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QUANTITATIVE AIDS TO ENVIRONMENTAL IMPACT ASSESSMENT

John H. Ross

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Environment Canada / Environnement Canada
Lands Directorate / Direction générale des Terres

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The methodology discussed in this report was utilised in the study of a British Columbia port development question in 1973-74. The full report on the port study, An Environmental Assessment of Nanaimo Port Alternatives, was published by Environment Canada.

J.H.C. Ross
Lands Directorate

Preface

The task of environmental assessment necessitates the determination of the future characteristics of an environmental system into which agents of change may be introduced. Although it is desireable to be able to characterize such future environmental systems in quantitative terms, it is unlikely that the attainment of this goal is close at hand. At present, environmentalists can only infer the characteristics of these systems because the interrelationships between their components are imperfectly understood.

This paper presents a novel approach to the identification of environmental interdependencies, and provides a numeric method which aids the researcher in his task of extracting the maximum amount of information from the data at his disposal. As such, it represents a step toward the evaluation of a set of techniques which will permit a more accurate and useful definition of alternate environmental systems.

R. J. McCormack,
Director General,
Lands Directorate.

Préface

La tâche que représente l'évaluation environnementale pose la nécessité de bien définir les caractéristiques futures d'un système environnemental à l'intérieur duquel peuvent être introduits des agents de changement. Il est naturellement souhaitable de parvenir à une caractérisation quantitative de tels systèmes environnementaux futurs, mais présentement, on ne semble pas près d'atteindre cet objectif. Actuellement, les environnementalistes ne peuvent déterminer que par inférence les caractéristiques de ces systèmes parce que l'interaction de leurs composantes n'est qu'imparfaitement comprise.

Dans le présent rapport, on présente une approche nouvelle pour l'identification des interdépendances environnementales et on soumet une méthode numérique qui aide le chercheur à tirer le plus de renseignements possible des données dont il en dispose. Ainsi, ce rapport constitue un pas de plus vers l'évaluation d'une série de techniques qui permettront une définition plus juste et plus utile des systèmes environnementaux possibles.

R.J. McCormack
Directeur générale
Direction générale des terres

ABSTRACT

This paper is concerned with methodologies designed to identify and estimate the relative degree of environmental disruption which may accrue to the environmental system as a result of the adoption of alternative development options. It utilizes a matrix powering technique adapted from network analysis to aid in the identification of environmental interdependencies of up to the Nth order, and provides a method of identifying interrelationships which may have been previously unperceived. The methodology presented here is not meant to be regarded as the final answer to the question of environmental assessment prediction, but merely as a step towards the evolution of a set of techniques which will permit a more accurate and useful definition of alternate environmental systems.

RÉSUMÉ

Ce rapport traite des façons d'identifier les perturbations que peut enfraîner pour un système environnemental l'adoption de différentes options d'aménagement et des facons d'évaluer l'ampleur de ces perturbations. Il se base sur une technique d'élévation de puissance des matrices empruntée à l'analyse par réseaux en vue d'aider à l'identification des interdépendances environnementales remontant jusqu'au nième ordre, et fournit une méthode d'identification des interrelations que auparavant, auraient pu demeurer imperçues.
Les méthodes exposées dans le présent rapport ne sont pas présentées somme une réponse définitive aux problèmes concernant la prévision des évaluations environnementales, mais seulement comme une étape vers la mise en oeuvre d'une série de techniques qui permettront une définition plus juste et plus utile des systèmes environnementaux possibles.

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THEORY

Introduction

Lay and scientific interest in the problems of environmental assessment have increased rapidly, especially in the area of the environmental effects of alternative development proposals. However, there have been few reported attempts to evolve rigorous methodologies aimed at the evaluation of the many environmental parameters involved.

Chief among the reasons for this apparent failure of environmental scientists is the feeling that the 'environment' is an intangible concept and therefore impossible to define, let alone describe in sufficiently precise terms. Accordingly, statements characterizing environmental systems have heretofore been couched in qualitative terms. Under such constraints, it is not difficult to understand why environmental considerations have taken roles subservient to those of economics and engineering. These, being able to present the consequences of each alternative development in 'hard figures', (ie., 'quantitatively' rather than 'qualitatively'), have enjoyed a considerable tactical advantage in the decision-making process, much to the chagrin of environmentalists.

The purpose of this paper is to present numerical aids designed to assist decision makers in their task of assessing environmental systems. Hopefully, the concerns of environmentalists will be more adequately represented in the total array of information which must be assessed before development decisions can be taken.

Theoretical Background

The premier work in the evaluation of environmental impact was undoubtedly that of Leopold et. al.[1] This document, designed to guide U.S. government agencies in the preparation of environmental impact statements called for by the Environmental Policy Act, sets forth a procedure for preparing an environmental impact matrix to facilitate "an assessment of the probable impacts of the variety of specific aspects of the proposed action upon the variety of existing environmental elements and factors".[2]

Using the Leopold approach, probable impacts are assigned numerical weights ranging from 1 to 10 according to both their magnitude and importance. Such weights are based on an objective evaluation of "factual data rather than on preference"[3]. The significant impacts identified by the foregoing process, (i.e., those with large "numerical values for magnitude and importance"[4]), are then discussed verbally in the environmental impact statement.

Although the Leopold approach may be extremely useful in the structuring of information in such a way as to reveal the incidence of probable environmental disruptions and estimates of the magnitude and importance of these disruptions (if indeed they can be identified separately), it has a number of shortcomings which severely restrict its utility. Chief among these are:

(1) only primary impacts may be identified;

(2) no method of between-impact weighting is suggested;

(3) no method of assessing the total impact of a project is presented.

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[1] Leopold, L.B., et. al., A Procedure for Evaluating Environmental Impact, U.S. Geological Circular 645, Washington, 1971

[2] Ibid, p. 4

[3] Idem, p. 6

[4] Ibid, p. 6

The purpose of this paper is to present a methodology designed to overcome the first of these shortcomings by outlining a procedure for identifying higher order disruptions.

An Environmental Component Interaction Matrix

Conventional environmental matrices have, by and large, failed to recognize the dynamic nature of the environmental systems which they have attempted to describe, and have only considered the impacts of proposed developments on environmental components. An alternative approach is to consider the effects of these developments on the interactions or dependencies between the environmental components. Such an approach is possible through the construction and consideration of a component interaction matrix.

The key elements in the construction of such an interaction matrix are, of course, the components. In this context the word 'component' is used to refer to each identifiable element of the environmental system being studied. Thus, for example, salmon, herring and eelgrass may be considered identifiable components. This is not to say that a single component, such as salmon, cannot be subdivided into further groups. Indeed it can. It would be equally valid to designate sockeye, chums, springs and pinks as components. Such creation of additional components invokes 'the argument of the beard' in that one may subdivide to infinity without finding a rationally defensible stopping point. In this respect one is probably best advised to adopt a very catholic attitude towards component creation, and designate only those which are absolutely necessary. It is anticipated that the process of component designation will involve a multi-disciplinary study team, thus several components which apply to the environmental aspects of the impact study may be defined.

Following the identification of a set of components, the study team completes an interaction matrix by entering symbols in the appropriate cells. These symbols denote important interactions or dependencies which may be disrupted by the proposed project. Just how the denotation is to be entered is a moot point. One may, in theory, enter nominal, ordinal, or interval measures of interaction. In the nominal case one may, for example, enter a '1' where an interaction is known to occur and a '0' where none takes place. The use of the ordinal scale is a theoretically simple extension of the nominal case in which the individual interactions are ranked in order of 'importance' and the ranks entered into the corresponding cells in the matrix. This is not to suggest that the difference between the first and second rank interactions and that of the third and fourth is of equal magnitude. Employment of the interval scale would necessitate knowledge of the exact magnitudes of the interactions between each of the variables included in a matrix. At the present time it is doubtful if attempts to proceed beyond the ordinal scale are advisable - if they are indeed possible.

