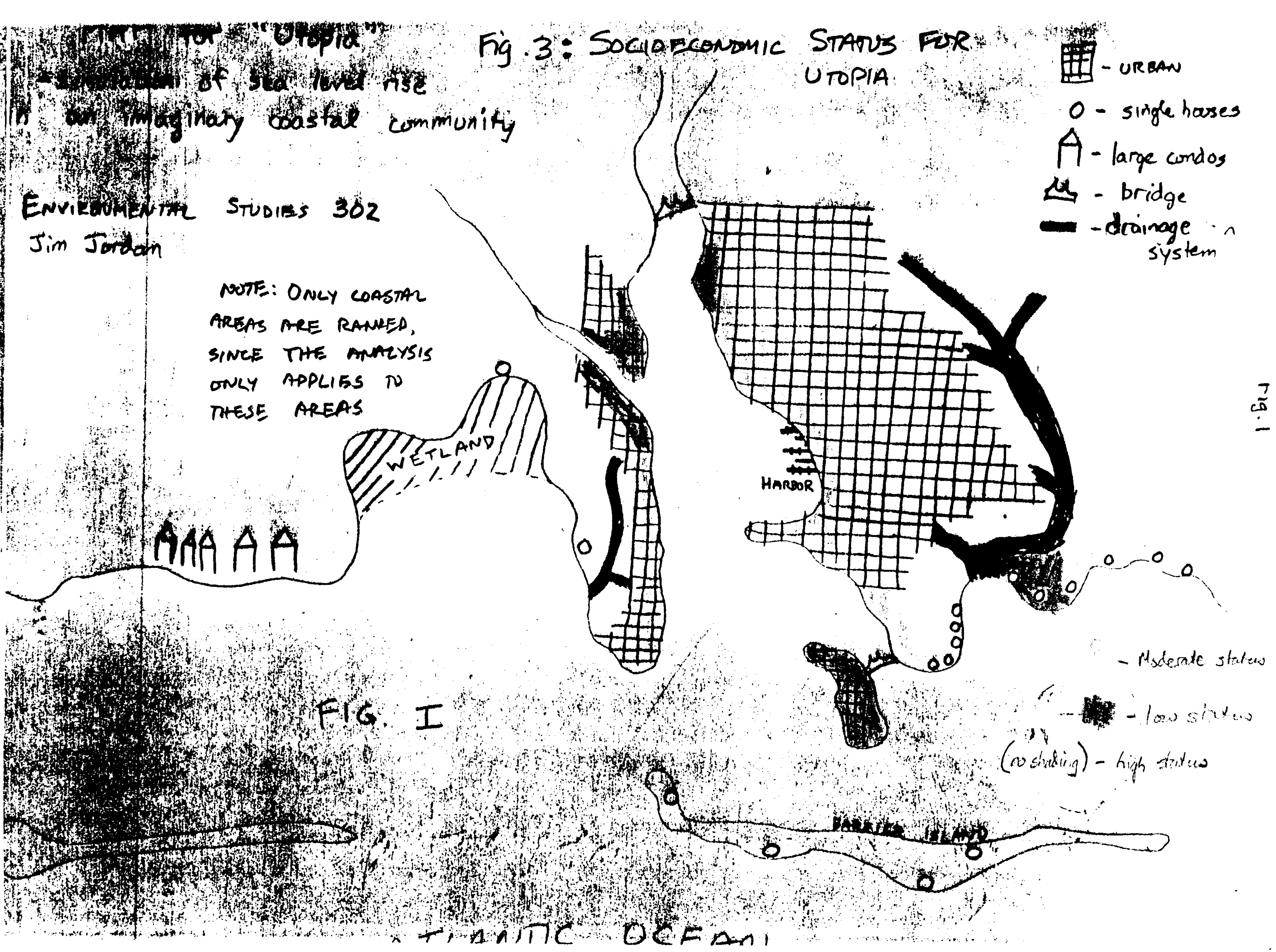
PAYOFFS in millions $

Fig. 2: PLANNING BALANCE SHEET

