A RANKING ANALYSIS OF CONTAMINATED SITES ALONG THE SHORES OF LAKE ONTARIO

Rainer Brüggemann[1] and Efraim Halfon[2]*

NWRI Contribution No. 89-22

[1] GSF - PUC
Ingolstaedterlandstrasse 1
Neuherberg
Federal Republic of Germany

[2] Lakes Research Branch
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario
Canada L7R 4A6

* To whom reprint requests should be sent.

May 1989

MANAGEMENT PERSPECTIVE

A ranking method based on systems analysis principles is applied to the classification and ranking of degraded areas in the inshore waters of Lake Ontario. The ranking method also identifies which parameters should be measured in future sampling programs to determine the status of degradation of environmental areas with minimal expense of dollars and manpower. The ranking method is based on the hypothesis that a set of numbers, attributes, is generally necessary to create a ranking file. These numbers can be considered the elements of a vector, the "vector performance." This "vector approach method" is different from the "scalar approach method," where a single number (a scalar performance index) is said to be sufficient to interpret concentrations and toxicity data, compare sampling sites and rank them according to their state of degradation. Results of this analysis are displayed using Hasse diagrams, a useful graphic tool commonly used in lattice theory (a genealogical tree is a special case of a Hasse diagram). Hasse diagrams allow a quick visual comparison of sampling sites based on thousands of test results, which might otherwise be very confusing when displayed in table form. Further work planned includes the development of an expert system that will help decision makers and government agencies interested in ranking other data in an organized manner.

PERSPECTIVES DE GESTION

Une méthode de classement fondée sur le principe de l'analyse des systèmes est utilisée pour la classification et le classement hiérarchique des zones dégradées des eaux côtières du lac Ontario. Cette méthode détermine également quels paramètres doivent être mesurés lors de futurs programmes d'échantillonnage pour évaluer le niveau de dégradation de certaines zones environnementales, et ce à un coût minimal en argent et en personnel. Le classement est fondé sur l'hypothèse voulant qu'un ensemble de nombres et d'attributs soit généralement nécessaire pour l'obtention d'un fichier de classement. Ces nombres peuvent être considérés comme les éléments d'un vecteur, le "vecteur performance". Cette technique du vecteur est différente de la méthode scalaire, où un seul nombre (indice scalaire de performance) est considéré comme étant suffisant pour interpréter les valeurs de concentration et de toxicité, comparer les sites d'échantillonnage et les classer selon leur niveau de dégradation. Les résultats de cette analyse sont affichés grâce aux diagrammes de Hasse, outils graphiques très utiles, qui sont employés généralement dans la théorie des treillis (l'arbre généalogique est un cas particulier de diagramme de Hasse). Ces diagrammes permettent une comparaison visuelle rapide des sites d'échantillonnage, fondée sur des milliers de résultats d'essais, qui autrement, par exemple sous forme de tableaux, prêteraient à confusion. D'autres recherches sont prévues, qui visent à élaborer un système spécialisé permettant aux décisionnaires et aux organismes gouvernementaux de classer d'autres données de façon organisée.

ABSTRACT

A ranking method based on set theory and systems analysis is used to identify degraded areas in the inshore waters of Lake Ontario. Data are provided by Dutka and coworkers. They developed a "battery of tests" procedure to identify degraded areas. These measurements can be considered the elements of a vector which identifies the environmental hazard of each location. Ranking of sampling stations is obtained by partial ordering the vectors representing each station. Partial ordering is a vectorial approach which recognizes that not all sites can be compared with all others in terms of environmental hazard when several criteria (test results or attributes) are used. In fact the higher the number of criteria, the higher is the probability that contradictions in ranking exist between criteria. Results are displayed using Hasse diagrams, a useful graphic tool commonly used in algebra to display lattices (a genealogical tree is a special case of a Hasse diagram). Dutka and coworkers and ourselves identify stations 31 (Humber STP outfall), 32 (Mimico Creek mouth), 35 (Credit River mouth), and 5 (Bay of Quinte near Belleville STP outfall) as the most degraded areas in the inshore waters of Lake Ontario. We also identify stations 25 (STP Toronto) and 33 (Etobicoke Creek). Our method not only ranks sites, but also identifies contradictions in the criteria used to rank the sites, and identifies which criteria are the most influential on this ranking scheme and should be measured on a routine basis in future sampling programs. Four tests need to be performed in water samples (concentrations of <u>E. coli</u>, of coliphages and of the fecal steroids cholesterol and coprostanol) and three in bottom sediments (concentrations of fecal coliforms, Microtox and Genotoxicity tests).