There remains the question of how one is to best record the presence or absence of an interaction. Several researchers have used ones and zeros, while some (with considerable justification) maintain that characters free of mathematical properties should be used to prevent decision makers from using these ordinal entries as interval. The former appears to be the most suitable at this time because it may easily be extended mathematically. Regardless of the exact way in which the interactions in the matrix are denoted, it is readily seen that the structuring of information in this manner will aid the study team in setting forth their knowledge in a simple way, and in defining areas of interaction which require further research, or about which sufficient information is obtainable. Because such an interaction matrix serves as the basic building block for the entire matrix approach, it is important that it be prepared at the outset of any environmental assessment study.

An example, interaction matrix A (with numbered rather than named components) is presented as Figure 1. In this matrix, a '1' is entered in the ij th cell because row component i is dependent on column component j. Thus it is seen, for example, that the fact that $A_{21} = 1$ indicates that component 2 is dependent on component 1 ($2 \leftarrow 1$). This might, for example,

Figure 1 -- Example of a Component Interaction Matrix (A)

Component	1	2	3	4
1	0	0	1	0
2	1	0	0	1
3	0	1	0	0
4	0	1	0	0

indicate that sockeye salmon (2) are dependent on herring (1). (Note that the matrix is not necessarily symmetrical - i.e., $A_{ij} = 1$ does not infer $A_{ji} = 1$).

Upon inspection of the interaction matrix A it is seen that only the first order or direct relationships are denoted. Study of the matrix reveals that component 1 is really dependent on component 2 ($1 \leftarrow 2$) because $1 \leftarrow 3$ and $3 \leftarrow 2$; therefore $1 \leftarrow 2$ through a two step dependency relationship, here referred to as a two-link chain. Similarly, other chains are present in the matrix but are tedious to find.

Rather than search through the A matrix manually, we may borrow a technique from the field of network analysis[5], and raise A to higher powers

[5]For a general reference see Hagget, P., and Chorley, R.J., Network Analysis in Geography, London, Edward Arnold, 1969.

to define these chains. If we raise A to the second power we get the matrix A^2 (Figure 2) in which each entry A^2_{ij} denotes the number of two-link chains through which variable i is dependent on variable j. From this matrix it is apparent that 1←2, 2←2, 2←3, 3←1, 3←4, 4←1, and 4←4. One may

Figure 2 -- Example Squared Interaction Matric (A^2)

Component	1	2	3	4
1	0	1	0	0
2	0	1	1	0
3	1	0	0	1
4	1	0	0	1

then consult the interaction matrix (A) to determine the exact links of these chains.

Raising the interaction matrix to the third power will reveal dependency chains of three links. Figure 3 presents the cubed interaction matrix, and indicates that nine three-link chains exist. Again, the members of these chains can be determined by inspection of the A matrix. The three-link chain 4←3, for example, results from the dependencies 4←2, 2←1, and 1←3. It must be noted that the entries in the powered matrices are often greater than unity, although in the examples presented this is not the case. Also, as may be noted from both the A^2 and A^3 matrices, the entries in the diagonal may be greater than zero - indicating that a component depends, at least in part, on itself. This is often the case when the components are very general.

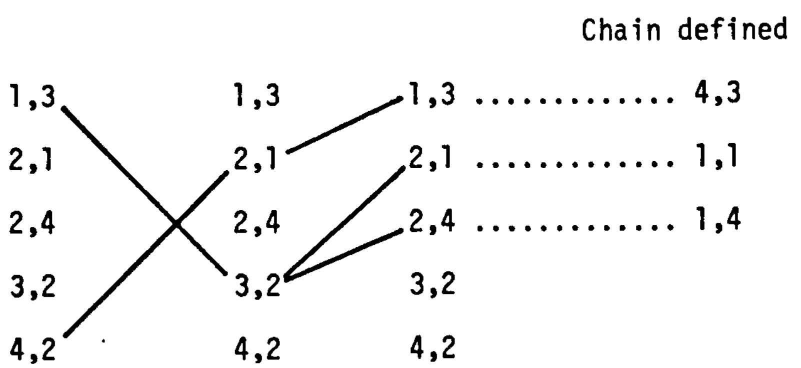
Figure 3 -- Example Cubed Interaction Matrix (A^3)

Variable	1	2	3	4
1	1	0	0	1
2	1	1	0	1
3	0	1	1	0
4	0	1	1	0

Theoretically there is no limit to the power to which A may be raised but the number of chains increases rapidly as higher powers are reached, and the identification of the links in these chains becomes very onerous. Also, once all off diagonal cells in the matrix become non-zero, no new information is obtained. The power of the matrix at this point is referred to as it's 'diameter', or solution time. It must be noted, however, that in cases where a component is not dependent on any other component, or on which no other component depends - i.e. if a row or column of the matrix contains only zeroes - the diameter is equal to infinity.

Although it would be possible to prepare a computer program to identify all the chains denoted in these dependency matrices, the sheer volume of output would soon overwhelm the researcher, particularly if the interdependencies between a large number of components were examined. A simpler approach is to list the subscripts of the single link chains, and then to follow the chain of interest manually. In order to accomplish this, one merely lists the first order links in one column, repeating the column once for each link in the longest chain for which he is identifying the links. The example presented in Figure 4 identifies three three-link chains denoted in Figure 3.

Figure 4 -- Interdependency Chain Definition



It is often useful to prepare a further matrix in which these individual cells contain numbers denoting the length of the shortest chains connecting the two components. This matrix, here referred to as the 'minimum link matrix', (A^{min}) is prepared by constructing a matrix in which each non-zero entry indicates the power of the matrix when that particular cell became non-zero. From the above example the matrix presented as Figure 5 has been prepared.

Figure 5 -- Example Minimum Link Matrix (A^{min})

Variable	1	2	3	4
1	3	2	1	3
2	1	2	2	1
3	2	1	3	2
4	2	1	3	2

Inspection of A^{min} reveals, for example, that variable 1 is dependent on variable 2 through a two-link chain, 4←3 through a three-link chain, and 3←2 directly. These chains may be identified by the approach described above.

The preparation of the minimum link matrix adds no real information to the interaction matrix itself, but it efficiently identifies dependencies beyond those visually identifiable from the original interaction matrix, and alerts students of the environmental system to relationships that may have been previously unperceived. Thus, as a technique for logically extending the simplest known relationships (the first order dependencies), it possesses great utility for students of systems of many types.

An Environmental Interaction Disruption Matrix

The interaction matrix may be used as a guide to assess the impact of the level of disruption which would be caused by the introduction of change into an environmental system. Once the environmental components have been defined, and the dependencies denoted in the interaction matrix A, it is usually possible to estimate the degree to which each of the interactions identified would be affected by each of the NP alternative development proposals or, similarly, by each of the alternative modes of construction. This may, for example, be accomplished by preparing NP interaction matrices and entering an estimate of disruption in each of the cells which was occupied in the original interaction matrix (A). It would be ideal if one could enter a precise figure to represent disruption, but the information on which a precise figure could be determined is seldom, if ever, available.

One is usually able to do no more than rank the alternatives in order of the disruption of each dependency. Figure 6 presents three hypothetical disruption matrices (based on the data of Figure 1) to illustrate this point. It is conceptually simple to consider these three two-dimensional matrices to be three layers of a single three-dimensional matrix D, and to designate the $_{ij}$ th cell of the first layer (pertaining to the first alternative) as the $_{ij1}$ st cell of the disruption matrix D.

Figure 6 -- Example 1 Disruption Matrices

Alternative 1					Alternative 2					Alternative 3				
Variable	1	2	3	4	Variable	1	2	3	4	Variable	1	2	3	4
1	0	0	1	0	1	0	0	2	0	1	0	0	3	0
2	2	0	0	3	2	2	0	0	1	2	3	0	0	1
3	0	1	0	0	3	0	2	0	0	3	0	2	0	0
4	0	1	0	0	4	0	2	0	0	4	0	3	0	0

Upon inspection of D_{13k} for all values of k, it is evident that the dependency 1↔3 would be most disrupted by the choice of Alternative 3, and that Alternative 2 would be more disruptive than Alternative 1, but less disruptive than Alternative 3. This may be denoted by the symbology $D_{131}<D_{132}<D_{133}$. All non-null cells of D may be treated in like fashion, although in the case of D_{21k} it can only be stated that $D_{211}<D_{213}$ and $<D_{212}<D_{213}$ because, according to the data $D_{121} = D_{213}$, i.e. Alternatives 1 and 3 are equally disruptive.