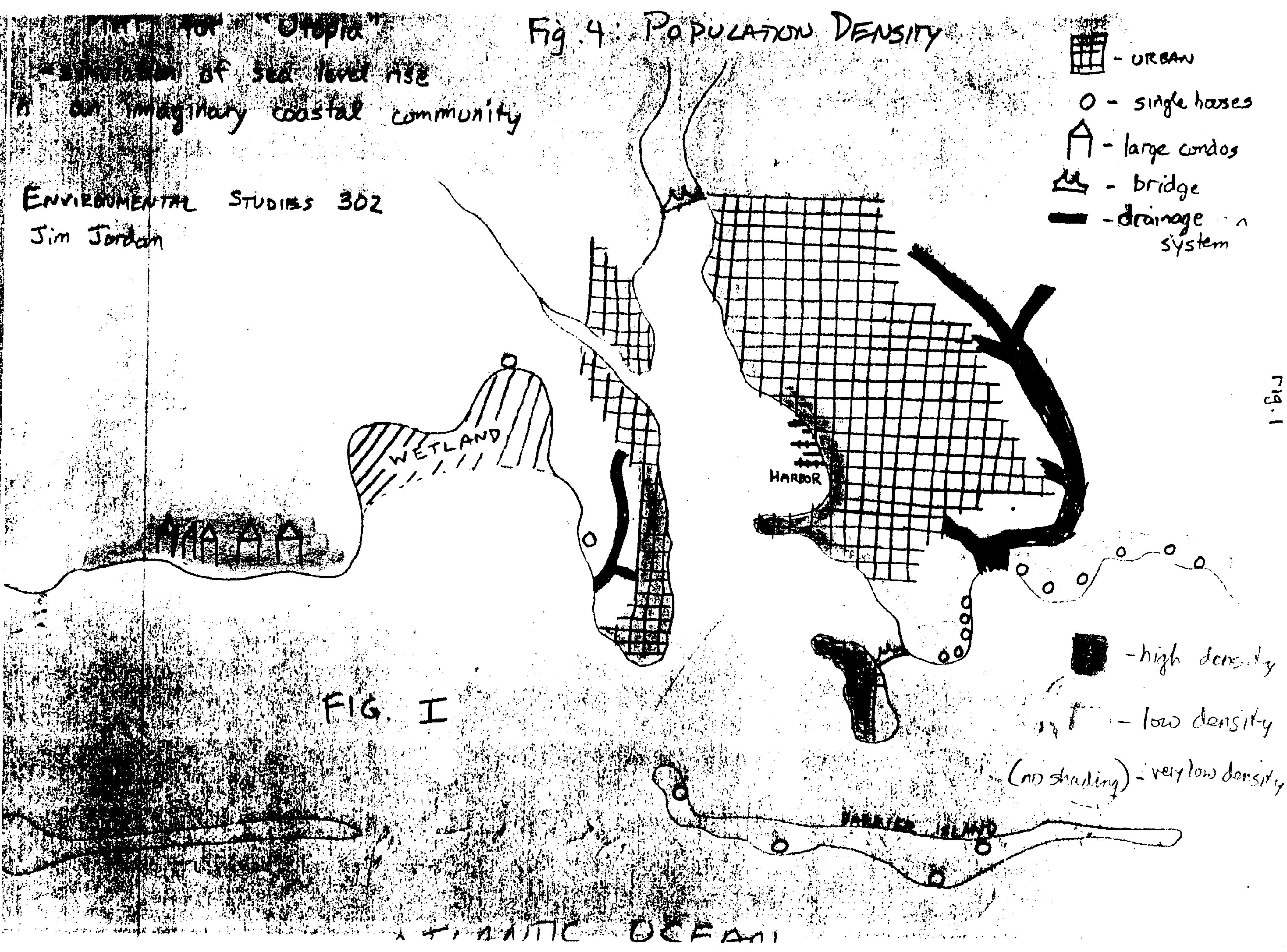
(SIMPLIFIED: ONE POSSIBLE APPLICATION)