RESUME

Une méthode de classement fondée sur la théorie des ensembles et sur l'analyse des systèmes sert à caractériser les zones dégradées des eaux côtières du lac Ontario. Pour cette caractérisation, Dutka et ses collègues ont mis au point une méthode utilisant une "batterie d'essais". Ces mesures peuvent être considérées comme les éléments d'un vecteur qui caractérise le risque environnemental pour chaque lieu. Le classement des stations d'échantillonnage est obtenu grâce au classement partiel des vecteurs représentant chaque station. Ce classement partiel est une méthode vectorielle qui reconnaît le fait que tous les sites ne peuvent être comparés à tous les autres pour ce qui est du risque environnemental, lorsque plusieurs critères (résultats d'essais ou attributs) sont utilisés. En fait, plus le nombre de critères est élevé, plus grande est la probabilité qu'il existe des contradictions entre les critères au niveau du classement. Les résultats sont affichés grâce aux diagrammes de Hasse, outils graphiques habituellement utilisés en algèbre pour afficher les treillis (l'arbre généalogique est un cas particulier de diagramme de Hasse). Dutka, ses collègues, et nous-mêmes avons caractérisé les stations 31 (exutoire de la station d'épuration des eaux usées de Humber), 32 (embouchure de Mimico Creek), 35 (embouchure de la rivière Credit) et 5 (Bay of

Quinte, près de l'exutoire de la SEEU de Belleville) comme étant les zones les plus dégradées des eaux côtières du lac Ontario. Nous avons également retenu les stations 25 (SEEU de Toronto) et 33 (Etobicoke Creek). Notre méthode ne consiste pas seulement à classer les lieux, mais également à relever les contradictions dans les critères utilisés pour le classement, et à déterminer quels critères sont les plus déterminants dans ce classement, en vue de les mesurer de façon régulière lors des futurs programmes d'échantillonnage. Quatre essais doivent être effectués sur les échantillons d'eau (concentrations de E. coli, de coliphages, et de stéroïdes fécaux, cholestérol et coprastanol), et trois sur les sédiments de fond (concentrations de coliformes fécaux, essais Microtox et de génotoxicité).

INTRODUCTION

The identification of degraded or degrading water bodies in Canada has been the object of research by Dutka et al. (1986). They developed a "battery of tests" procedure to identify these areas. This battery of tests includes a variety of microbiological, biochemical and bioassays tests. According to Dutka et al., the battery of test approach makes it possible to establish "hot spots," i.e., areas of immediate concern which were not previously suspected using one dimensional testing procedures. The battery of tests approach consists of a number of measurements at each location. These measurements can be considered the elements of a vector which identifies the environmental hazard of each location. The Ontario Ministry of the Environment has also encouraged the use of a vector scoring system to identify areas of concern.