To this point, four critical problems have become evident.

1. The necessary analysis procedure used to investigate the environmental interdependencies is static in nature. No time parameters have been taken into account. One could partially overcome this problem by incorporating a time dimension, which would allow the preparation of interaction and disruption matrices at times t_1, t_2 ...t_n. This, however, would imply that one knew the critical time intervals, and such is not the case.

2. This type of analysis incorporates only the fact that a dependency exists, and offers no indication of the strength of the dependency or of the capacity of any dependency chains defined.

3. Not all the interdependencies are of equal importance, and there is no generally acceptable method of weighting them to reflect their true values.

4. There is no method of summarizing the information pertaining to the amount of disruption which would be caused by each alternative, in order that the alternatives may be compared easily. It might be thought that we could merely sum up the entries in each layer of the D matrix, but this approach is ruled out because the summation of

ranks is invalid. Consider Figure 7, for example, which presents disruption weights and between-alternative rankings for two alternatives, A and B. It is evident that the sums of the weights would lead us to the conclusion that Alternative A was more disruptive than Alternative B. The sums of the ranks leads us to the opposite conclusion. Which is correct?

Figure 7 -- Hypothetical Disruption Weights and Rankings

	Alternative A		Alternative B	
Interaction	Weight	Rank	Weight	Rank
1	10	1	15	2
2	20	1	30	2
3	20	1	25	2
4	40	2	20	1
5	50	2	45	1
	140	7	135	8

The problems of weighting and summarizing the disruption levels remain unsolved at present. One may, however, use the disruption matrices, together with the interaction matrices discussed above, to structure a verbal statement of the consequences of a particular course of action. One should be careful to state that the disruption measures are only of an ordinal nature, and are not of equal weight between interactions.

This section of the paper has been concerned with the concept of an environmental component interaction matrix, and the identification of interaction or dependency chains within the environmental system being studied. It has also discussed, albeit in a preliminary fashion, the notion of disruption matrices as tools in the task of assessing the environmental consequences of alternative development strategies. The following sections will present an application of these techniques to a real world problem.

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APPLICATION -- THE NANAIMO CASE

The foregoing portions of this paper have outlined a methodology designed to identify the location and relative degree of the environmental disruptions which may accrue to an environmental system as a result of the construction of alternative development projects. This portion of the paper will present the application of the methodology to a problem concerning the location of a lumber transshipment facility on the east coast of Vancouver Island.

Background

A six-man Task Force established by Environment Canada was directed to study the question of alternative locations for the transshipment facility, and to rank these alternatives in order of their environmental disruption. The alternative sites identified by the Task Force (as shown in Figure 8) were:

1. Inner Harbour

Development of the transshipment facility in the Inner Harbour (as per the plans of the Nanaimo Harbour Commission) would involve the creation of 150 acres of new ground immediately adjacent to the present Assembly Wharf, dredging of the surrounding waters to a depth of at least 45 feet, and the diversion of the Nanaimo River around the facility. Although the area to be created is 150 acres, approximately 80 additional acres of the adjacent estuarine area will be dredged. This results in a total of approximately 230 acres of estuary which will be directly affected by construction of the Inner Harbour Alternative. Two saw mills are planned for this site.

2. Jack Point

Development of the port addition at Jack Point (as outlined in the plans of Tudor Forest Products Ltd.) would provide 175 acres of land

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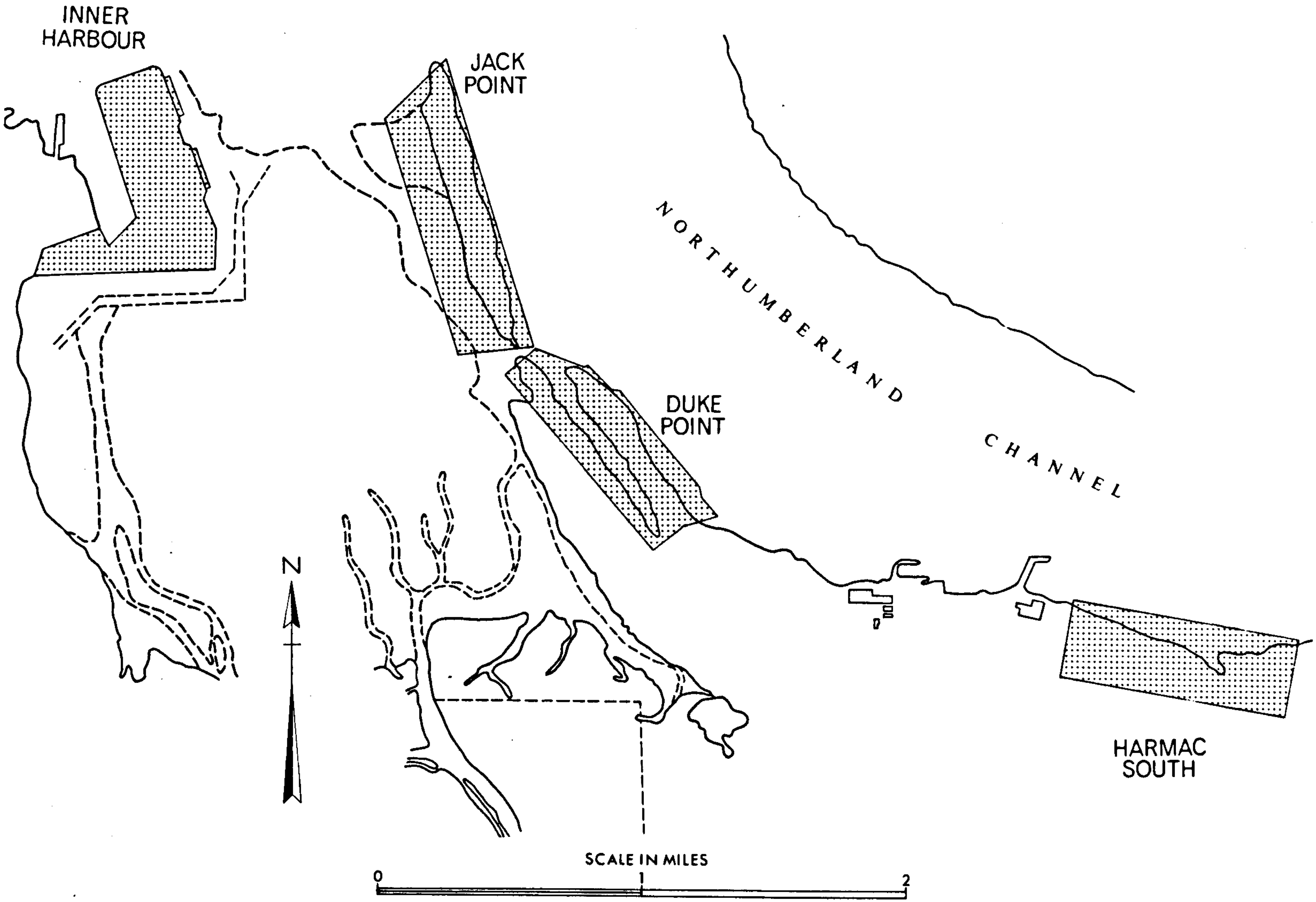
ALTERNATIVE DEVELOPMENT SITES



by levelling Jack Point and filling about 85 acres of the eastern part of the estuary with the rock debris. No dredging is presently called for, the berthing area being located on the deep water of Northumberland Channel. Two saw mills, a wood-chip operation and a plate board plant are planned for this site.

Of the 175 acres involved in this alternative, approximately 85 will overlie the present estuarine area, and 15 the rock beach at the southeast corner of Jack Point.