Sector	Benefit	Cost
City	Tax revenues to support project	Implementation of project
Coastal residents	Safety from rising waters. No loss of life or property	Tax payments to city
Non-Coastal residents		Tax payments to city
Environment		Damage from groins, levees, bulkheads *

* these damages only applicable if the "defending the shoreline" method is employed. No environmental damage would directly result from "retreat"



"Utopia"
of sea level rise
an imaginary coastal community
Fig. 3: SOCIOECONOMIC STATUS FOR UTOPIA
- URBAN
O - single houses
- large condos
- bridge
- drainage system
ENVIRONMENTAL STUDIES 302
Jim Jordan
NOTE: ONLY COASTAL AREAS ARE RANKED, SINCE THE ANALYSIS ONLY APPLIES TO THESE AREAS
WETLAND
HARBOR
- Moderate status
- low status
(no shading) - high status
FIG. I
BARRIER ISLAND
Fig. 1



"Utopia"
of sea level rise
an imaginary coastal community
Fig. 4: Population Density
ENVIRONMENTAL STUDIES 302
Jim Jordan
- URBAN
O - single houses
- large condos
- bridge
- drainage system
WETLAND
HARBOR
-high density
- low density
(no shading) - very low density
FIG. I

Fig. 1

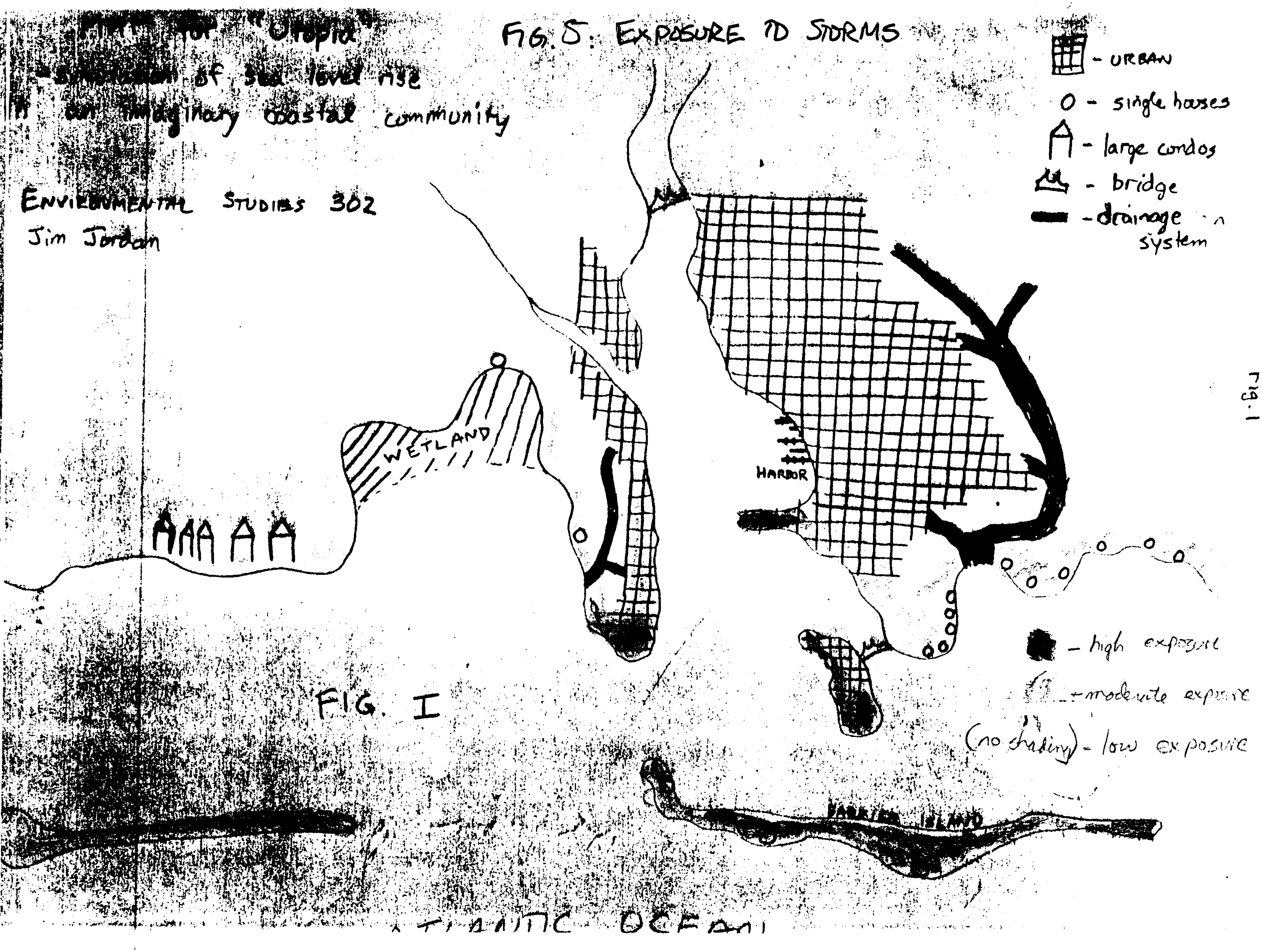

"Utopia"
of sea level rise
an imaginary coastal community
FIG. 5: EXPOSURE TO STORMS
ENVIRONMENTAL STUDIES 302
Jim Jordan
- URBAN
O - single houses
- large condos
- bridge
- drainage system
WETLAND
HARBOR
- high exposure
- moderate exposure
(no shading) - low exposure
FIG. I
TLANTIC OCEAN