In this paper we present an application of a ranking method (Reggiani and Marchetti, 1975; Halfon and Reggiani, 1986) based on set theory and systems analysis. Ranking of sampling stations is obtained by comparing test results obtained at one site with test results obtained from the same tests at other sites. This approach is called partial ordering. Partial ordering is a vectorial approach which recognizes that not all sites can be compared with all others in terms of environmental hazard when several criteria (test results or attributes) are used. In fact the higher the number of criteria, the higher is the probability that contradictions in ranking exist between criteria. This statement means that different ranking results might be obtained if each criterion was used alone or if tests results are combined in an index function. Results are displayed on paper or on a TV monitor driven by desk top personal computers using Hasse diagrams (Harary, 1969; Preparate and Yeh, 1973; Reggiani and Marchetti, 1975), a useful graphic tool commonly used in algebra to display lattices (a genealogical tree is a special case of a Hasse diagram). This method not only ranks sites, but also identifies contradictions in the criteria used to rank the sites, and identifies which criteria are the most influential in this ranking scheme and should be measured on a routine basis in future sampling programs. Analysis of the data used in the ranking scheme is an important part of the the ranking scheme itself.

One basic premise of a ranking scheme is that a low numerical value on a test indicates less environmental hazard. The measurements made at each site are elements of a vector. These vectors are ranked without having to summarize measurements from each site with a one dimensional index. The method is described in detail in Halfon and Reggiani (1986) and applications are presented in Halfon and Brueggemann (1989a;b). Note that Dutka et al. recognize the need of ranking sites according a to number of tests, using a vectorial approach, but they employ a one dimensional index, a figure of merit, to rank sites sampled in Lake Ontario. This approach provides a ranking but it loses some of the information present in test result.

DATA

Dutka et al. (1986) collected data in Lake Ontario as part of a nationwide effort to estimate the environmental degradation at different locations. As part of this study they sampled 55 stations along the shores of Lake Ontario. The sampling sites were located on the north shore of Lake Ontario from Kingston on the east to the Niagara River on the western end of

Lake Ontario.

Sediments and water samples were collected in June 1985 according to a procedure described by Dutka et al. (1986). A number of microbiological tests (presence of Legionella, fecal coliform densities, E. coli densities and coliphage concentrations), biochemical tests and toxicity screening tests (concentrations of fecal sterols, cholesterol and coprostanol, dehydrogenase activity using Bacillus cereus, a genotoxicity test and the Microtox test) were performed on water and sediment samples. The full sets of results is presented in Dutka et al. (1986). Dutka et al. performed seven tests (criteria or attributes) to analyze, and rank, the water samples and performed six tests in the bottom sediments. Unfortunately not all analysis proved successful and therefore in this study we rank only 26 stations according to five tests in water and all 55 stations according to five tests in bottom sediments (the tests in water and bottom sediments are different from each other). Table 1 presents the tests used and the classification scheme used by Dutka et al. and Tables 2 and 3 present the data used in this exercise.

ASSIGNMENT OF WEIGHTS TO THE CRITERIA

Dutka et al. (1986) did not use the raw data to rank stations but they weighted their results with scores (Table 1). The choice of weighting factors is important and should be approached with care (Keeley and Raiffa, 1969). Dutka et al. weighted two sets of experiments more heavily than the others, the Microtox test in the bottom sediments and the concentration of coprostanol in water and bottom sediments. Coprostanol is one of the principal sterols in feces of man and higher animals. Thus, according to Dutka et al., the presence of coprostanol in water or sediment would indicate contamination by excreta from either domestic wastes or runoff from pastures or barnyards. Table 1 shows the weighting factors attributed by Dutka et al. to the different tests. Dutka et al. (1986) assigned weights or scores to the data; they summed these scores in a scalar performance index to provide a rank. Locations with a high score were identified as degraded areas.

RESULTS OF RANKING USING HASSE DIAGRAMS (Bottom sediment samples)

The ranking method

The ranking method (Halfon and Reggiani, 1986) is based on the hypothesis that a set of numbers, attributes, is generally necessary to create a ranking file. These numbers can be considered the elements of a vector, the "vector performance." This "vector approach method" is different from the "scalar approach method," where a single number (a scalar performance index) is said to be sufficient to interpret concentrations and toxicity data, compare sampling sites and rank them according to their degraded state. The formal logical development of the method can be found in Preparate and Yeh (1973). The hazard levels are determined by comparing the test data for each site with all the others according to prespecified logical rules. These rules are based on principles of lattice and graph theory developed in the 1960's and 1970's (Harary, 1969; Preparate and Yeh, 1979; Reggiani and Marchetti, 1975). The methodology is therefore well established. A FORTRAN computer program has been developed for easy usage of the method and a BASIC program to display results with a desk top personal computer is available from the author. Note that the method is simple enough that calculations can be done by hand even if they are lengthy.