3. Duke Point A

Consideration of the construction of the port facility at Duke Point is made difficult by the fact that no construction plans have been made available to the Task Force, which has had to assume that a preliminary drawing[6] is an accurate representation of reality. This alternative would involve the creation of approximately 160 acres of level ground by levelling Duke Point and filling the small inlet opening onto Northumberland Strait. Conversation with a McMillan-Bloedel representative[7] has revealed that this alternative would include a dredged barge channel extending along the western shore of Jack Point to deep water.

The total area involved in this alternative is estimated to be 260 acres, 100 for the barge channel through the estuary, about 35 acres involving the tidal lagoon, 85 acres of upland, and about 40 acres of the Northumberland Channel coast. It has been assumed that one saw mill would be involved.

[6]Plan 2845, Swan-Wooster Ltd., Vancouver, n.d.

[7]D. McCrimmon, Land Manager, McMillan-Bloedel, personal communication, June 1, 1973

4. Duke Point B

This alternative is assumed to be the equivalent of the above Duke Point A scheme without the dredged barge channel along Jack Point.

The are required in this case is about 160 acres, approximately 35 of which involve the tidal lagoon.

5. Harmac South

The Harmac South alternative was identified by the Task Force and, consequently, no detailed plans of it are available. It is envisioned, however, as being of approximately the same dimensions as the Duke Point A scheme, and being located immediately to the southeast of the Harmac Industrial complex. One saw mill has been assumed at this site.

The total area to be affected by this alternative is estimated to be 160 acres, 120 acres of which is upland, and the rest rocky Northumberland Strait coastline.

Environmental Components

The first step in the analysis of the problem was to identify the environmental components of critical import to the environment of the area under consideration.

The precise definition of the environmental components for the Nanaimo study was made difficult by the study team's desire to be parsimonious while at the same time being precise in their classification. Obviously, they could not realize both aims, and were forced to lump together some dissimilar items. A full list of the twenty-one components defined, together with their descriptions, is presented as Figure 9.

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Figure 9 -- Nanaimo Component Definitions

1. Currents -- Tidal Streams, the direction and rate of flow of the water due to the tide. Very susceptible to meteorological conditions. Wind induced current on the surface is about 3% of the wind speed.

2. Wind -- Horizontal motion of air.

3. Temperature -- The temperature of the sea water in Nanaimo Harbour and its approaches. This temperature varies from about 43^{o}F. in winter to 72^{o}F. in summer.

4. Light -- Solar radiation reaching sea or ground surface.

5. Intertidal Vegetation -- Includes seaweeds, phytoplankton and eelgrass. By agreement, it excludes sedges and grasses.

6. Upland Vegetation -- In general, this component includes all of those plants which occur above the high tide line. By definition, all of those plant species identified as being part of the sedge (marsh) community, even though they may at times be partially or totally immersed in salt or brackish water, are considered to be upland vegetation.

7. Bacteria -- Refers to the system which degrades organic matter into its organic and mineral constituents. This organic matter and associated bacteria forms an important food resource for many invertebrates.

8. Insects -- Includes drift, wind borne, and intertidal insects.

9. Larvae -- Includes pelagic larvae of fish, crustaceans, shellfish and zooplankton.

10. Shellfish -- Clams, oysters and snails.

11. Crabs -- Dungeness crabs only.

12. Other Crustaceans -- All shrimp, non-commercial crabs, mud shrimps, amphipods, isopods, barnacles, non-larval forms of above.

13. Pelagic Fish -- Free swimming fish such as salmon, herring, smelts, sticklebacks, sandlance, anchovy, etc.

14. Bottom Fish -- Non-pelagic fishes that live on or near the bottom, usually not schooled. Examples are sculpins, rock fishes, flounders, dabs and greelings.

15. Waterbirds -- This component includes nearly all the groups of birds that obtain their food largely from the water. Some groups, such as the herons and kingfishers are included in other variables. waterbirds include the following: Loons, Grebes, Cormorants, Coots, Gulls and Terns, Waterfowl - ducks, geese, swans; Alcids - murres, murrelets, guillemots and auklets.

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16. Birds of Prey -- Although any bird that feeds on other animals might logically be classed as a 'bird of prey', this component will include only: Hawks, Eagles, Ospreys, Vultures, Owls.

17. Songbirds -- This component is designated by the name 'songbirds' although some of its component species do not deserve it. This group includes most of the birds not included in the other categories and encompasses such species as crows, ravens, jays, starlings, nighthawks, shrikes and kingfishers. In general, however, this group is typified by the 'Passerine' species (those classified scientifically into Order Passerformes) of which, the songbird species such as robins, sparrows, warblers, finches are best known. For our purposes this component will include:

    Passerine Species - Order Passerformes which contains many families of 'song' birds as well as crows, jays, ravens and shrikes.

    Other Species - (Not really songbirds but do not fit other components and do not warrant separate status), woodpeckers, kingfishers, nighthawks.

18. Marshbirds and Shorebirds -- This component includes bird species which inhabit the 'water margin' habitat. Generally these species are the long-legged wading birds such as the herons as well as the numerous other species of smaller birds that run along the beaches in search of food. In the Nanaimo area this group includes: herons; oystercatchers; plovers, turnstones and surfbirds; the sandpiper family - snipes, many species of sandpipers, etc.

19. Upland Game Birds -- This component includes those species of birds (exclusive of waterfowl and snipe) which are important to hunters and for which a hunting season generally is provided. In the Nanaimo area this group includes: grouse (both blue and ruffed), ring-necked pheasant, band-tailed pigeon.

20. Aquatic and Marine Mammals -- This component includes mammalian species entirely dependent or largely dependent on water (fresh or salt) for their daily requirements. In the Nanaimo area, this group might logically be expected to include: seals, whales, river otter, mink, beaver, muskrat.

21. Upland Mammals -- This component includes all those mammals found in the vicinity of the estuary of the Nanaimo River and the proposed port sites on Northumberland Channel except those classed as aquatic and marine mammals. Raccoons, in spite of their affinity for water, are included with the upland mammals.

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Component Interactions

The component interaction matrix identifying the dependencies between the environmental variables was prepared by the Task Force in concert. This matrix, presented as Figure 10, contains a '1' where the row component was judged to be directly dependent on the column component, thus identifying the first order links in the Nanaimo environment. These first order dependencies are also presented (graphically) in Figure 11. The most noticeable features of both the graphic and symbolic presentations are the complexity of the relationships which are shown to exist, and the degree to which the environmental system (as described by its components) is dependent on its marine components, which support roughly twice as many of the interdependencies as the non-marine components.

Powering of the interaction matrix produced the matrices presented as Figures 12-15,which identify a great number of dependencies many of which were previously unperceived. Figure 17 presents the data from which dependency chains were identified.

Figure 10
COMPONENT INTERACTION MATRIX

		CURRENTS 1	WIND 2	WATER TEMPERATURE 3	LIGHT 4	INTERTIDAL VEGETATION 5	UPLAND VEGETATION 6	BACTERIA 7	INSECTS 8	LARVAE 9	SHELL FISH 10	CRABS 11	OTHER CRUSTACEANS 12	PELAGIC FISH 13	BOTTOM FISH 14	WATERBIRDS 15	BIRDS OF PREY 16	SONG BIRDS 17	MARSH & SHORE BIRDS 18	UPLAND GAME BIRDS 19	AQUATIC & MARINE MAMMALS 20	UPLAND MAMMALS 21
CURRENTS	1		1																			
WIND	2						1															
WATER TEMPERATURE	3	1	1		1																	
LIGHT	4																					
INTERTIDAL VEGETATION	5	1		1	1																	
UPLAND VEGETATION	6				1			1	1									1	1	1		1
BACTERIA	7			1		1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
INSECTS	8	1	1	1		1	1	1														
LARVAE	9	1		1		1		1			1	1	1	1	1							
SHELL FISH	10	1		1		1		1														
CRABS	11			1		1				1	1		1	1	1							
OTHER CRUSTACEANS	12			1		1		1	1	1	1	1		1	1							
PELAGIC FISH	13			1					1	1												
BOTTOM FISH	14			1		1			1	1	1	1	1	1								
WATERBIRDS	15					1			1	1	1	1	1	1	1							
BIRDS OF PREY	16						1		1			1	1	1	1	1		1	1	1		1
SONG BIRDS	17						1		1		1		1	1	1							
MARSH & SHORE BIRDS	18						1		1		1	1	1	1	1							
UPLAND GAME BIRDS	19						1		1													
AQUATIC & MARINE MAMMALS	20										1	1	1	1	1							
UPLAND MAMMALS	21						1				1	1	1					1		1		

Note: A(1) in any cell indicates that the row component is dependent on the column component.