Fig. 1

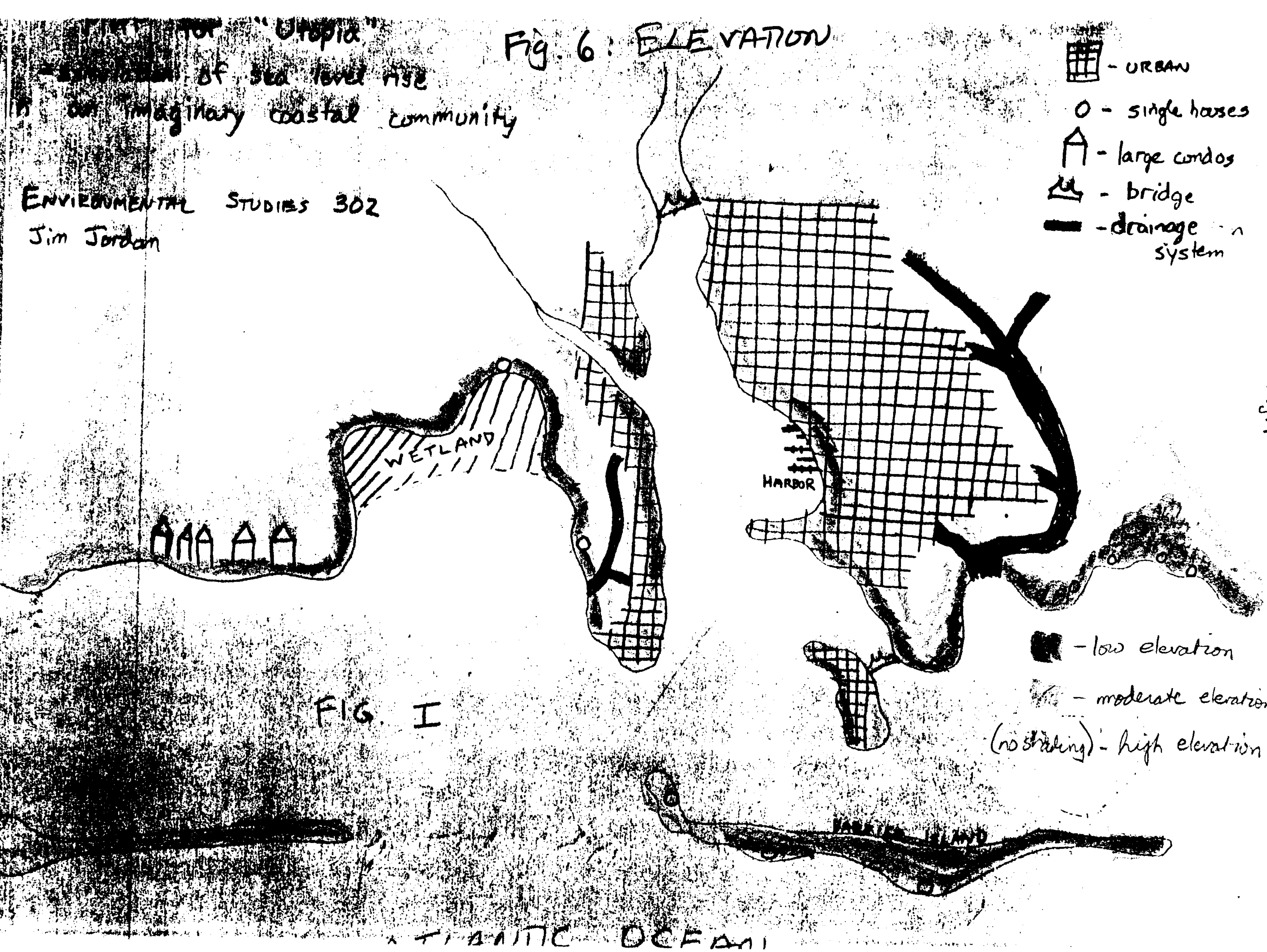

"Utopia"
of sea level rise
an imaginary coastal community
ENVIRONMENTAL STUDIES 302
Jim Jordan
Fig. 6: ELEVATION
- URBAN
O - single houses
- large condos
- bridge
- drainage system
WETLAND
HARBOR
- low elevation
- moderate elevation
(no shading) - high elevation
FIG. I

Fig. 1

Annotated References

Author not cited, "Peer Review Draft of The Greenhouse Effect, Sea Level Rise, and Salinity in the Delaware Estuary", (Wash, D.C. 1985.)

This reference was useful in prediction of effects on natural systems

Barth, Michael C. et al., "The Economic Impacts of Sea Level Rise on the Galveston, Texas Area". (Wash., D.C., July, 1984)

This reference was useful for its natural systems modeling. It's close parallels with the Charleston study were useful in comparisons of site variables

Barth, Michael C. et al., "The Economic Impacts of Sea Level Rise on the Charleston, South Carolina Area". (Wash., D.C., Feb., 1984)

This reference was also useful in analysis of the different strategies used in combatting sea-level rise

Barth, Michael and Titus, James, eds., <u>Greenhouse Effect and Sea Level Rise: A Challenge for This Generation.</u> (Van Nostrand Reinhold, 1984)