Hasse diagrams are used to display the ranking of data collected by Dutka et al. (1986) in the bottom sediments of 55 stations. Five criteria are used here: The concentration of coliforms and _E. coli_ in a broth, concentration of coprostanol, concentration of cholesterol, the Microtox test, and genotoxicity (Table 2). A full theoretical explanation of Hasse diagrams are given in Halfon and Marchetti (1986). The numerical computations necessary to create a Hasse diagram from an array of data can be performed either on a mainframe or on a personal computer. Camera ready Hasse diagrams can be prepared on Calcomp plotters. The following paragraph explains the information in a Hasse diagram using sediment data.

Hasse Diagrams

Figure 1 shows the ranking of 55 stations (bottom sediments) according to all five criteria presented in Table 2. Figure 1, a Hasse diagram, includes a large amount of information.

a) The number within each circle represents a sampling station (Table 2).

b) The sampling stations are ranked in seven hazard levels. The figure of merit approach, index functions, always rank sites in a chain. Some sites are always worse than other even if by small numerical amounts. The division in levels allows the user a more direct understanding of the ranking structure.

c) The circles near the top of the page represent more degraded or hazardous areas while circles at the bottom represent less degraded, or cleaner, areas.

d) The Hasse diagram also recognizes that a number of sampling stations can be ranked exactly as other stations, for example stations 27, 33, 46 and 47 are equally hazardous according to the five tests. Table 2 shows that these four stations have scores of

Fecal coliforms	Coprostanol	Cholesterol	Microtox	Genotoxicity	
5	0	0	0	0	stations 27,33,46,47

for the five tests and therefore they are indistinguishable from a ranking point of view. A number of other stations are also ranked the same, for example, stations 4, 6, 94, 10, 13, 19, 21, 22, 29, 30 and 48 on the 5th level.

e) Some circles (stations) are connected by lines and others are not. Note that circles on the same level are not connected by lines. The presence of a line between two circles indicates that the station located on the superior level has ranked worse, for all tests, than the station located in the lower level. For example note the differences in results for the stations 25 (sewage treatment plant, STP, in toronto) and 31 (STP outfall, Humber River):

Fecal coliforms	Coprostanol	Cholesterol	Microtox	Genotoxicity	
4	0	0	0	0	station 25
4	5	4	0	0	station 31.

Each vector element of station 25 is lower or equal than the respective element of station 31. Station 25 is therefore less degraded than station 31.

Conversely stations 27 (Cherry St., Toronto) and 31 are located on the same level and are not connected by a line.

Fecal coliforms	Coprostanol	Cholesterol	Microtox	Genotoxicity	
5	0	0	0	0	station 27
4	5	4	0	0	station 31.

Station 27 is worse than station 31 according to the first test, but is better than 31 according to the second and third test. The Hasse diagram points this contradiction to the user in the form that both stations are located on the same level.

From the analysis of these three stations (25, 27 and 31) we can note the following: Station 31 is worse than station 25 for all tests (the first three tests have higher scores and the last two are equal), station 27 is worse than station 25 for all tests (the first test has a higher score and the other four tests are equal), stations 27 and 31 are both worse than station 25 but we cannot say whether 27 is worse than 31 or viceversa.

f) Hasse diagrams not only rank the stations but also indicate to the user that for some stations it is impossible to make a rationale decision since some tests, or criteria, used for ranking, are contradictory. In lattice theory circles on the same level and circles not connected by a line are called incomparable.

g) A final item of information is added to the Hasse diagram in this instance, namely the ranking of Dutka et al. In this example, Dutka et al. ranked station 31 as the second worst, station 27 as the 17th and station 25 as the 21st.