Figure 11

NANAIMO COMPONENT INTERACTIONS (GRAPHIC)

COMPONENTS ←	DEPENDENT COMPONENTS
CURRENTS	WATER TEMP., SHELL FISH, INTERTIDAL VEG., LARVAE, INSECTS
WIND	CURRENTS, WATER TEMP., INSECTS
WATER TEMPERATURE	INTERTIDAL VEG., BACTERIA, INSECTS, LARVAE, SHELL FISH, CRABS, OTHER CRUST'NS, BOTTOM FISH, PELAGIC FISH
LIGHT	WATER TEMP., INTERTIDAL VEG., UPLAND VEG.
INTERTIDAL VEGETATION	BACTERIA, INSECTS, LARVAE, SHELL FISH, CRABS, OTHER CRUST'NS, BOTTOM FISH, WATERBIRDS
UPLAND VEGETATION	WIND, BACTERIA, INSECTS, BIRDS OF PREY, SONG BIRDS, MARSH AND SHORE BIRDS, UPLAND GAME BIRDS, UPLAND MAMMALS
BACTERIA	UPLAND VEG., INSECTS, LARVAE, SHELL FISH, OTHER CRUST'NS
INSECTS	UPLAND VEG., BACTERIA, OTHER CRUST'NS, PELAGIC FISH, BOTTOM FISH, WATERBIRDS, BIRDS OF PREY, SONG BIRDS, MARSH AND SHORE BIRDS, UPLAND GAME BIRDS
LARVAE	BACTERIA, CRABS, OTHER CRUST'NS, PELAGIC FISH, BOTTOM FISH, WATERBIRDS
SHELL FISH	BACTERIA, LARVAE, CRABS, OTHER CRUST'NS, BOTTOM FISH, WATERBIRDS, SONG BIRDS, MARSH AND SHORE BIRDS, AQUATIC AND MARINE MAMMALS, UPLAND MAMMALS
CRABS	BACTERIA, LARVAE, OTHER CRUST'NS, BOTTOM FISH, WATERBIRDS, BIRDS OF PREY, MARSH AND SHORE BIRDS, AQUATIC AND MARINE MAMMALS, UPLAND MAMMALS
OTHER CRUSTACEANS	BACTERIA, LARVAE, CRABS, BOTTOM FISH, WATERBIRDS, BIRDS OF PREY, SONG BIRDS, MARSH AND SHORE BIRDS, AQUATIC AND MARINE MAMMALS, UPLAND MAMMALS
PELAGIC FISH	BACTERIA, LARVAE, CRABS, OTHER CRUST'NS, BOTTOM FISH, WATER BIRDS, BIRDS OF PREY, SONG BIRDS, MARSH AND SHORE BIRDS, AQUATIC AND MARINE MAMMALS
BOTTOM FISH	BACTERIA, LARVAE, SHELL FISH, CRABS, OTHER CRUST'NS, WATERBIRDS, BIRDS OF PREY, SONG BIRDS, MARSH AND SHORE BIRDS, AQUATIC AND MARINE MAMMALS
WATERBIRDS	BACTERIA, BIRDS OF PREY
BIRDS OF PREY	BACTERIA
SONG BIRDS	UPLAND VEG., BACTERIA, BIRDS OF PREY, UPLAND MAMMALS
MARSH AND SHORE BIRDS	UPLAND VEG., BACTERIA, BIRDS OF PREY
UPLAND GAME BIRDS	UPLAND VEG., BACTERIA, BIRDS OF PREY, UPLAND MAMMALS
AQUATIC AND MARINE MAMMALS	BACTERIA
UPLAND MAMMALS	UPLAND VEG., BACTERIA, BIRDS OF PREY

NOTE: THE ARROWS INDICATE THE DIRECTION OF DEPENDENCY.

FIGURE 12

Nanaimo Squared Interaction Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1	1	0	1
3	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	1	2	0	2	6	1	4	1	4	3	4	3	3	1	1	2	1	2	1	1
7	5	2	8	3	7	6	5	9	5	9	8	9	9	8	1	0	3	2	3	0	2
8	2	2	2	3	1	2	1	2	1	1	1	1	1	1	1	1	2	2	2	1	2
9	3	2	7	2	5	1	2	4	5	4	3	3	4	3	1	1	1	1	1	1	1
10	2	2	2	2	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	4	1	6	2	4	0	3	3	3	3	3	2	3	2	0	0	0	0	0	0	0
12	5	2	8	2	6	2	3	3	4	4	3	4	4	3	1	1	1	1	1	1	1
13	3	2	2	1	2	1	2	0	0	1	1	1	1	1	0	0	0	0	0	0	0
14	5	2	7	2	5	1	4	2	3	3	2	2	3	3	0	0	0	0	0	0	0
15	4	1	8	1	6	1	4	3	4	4	3	3	4	3	0	0	0	0	0	0	0
16	1	1	5	1	5	5	3	8	5	7	5	6	6	5	0	0	2	1	2	0	1
17	2	1	5	1	4	1	4	4	3	2	2	1	2	1	0	0	1	1	1	0	1
18	2	1	6	1	5	1	4	4	4	3	2	2	3	2	0	0	1	1	1	0	1
19	1	1	1	1	1	1	2	1	0	0	0	0	0	0	0	0	1	1	1	0	1
20	1	0	5	0	4	0	2	3	4	3	2	2	3	2	0	0	0	0	0	0	0
21	1	0	3	1	3	2	3	4	2	3	1	2	3	3	0	0	1	1	1	0	1

FIGURE 13

Nanaimo Cubed Interaction Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1	1	0	1
2	1	1	2	0	2	6	1	4	1	4	3	4	3	3	1	1	2	1	2	1	1
3	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	1
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	13	7	25	10	21	13	19	24	15	18	14	15	18	15	2	1	9	8	9	1	8
7	38	22	69	21	54	26	38	46	40	43	32	34	41	33	5	5	13	11	13	5	11
8	7	6	10	5	9	14	7	14	6	13	11	13	12	11	2	1	6	4	6	1	4
9	25	14	33	13	25	13	17	18	16	21	18	19	21	18	3	2	5	4	5	2	4
10	6	5	8	4	7	8	5	9	5	9	8	9	9	8	1	0	3	2	3	0	2
11	19	13	26	10	19	7	11	10	13	13	10	11	13	11	3	3	3	3	3	3	3
12	25	16	34	16	25	13	17	21	18	22	19	19	22	19	4	3	7	6	7	3	6
13	5	5	9	5	6	4	3	6	6	5	4	4	5	4	2	2	3	3	3	2	3
14	20	14	27	13	19	8	11	13	14	14	12	12	14	11	4	4	5	5	5	4	5
15	25	15	34	15	24	8	15	15	17	17	14	14	17	14	4	4	5	5	5	4	5
16	30	14	50	15	39	18	31	30	25	28	21	22	27	22	3	3	9	8	9	3	8
17	18	11	23	10	17	13	11	12	10	14	11	13	13	12	4	4	6	5	6	4	5
18	22	12	29	12	21	13	14	15	13	17	14	15	16	14	4	4	6	5	6	4	5
19	3	3	4	3	3	8	2	6	2	5	4	5	4	4	2	2	4	3	4	2	3
20	19	9	25	9	18	5	12	9	11	12	10	10	12	10	2	2	2	2	2	2	2
21	15	8	24	8	18	11	13	16	12	14	12	12	13	10	3	3	6	5	6	3	5