Of all of the Barth/Titus articles, this one seemed the most polished, and it was very helpful in getting an overview of the problem as a whole

Eckholm, Erik. "Significant Rise in Sea Level Now Seems Certain", NY Times, (New York, Feb. 18, 1986)

This recent article from the times is an accurate summary of Barth and Titus, and it shows good journalistic accuracy

Noll, Roger C. "Adaptive Approaches to the CO2 Problem". (Cal Tech, 1980+?) *This article was used as a supplement to the research on the greenhouse effect*

Thatcher and Harleman, "Mathematical modeling of the salinity change in the Delaware River Estuary", 1981 *this article was useful for its detailed natural systems model of the river*

Titus, James G., et al. "An Overview of the Possible Impacts of the Expected Greenhouse Warming on Storm Drainage Systems in Coastal Areas" (Wash., D.C. 1985) *This article was very useful for the specific activities and ressiduals involved in storm drainage systems*

Titus, James G., et al. "Sea Level Rise and Wetlands Loss in the United States" from <u>National Wetlands Newsletter</u>, (Sept.-Oct. 1984) *useful for the natural systems and ecological sections. Good scientific reporting*

US Dept of Commerce, <u>Statistical Abstract of the United States</u>. (US Dept. of Commerce, Wash., D.C., 1985) *provided raw data on coastal communities*