CHOICE OF CRITERIA TO USE IN RANKING

Another important aspect of ranking is whether to use all data collected, all criteria, or whether some criteria are redundant. This aspect is important to minimize dollar and manpower costs in future data collection projects. If for example test A provides information to the ranking scheme, similar to the information already present in the combination of the other tests, then test A can be safely eliminated. From a practical point of view the problem is not the estimation of the correlation among tests, or even between the ranking and each test, but rather the holistic relations among all tests and the ranking. One test can be eliminated not because its results are correlated with one or more other criteria, but because its elimination from the analysis does not change the ranking results.

Analysis of the most important criteria for ranking (bottom sediments)

To establish which tests, or criteria, are most significant to the ranking the following procedure can be used. The data set from the bottom sediments is ranked with Hasse diagrams using all five tests (the full set); one test at the time can be eliminated and the Hasse diagrams compared with the full set. Once this step is completed two tests at the time are eliminated and rankings compared with the full set. Once all possible combinations are performed it is possible to decide which ranking diagrams using fewer criteria) are most similar to the full set. Some criteria can therefore be eliminated with no loss of information.

A straightforward method is to have the computer draw all Hasse diagrams excluding one criterion at the time and to compare each new Hasse diagram with the original one. This effort can be easily automated. This brute force approach has been used in this case. Brueggemann and Halfon (1989) have now developed a more elegant method to solve this problem with a minimal amount of computation by an analysis of the effects of each test on the structure of a Hasse diagram.

An analysis of all possible Hasse diagrams shows (Fig. 2) that elimination of tests 2 and 3, namely the concentrations of cholesterol and coprostanol in bottom sediments, does not change significantly the ranking of these stations. The bottom five levels are the same in both Figures 1 and 2. The only difference between Figures 1 and 2 is that stations 31 and 95 (station 9A in Dutka et al. paper located in the Harbour of Port Hope) have been ranked on the second level in Fig. 2.

The conclusion of this analysis is that in future sampling projects the measurements of the fecal steroids in bottom sediments can be eliminated with negligible influence on the overall results and that only three tests are critical.

Comparison of the Hasse diagram analysis with a conventional correlation analysis to eliminate redundant tests

The correlation of each individual test score with the ranking by Dutka et al. is the following:

Fecal coliforms	Coprostanol	Cholesterol	Microtox	Genotoxicity
.315	. 623	.566	.747	.154

These results seem to indicate that measurements of cholesterol and coprostanol concentrations are important in ranking the bottom sediments of Lake Ontario, since they are correlated with the final ranking. Our analysis with Hasse diagrams has shown instead that the influence of these two tests on the ranking process is minimal. The discrepancy of these two analysis can be easily understood by looking at the data in Table 2. Most of the scores for cholesterol and coprostanol are zero. These scores are not zero only when the rank by Dutka et al. is high [Stations 5 (Sewage outfall area, Belleville), 95 (9A) and 31]. The other three tests, fecal coliforms, Microtox and Genotoxicity are less correlated with the ranking provided by Dutka. Their scores, however, are often different from zero and provide real information about the ranking. The numerical procedure used in building Hasse diagrams realizes that the presence of many zero scores does not add much information to the ranking process, even if the correlation analysis seems to indicate the contrary. In other words: correlation does not imply causation. The mathematical method at the base of Hasse diagrams looks for this causation in comparing ranking using different criteria.

RANKING OF STATIONS ACCORDING TO WATER SAMPLES

Determination of criteria to be eliminated in future sampling programs

As for the bottom sediments, we compared the ranking of the 26 stations where water measurements were available using all five criteria with all the other rankings obtained by eliminating one or more criteria at the time. Results (Fig. 3) show that the elimination of test #1, the concentration of fecal coliforms does not change the ranking of the 26 stations. Thus, in future samplings of Lake Ontario inshore waters, the presence of fecal coliforms need not be measured for ranking purposes.