FIGURE 14

Nanaimo Fourth Order Interaction Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1	1	2	0	2	6	1	4	1	4	3	4	3	3	1	1	2	1	2	1	1
2	13	7	25	10	21	13	19	24	15	18	14	15	18	15	2	1	9	8	9	1	8
3	1	1	2	1	2	6	2	5	1	4	3	4	3	3	1	1	3	2	3	1	2
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	2	0	1	2	2	0	0	0	0	0	0	0	0	2	2	2	0	2
6	103	62	159	59	122	85	85	109	83	106	84	92	99	84	20	19	41	33	41	19	33
7	252	153	361	149	271	159	189	219	183	222	182	193	216	183	43	38	80	69	80	38	69
8	52	31	96	33	77	48	60	76	56	65	49	53	62	51	8	7	26	22	26	7	22
9	113	76	173	71	130	69	87	107	96	106	85	89	104	86	19	17	36	32	36	17	32
10	38	23	69	23	54	29	40	48	40	43	32	34	41	33	5	5	15	13	15	5	13
11	81	55	111	52	82	49	54	68	59	71	61	63	71	60	14	11	24	21	24	11	21
12	120	80	182	72	139	83	93	117	100	118	95	102	115	96	20	17	39	33	39	17	33
13	32	20	43	19	34	28	25	33	22	34	29	32	33	29	5	3	12	9	12	3	9
14	87	60	120	54	91	62	61	79	64	83	70	75	82	71	15	11	28	23	28	11	23
15	107	74	147	66	110	69	71	91	78	97	82	87	96	82	19	15	32	27	32	15	27
16	172	110	245	107	182	112	123	152	126	152	125	133	147	125	34	31	60	52	60	31	52
17	76	53	113	53	87	60	62	87	64	81	68	72	80	68	15	11	33	28	33	11	28
18	95	66	139	63	106	67	73	97	77	94	78	83	93	79	18	14	36	31	36	14	31
19	20	13	35	15	30	27	26	38	21	31	25	28	30	26	4	2	15	12	15	2	12
20	75	53	104	48	76	40	47	59	56	63	53	55	63	53	14	12	21	19	21	12	19
21	84	55	120	53	92	62	65	82	63	81	66	72	79	69	16	13	32	27	32	13	27

FIGURE 15

Nanaimo Fifth Order Interaction Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	13	7	25	10	21	13	19	24	15	18	14	15	18	15	2	1	9	8	9	1	8
2	103	62	159	59	122	85	85	109	83	106	84	92	99	84	20	19	41	33	41	19	33
3	14	8	27	10	23.	19	20	28	16	22	17	19	21	18	3	2	11	9	11	2	9
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2	2	4	1	4	12	3	9	2	8	6	8	6	6	2	2	5	3	5	2	3
6	579	371	864	366	663	423	475	599	464	574	468	501	560	476	104	85	222	189	222	85	189
7	1256	832	1858	791	1414	897	976	1250	1006	1229	1005	1074	1198	1015	227	189	455	386	455	189	386
8	370	224	549	221	418	270	298	363	283	354	286	308	339	288	67	60	137	115	137	60	115
9	612	393	890	372	675	423	467	575	470	579	475	507	564	478	104	87	205	173	205	87	173
10	254	155	365	152	275	172	194	230	185	230	188	201	222	189	45	40	87	74	87	40	74
11	391	260	589	242	450	278	310	391	323	388	314	336	378	318	65	54	135	114	135	54	114
12	656	419	975	404	741	451	520	637	521	628	511	543	612	516	110	93	226	193	226	93	193
13	166	108	271	105	209	123	149	188	153	175	137	146	169	140	28	25	65	56	65	25	56
14	437	286	676	273	518	313	363	456	374	441	354	377	429	358	72	61	157	134	157	61	134
15	523	345	794	326	607	369	422	530	437	520	421	448	508	426	86	71	182	155	182	71	155
16	857	569	1265	539	970	640	675	877	687	861	707	759	840	715	154	123	318	266	318	123	266
17	432	276	669	260	517	335	364	462	365	449	359	388	432	364	73	62	161	133	161	62	133
18	513	331	780	312	599	384	418	530	424	520	420	451	503	424	87	73	185	154	185	73	154
19	155	93	255	92	199	133	145	185	139	171	133	145	161	135	28	26	67	55	67	26	55
20	358	238	525	220	400	251	273	345	285	349	287	306	342	289	59	47	118	99	118	47	99
21	438	286	669	274	514	333	360	467	367	450	365	391	436	367	78	65	167	140	167	65	140

FIGURE 16

Nanaimo Minimum Link Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	4	1	4	3	4	2	3	3	4	4	4	4	4	4	4	4	3	3	3	4	3
2	3	3	3	2	3	1	2	2	3	3	3	3	3	3	3	3	2	2	2	3	2
3	1	1	4	1	4	2	3	3	4	4	4	4	4	4	4	4	3	3	3	4	3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	2	1	1	5	3	4	4	5	5	5	5	5	5	5	5	4	4	4	5	4
6	2	2	2	1	2	2	1	1	2	2	2	2	2	2	2	2	1	1	1	2	1
7	2	2	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
9	1	2	1	2	1	2	1	2	2	1	1	1	1	1	2	2	2	2	2	2	2
10	1	2	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
11	2	2	1	2	1	3	2	2	1	1	2	1	1	1	3	3	3	3	3	3	3
12	2	2	1	2	1	2	1	1	1	1	1	2	1	1	2	2	2	2	2	2	2
13	2	2	1	2	2	2	2	1	1	2	2	2	2	2	3	3	3	3	3	3	3
14	2	2	1	2	1	2	2	1	1	1	1	1	1	2	3	3	3	3	3	3	3
15	2	2	2	2	1	2	2	1	1	1	1	1	1	1	3	3	3	3	3	3	3
16	2	2	2	2	2	1	2	1	2	2	1	1	1	1	1	3	1	1	1	3	1
17	2	2	2	2	2	1	2	1	2	1	2	1	1	1	3	3	2	2	2	3	2
18	2	2	2	2	2	1	2	1	2	1	1	1	1	1	3	3	2	2	2	3	2
19	2	2	2	2	2	1	2	1	3	3	3	3	3	3	3	3	2	2	2	3	2
20	2	3	2	3	2	3	2	2	2	1	1	1	1	1	3	3	3	3	3	3	3
21	2	3	2	2	2	1	2	2	2	1	1	1	2	2	3	3	1	2	1	3	2