Ranking of 26 stations in Lake Ontario according to four criteria

Hasse diagrams simplify the display of hundreds of test data in an easy to understand form. Figure 3 shows the ranking of 26 stations where water samples data are available according to four criteria. The 26 stations are ranked in eight levels. Stations 1 (Cataraqui River, Kingston), 31 and 33 (Etobicoke Creek) are ranked as the most degraded areas, followed in turn by stations 5, 25, 30 (Humber River) and 47 (Inside of Bay, Port Dalhousie). The interesting point is that Dutka et al. ranked stations 30 and 5 as 9th and 10th respectively. As noticed before stations on the same hazard level cannot, by definition of a Hasse diagram, be compared with each other because of contradictions in the data. Thus even if overall stations 1, 31 and 33 are worse than all other stations, for at least least one of the five criteria each of these three stations is more hazardous than the other two. An analysis of Table 3 provides an answer. The top three stations have the following scores:

<u>E. coli</u>	coliphage	Cholesterol	Coprostanol	
4	1	2	0	Station 1
2	4	4	10	Station 31
3	3	1	0	Station 33

Thus, station 1 is the worst of all three for the first test, while station 31 is the worst for the last three tests. Station 33 is worse than station 31 for the first test and better in the last three. As mentioned above the Hasse diagram not only shows a ranking of the data but it also allows a precise understanding of how the ranking was obtained. The figure of merit approach does provide a ranking but does not provide an insight to the data used to create the ranking. As the number of stations and the number of criteria used for ranking increase, the advantages of Hasse diagrams are clearly self evident.

Figure 3 shows that the 26 stations are ranked into eight groups. Stations 1, 31 and 33 rank as the most degraded. A second group of degraded locations include stations 5, 25, 30 and 47. A third group of hazardous locations include 29 (Sunnyside Beach, Toronto), 32 (Mimico Creek), 35 (Mouth of Credit River) and 50 (Mouth of Niagara River). Figure 3 also shows the rank assigned by Dutka et al. to the same stations. Dutka et al. ranked station 31 as the most hazardous followed by stations 25, 1, 32, 47 and 33; these stations are ranked in the top 25% (6 stations out of 26). The Hasse diagram provides a slightly different ranking of the stations but it also provides additional information usually not included in ranking studies. Even if stations 1, 31 and 33 are the most degraded areas overall, we must recognize that for at least one of the four criteria, some stations might be worse the three top. For example station 5, on the second level, and station 33 on the first level, are not connected by a line. An analysis of Table 3 shows that station 5 has higher levels of cholesterol than station 33:

E. coli	coliphage	Cholesterol	Coprostanol	
2	1	3	0	Station 5
3	3	1	0	Station 33.

This information might be important in some instances and it reinforces the opinion that visual information is important in ranking analysis. Hasse diagrams allow an easy transfer of information between the ranking and the data.

The least degraded areas

According to all test performed in the bottom sediments and in the water, three stations are the least degraded. They are station 20 (Rouge River), station 44 (Grimsby Beach) and station 45 (Jordan Harbour). These stations were also ranked very low by Dutka et al.

The most degraded areas

Identification of the most degraded areas can be accomplished by considering together both tests performed in the water and in the bottom sediments. Dutka et al. identified stations 31 (Humber STP outfall), 32 (Mimico Creek mouth), 35 (Credit River mouth), and 5 (Bay of Quinte near Belleville STP outfall) as the most degraded areas in the inshore waters of Lake Ontario. In our work we also identified the same stations with the addition of station 25 (STP Toronto) and 33 (Etobicoke Creek). Station 25 is degraded because of the high level of fecal coliforms and *E. coli* in the bottom sediments in addition to high level of pollution in water. Station 33 also has high levels of fecal coliforms and *E. coli* in bottom sediments in addition of widespread pollution in water.