FIGURE 17

Dependency Chain Data

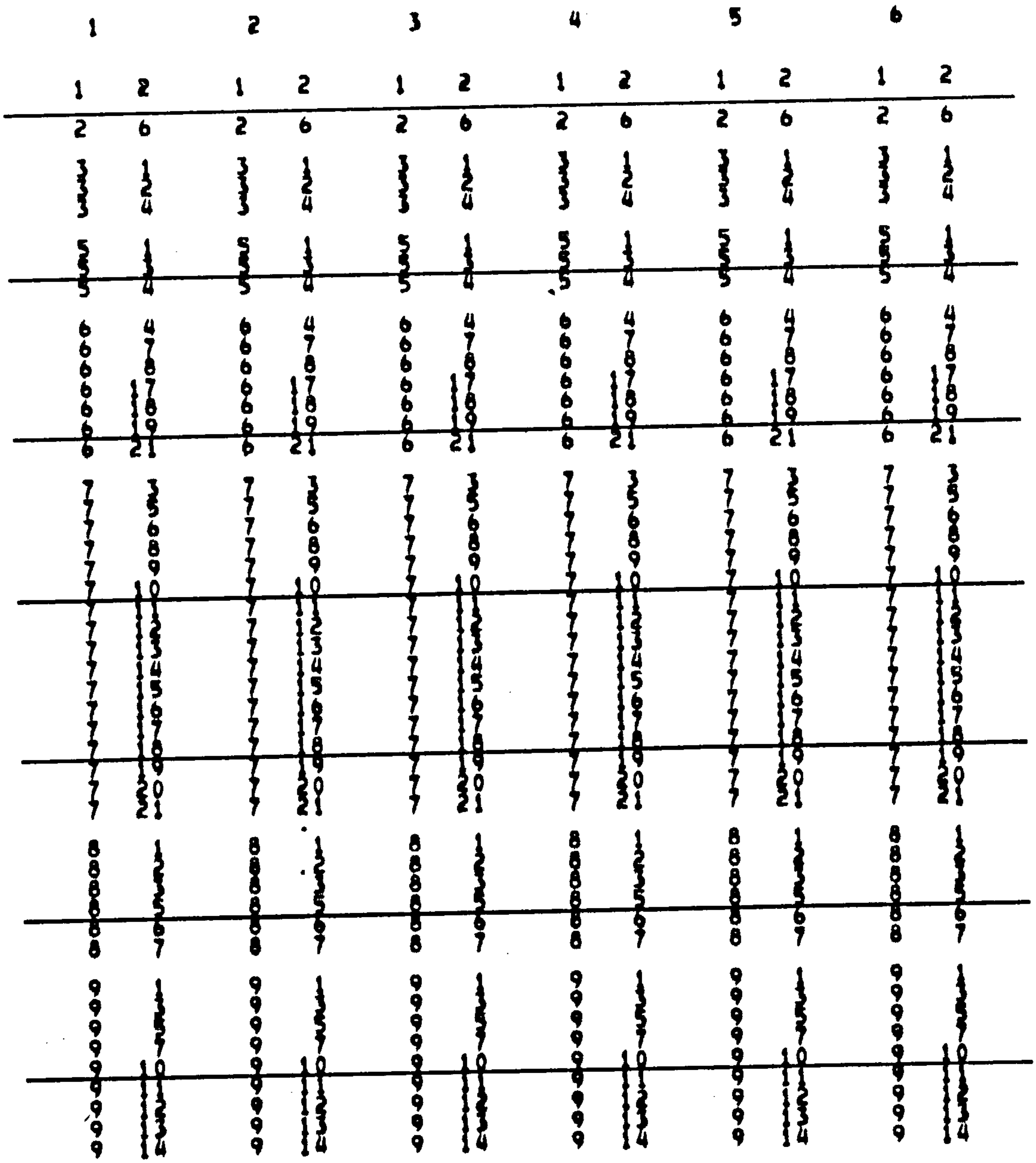
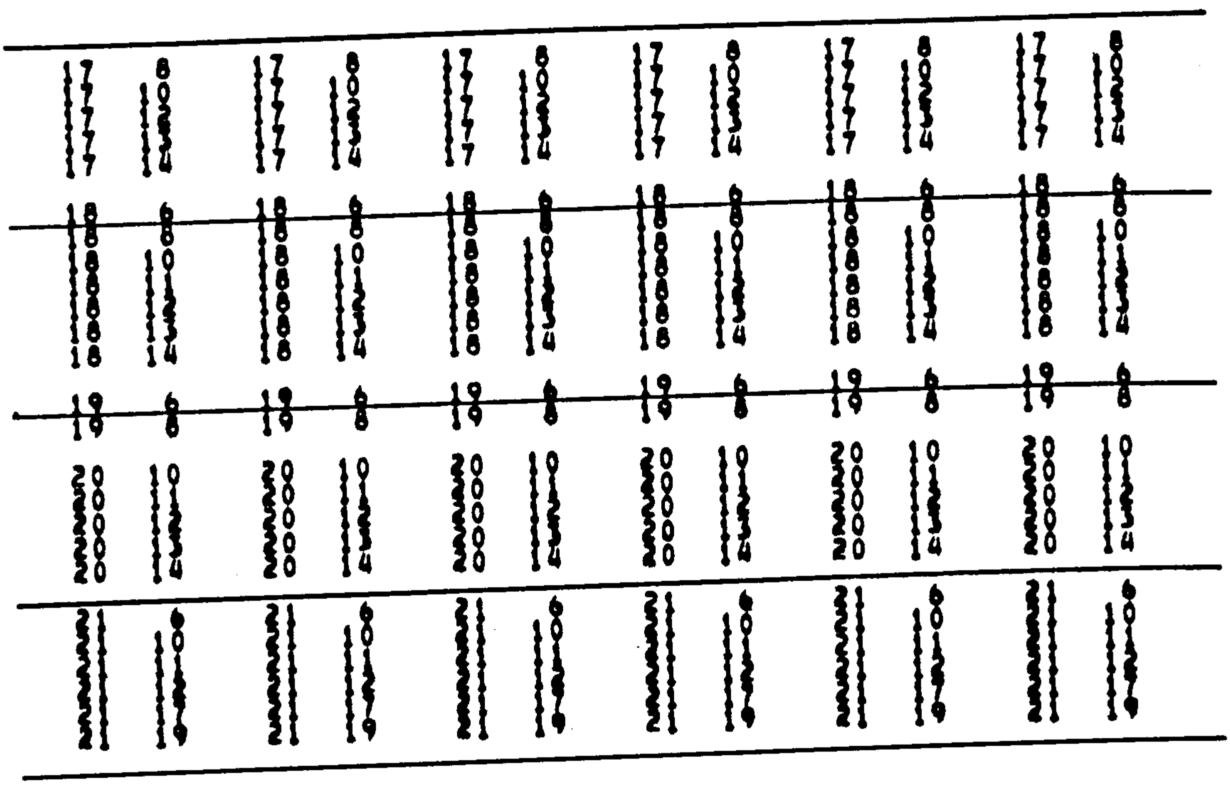


FIGURE 17, p.2

10	1	10	1	10	1	10	1	10	1	10	1
10	3	10	3	10	3	10	3	10	3	10	3
10	5	10	5	10	5	10	5	10	5	10	5
10	7	10	7	10	7	10	7	10	7	10	7
11	3	11	3	11	3	11	3	11	3	11	3
11	5	11	5	11	5	11	5	11	5	11	5
11	9	11	9	11	9	11	9	11	9	11	9
11	10	11	10	11	10	11	10	11	10	11	10
11	12	11	12	11	12	11	12	11	12	11	12
11	13	11	13	11	13	11	13	11	13	11	13
11	14	11	14	11	14	11	14	11	14	11	14
12	3	12	3	12	3	12	3	12	3	12	3
12	5	12	5	12	5	12	5	12	5	12	5
12	7	12	7	12	7	12	7	12	7	12	7
12	8	12	8	12	8	12	8	12	8	12	8
12	9	12	9	12	9	12	9	12	9	12	9
12	10	12	10	12	10	12	10	12	10	12	10
12	11	12	11	12	11	12	11	12	11	12	11
12	13	12	13	12	13	12	13	12	13	12	13
12	14	12	14	12	14	12	14	12	14	12	14
13	3	13	3	13	3	13	3	13	3	13	3
13	8	13	8	13	8	13	8	13	8	13	8
13	9	13	9	13	9	13	9	13	9	13	9
14	3	14	3	14	3	14	3	14	3	14	3
14	5	14	5	14	5	14	5	14	5	14	5
14	8	14	8	14	8	14	8	14	8	14	8
14	9	14	9	14	9	14	9	14	9	14	9
14	10	14	10	14	10	14	10	14	10	14	10
14	11	14	11	14	11	14	11	14	11	14	11
14	12	14	12	14	12	14	12	14	12	14	12
14	13	14	13	14	13	14	13	14	13	14	13
15	5	15	5	15	5	15	5	15	5	15	5
15	8	15	8	15	8	15	8	15	8	15	8
15	9	15	9	15	9	15	9	15	9	15	9
15	10	15	10	15	10	15	10	15	10	15	10
15	11	15	11	15	11	15	11	15	11	15	11
15	12	15	12	15	12	15	12	15	12	15	12
15	13	15	13	15	13	15	13	15	13	15	13
15	14	15	14	15	14	15	14	15	14	15	14
16	6	16	6	16	6	16	6	16	6	16	6
16	8	16	8	16	8	16	8	16	8	16	8
16	11	16	11	16	11	16	11	16	11	16	11
16	12	16	12	16	12	16	12	16	12	16	12
16	13	16	13	16	13	16	13	16	13	16	13
16	14	16	14	16	14	16	14	16	14	16	14
16	15	16	15	16	15	16	15	16	15	16	15
16	17	16	17	16	17	16	17	16	17	16	17
16	18	16	18	16	18	16	18	16	18	16	18
16	19	16	19	16	19	16	19	16	19	16	19
16	21	16	21	16	21	16	21	16	21	16	21
17	6	17	6	17	6	17	6	17	6	17	6

FIGURE 17, p.3



Disruption Matrices

The environmental disruption matrices prepared by the study group, here combined into one matrix for ease of presentation, are presented in Figure 18. In this case levels of disruption have been denoted by ordinal figures ranging from 0 (no noticeable effect) to 3 (severe disruptive effect). The most salient feature of the disruption matrices is the number of dependencies for which equal orders of disruption have been assigned. In these cases the study group was agreed that each alternative would be equally disruptive to the relationship, although the level of disruption could not be precisely determined. Sixty-nine of the interdependencies showed levels of disruption which differed between sites. When applied to the dependency chains discussed above, these yield indications of the effects each alternative proposal would have on the Nanaimo environmental system.

The chief obstacle to the use of the interaction matrices in proceeding beyond the identification of dependencies is that they designate only that a dependency does exist, but do not give us any idea of the magnitude or importance of the interaction - precisely the same problem as Leopold faced. Until environmental scientists can measure these factors accurately, environmental assessments will be restricted to qualitatively phrased assessments. The use of techniques such as these, as well as those of the disruption matrices discussed above, will serve to hasten such measurement.

The component interdependencies deduced for the components of the Nanaimo environmental system served to guide the investigation of the disruptions which would be caused by the modification of any of the components. The disruption matrices, on the other hand, were found to be

Figure 18

NANAIMO DISRUPTION MATRICES

(Each cell gives the disruption level for the five alternatives, arranged as in the key: 1 5 3 / 2 4.)

		1 CURRENTS	2 WIND	3 WATER TEMPERATURE	4 LIGHT	5 INTERTIDAL VEGETATION	6 UPLAND VEGETATION	7 BACTERIA	8 INSECTS	9 LARVAE	10 SHELL FISH	11 CRABS	12 OTHER CRUSTACEANS	13 PELAGIC FISH	14 BOTTOM FISH	15 WATERBIRDS	16 BIRDS OF PREY	17 SONG BIRDS	18 MARSH & SHORE BIRDS	19 UPLAND GAME BIRDS	20 AQUATIC & MARINE MAMMALS	21 UPLAND MAMMALS
CURRENTS	1		0 0 0 / 0 0																			
WIND	2						0 1 1 / 1 1															
WATER TEMPERATURE	3	1 1 1 / 1 1	2 1 1 / 1 1		3 1 1 / 2 1																	
LIGHT	4																					
INTERTIDAL VEGETATION	5	3 1 2 / 2 1		1 1 1 / 1 1	3 3 3 / 3 3																	
UPLAND VEGETATION	6				0 3 3 / 3 3			0 1 1 / 1 1	0 1 1 / 1 1									0 1 1 / 1 1	0 1 1 / 1 1	0 1 1 / 1 1		0 1 1 / 1 1
BACTERIA	7			1 1 1 / 1 1		2 2 2 / 2 1	0 2 2 / 2 2		1 1 1 / 1 1	1 1 1 / 1 1	1 1 1 / 1 1	1 1 1 / 1 1	1 1 1 / 1 1	1 1 1 / 1 1	1 1 1 / 1 1	1 1 1 / 1 1	0 1 1 / 1 1	0 1 1 / 1 1	1 1 1 / 1 1	0 1 1 / 1 1	1 1 1 / 1 1	0 1 1 / 1 1
INSECTS	8	1 0 0 / 0 0	1 1 1 / 1 1	1 1 1 / 1 1		1 1 1 / 1 1	0 1 1 / 1 1	1 1 1 / 1 1														
LARVAE	9	2 2 2 / 2 2		2 2 2 / 2 2		3 3 3 / 3 3		2 2 2 / 2 2			2 2 2 / 2 2	2 1 2 / 2 0	2 2 2 / 2 2	2 2 2 / 2 2	2 2 2 / 2 2							
SHELL FISH	• 10	2 2 2 / 2 2		2 2 2 / 2 2		3 3 3 / 3 3		2 2 2 / 2 2														
CRABS	• 11			2 0 2 / 2 0		2 0 2 / 2 0				2 0 2 / 2 0	2 0 1 / 2 0		2 0 2 / 2 0	1 0 1 / 1 0	2 0 1 / 2 0							
OTHER CRUSTACEANS	12			2 2 2 / 2 2		2 2 2 / 2 2		1 1 1 / 1 1	1 1 1 / 1 1	2 1 1 / 2 1	2 2 2 / 2 2	1 0 1 / 1 0		1 1 1 / 1 1	1 1 1 / 1 1							
PELAGIC FISH	13			2 2 2 / 2 2					2 2 2 / 2 2	3 3 3 / 3 3												
BOTTOM FISH	14			2 2 2 / 2 2		2 2 2 / 2 2			2 2 2 / 2 2	3 3 3 / 3 3	1 0 1 / 1 0	1 0 1 / 1 0	3 3 3 / 3 3	1 2 2 / 2 2								
WATERBIRDS	15					3 1 1 / 2 1			1 0 0 / 1 0	2 0 1 / 2 0	3 1 1 / 2 0	3 0 1 / 2 0	3 1 1 / 2 0	2 1 1 / 2 1	2 1 1 / 2 0							
BIRDS OF PREY	16						0 3 3 / 3 3		0 1 1 / 1 1			1 0 0 / 1 0	1 0 1 / 1 0	1 1 1 / 1 1	1 0 1 / 1 0	2 1 1 / 2 1		0 2 2 / 2 2	0 0 1 / 1 0	0 1 1 / 1 1		0 2 2 / 2 2
SONG BIRDS	17						0 3 3 / 3 2		1 3 3 / 3 2		1 0 1 / 1 0		2 1 2 / 3 1	1 1 / 1 0	1 1 1 / 1 1							
MARSH & SHORE BIRDS	18						0 2 2 / 2 2		0 1 1 / 1 0		1 0 1 / 1 0	1 0 1 / 1 0	2 2 2 / 2 2	1 1 1 / 1 1	3 1 3 / 3 1							
UPLAND GAME BIRDS	19						0 3 3 / 3 3		0 1 1 / 1 1													
AQUATIC & MARINE MAMMALS	20										1 1 1 / 1 0	2 0 2 / 2 0	2 2 2 / 2 2	2 2 2 / 2 2	2 2 2 / 2 2							
UPLAND MAMMALS	21						0 3 3 / 3 3				0 2 3 / 2 2	0 0 1 / 1 0	0 3 3 / 3 3					0 1 1 / 1 1		0 1 1 / 1 1		

ALTERNATIVE [1 5 3 / 2 4]

ALTERNATIVE 1 = INNER HARBOUR
ALTERNATIVE 2 = JACK POINT
ALTERNATIVE 3 = DUKE POINT (A)
ALTERNATIVE 4 = HARMAC SOUTH
ALTERNATIVE 5 = DUKE POINT (B)

DISRUPTION LEVEL

0 — NO NOTICEABLE DISRUPTION
1 — SLIGHT DISRUPTION
2 — APPRECIABLE DISRUPTION
3 — SEVERE DISRUPTION

useful in estimating the degrees of disruption which might occur. The information gained through the use of these techniques is not discussed here, but was used during the synthesis of the information contained in other studies of the Nanaimo environmental system. This synthesis then formed the basis of a summary report[8] on the port development question.

[8] An Environmental Assessment of Nanaimo Port Alternatives, Lands Directorate, Environment Canada, Ottawa, 1973.

DATE	ISSUED TO
13/02/90	Zal Davar