In conclusion, as could have been expected from the large populations, the most polluted areas are located near the metropolitan Toronto area while some of the cleaner areas are located in the Niagara Peninsula. Interestingly enough, the Rouge River was also found to be one of the cleanest areas of Lake Ontario even though it is very close to Toronto.

DISCUSSION

The inshore waters of Lake Ontario are degraded mostly by local sources of pollution rather than from far away sources. This conclusion can be reached given the different ranking given to sampling stations close to each other, for example stations 20 and 25.

Both ranking schemes, Dutka et al.'s and ours, have identified the same stations as the most polluted, even if our analysis has pointed out two additional locations not considered excessively degraded by Dutka et al. The ranking scheme using Hasse diagrams has also identified contradictions in the test results, contradictions not immediately evident when an index function is used. The visual identification of contradictions is as useful as the ranking itself. The lines that connect circles in the Hasse diagram identify a structure in the tests used for ranking. Where lines are missing conflicting test results have occurred. A visual analysis of Hasse diagrams therefore allows the reconstruction of the ranking, or decision making process.

Hasse diagrams allow to visually compare sampling sites based on many test results, which might otherwise bye very confusing when displayed in table form. For example is very difficult to understand all the information presented in the Tables 2 and 3 by pure inspection of the numbers. The Hasse diagram is an effective graphical display of data difficult to understand otherwise.

An interesting result is that this ranking methodology identifies the 55 stations into eight distinct hazard groups. The stations are therefore not ranked 1 to 55 in terms of environmental hazard but in more easy understandable division in hazard levels. The important point is the number of classification levels is directly proportional to the number of sampling sites and is inversely proportional to the number of criteria. <u>In fact the more criteria considered at the same time, the higher the probability of contradictions in the data and therefore the higher the probability of having fewer discrimination levels.</u>

This ranking analysis also helps the principal investigators in deciding which tests are more crucial and should be repeated in collecting data from other sampling sites. Dutka et al. performed seven tests in water and six tests in the bottom sediments. Dutka et al. reported that the measurements from the <u>Legionella</u> and Microtox tests in water were all negative, thus these two experiments might be eliminated in future experiments. Kaiser et al. (1989) however stated that the Microtox experiments might have given negative results mainly because a boiling procedure was performed to identify the fecal steroids. In bottom sediments the dehydrogenase activity was also always negative and therefore we did not use this set of data. Our analysis shows that to rank sites in Lake Ontario only four tests need to be performed in water, namely concentrations <u>E. coli</u>, of coliphages and of the fecal steroids cholesterol and coprostanol. In bottom sediments the measurements of cholesterol and coprostanol are not relevant to ranking and in the future only measurements concentrations of fecal coliforms and <u>E. coli</u> and the Microtox and Genotoxicity tests should be performed.

The ranking procedure using a vectorial approach is applicable to a variety of problems in environmental toxicology. This procedure maintains the vectorial information collected under the form of different tests. Information is therefore not lost. The analysis provides a ranking of stations in groups, it identifies contradictory results and identifies which criteria should be used in future surveillance projects. Once data have been collected a computer can process them in a few seconds. A graphical display program has been developed for desk top computers and Calcomp plotters and is available on request. Further work along this line now includes the inclusion of this ranking method into an expert system that will help decision makers interested in ranking analyze their data in an organized manner.

REFERENCES

Brueggemann, R. and Halfon, E. 1989. A systematic way to analyze Hasse diagrams for sensitivity to multiple criteria (in preparation)

Dutka, B.J., Walsh, K., Kwan, K.K., El Shaarawi, A., Liu, D.L. and Thompson, K. 1986. Priority site selection for degraded areas based on microbial and toxicant screening tests. Water Poll. Res. J. Canada, 21: 267-282

Halfon, E. and Reggiani, M. 1986. On ranking chemicals for environmental hazard. Environ. Sci. Technol., 20: 1173-1176.

Halfon, E. and Brueggemann, R. 1989a. Environmental hazard of eight chemicals present in the Rhine River. Wat. Sci. Tech., 21:815-820.

Halfon, E. and Brueggemann, R. 1989b. Environmental hazard ranking of chemicals spilled in the Rhine River in November 1986. Acta Hydrochim. Hydrobiol., 17:47-60.

Harary, F. 1969. Graph Theory. Addison-Wesley, Reading, Mass.

Kaiser, K.L.E., Lum K.R. and Palabrica, V.S. 1989.. Review of field applications of the Microtox test in Great Lakes and St. Lawrence River waters. Water Poll. Res. J. Canada (in press)

Keeley, R.L. and Raiffa, H. 1976. Decisions with Multiple Objectives: Preferences and Value Tradeoffs. John Wiley and Sons, New York and Toronto.

Preparate, F.P and Yeh, R.T. 1973. Introduction to Discrete Structures. Addison-Wesley, Reading, Mass.

Reggiani, M.G. and Marchetti, F.E. 1975. On assessing model adequacy. IEEE Trans. Systems Man Cyber., SMC-5: 322-330.

Table 1: Points awarding scheme used to rank samples, based on suspected contained hazards (modified from Dutka et al. (1986).

Fecal coliform/*E. coli* Sediment 10/100 mL MPN Water /100 mL	Pts	Coliphage /100 mL	Pts	Coprostanol Sediment mg/Kg Water ng/L	Pts
< .1	0	< 5	0	< .1	0
.1 - 100	1	5 - 25	1	.1 - 1	1
100 - 500	2	25 - 100	2	1 - 3	2
500 - 2500	3	100 - 250	3	3 - 5	5
2500 - 10,000	4	250 - 1000	4	5 - 7	7
> 10,000	5	> 1000	5	> 7	10

Cholesterol Sediment mg/Kg Water ng/L	Pts	Microtox EC_{50} /g wet wt or /mL	Pts	Genotoxicity Equivalent to ng/mL 4NQO*	Pts
< .1	0	< .1	10	< 200	2
.1 - 2	1	.1 - .2	8	200 - 400	4
2 - 4	2	.2 - .3	6	400 - 600	6
4 - 6	3	.3 - .4	4	600 - 800	8
6 - 8	4	> .4	2	> 800	10
> 8	5				

*4 Nitro Quinoline Oxide

Table 2: Sediment scores of data collected at 55 stations in Lake Ontario. The five sets of criteria used to rank the sites are 1) Fecal coliforms, 2) Coprostanol, 3) Cholesterol, 4) Microtox and 5) Genotoxicity (See Table 1).

No.	station (Dutka label)	Hasse Diagram identifier	test results					Sampling Site
			1	2	3	4	5	
1	1	1	2	0	0	4	0	Cataraqui River, Kingston
2	2	2	1	0	0	2	0	Carruthers Point, Kingston
3	3	3	2	0	0	2	0	Deseronto
4	4	4	3	0	0	0	0	Napanee River
5	5	5	3	3	2	0	0	Outfall area, Belleville STP
6	6	6	3	0	0	0	0	Moira River
7	7	7	2	0	0	8	0	Trent River
8	8	8	1	0	0	2	0	Coburg
9	9A	95	3	5	2	6	0	Harbour - Port Hope
10	9D	91	2	0	0	0	0	Harbour - Port Hope
11	9H	92	3	0	0	4	0	Harbour - Port Hope
12	9J	93	2	0	0	0	0	Harbour - Port Hope
13	9M	94	3	0	0	0	0	Harbour - Port Hope
14	9T	9	1	0	0	6	2	Harbour - Port Hope
15	10	10	3	0	0	0	0	Breakwall - Port Hope
16	11	11	1	0	0	0	0	Newcastle
17	12	12	3	0	0	2	0	Bowmanville
18	13	13	3	0	0	0	0	Bowmanville Creek
19	14	14	1	0	0	8	0	Ruby Head
20	15	15	3	0	0	4	0	Marina Oshawa
21	16	16	1	0	0	0	0	Oshawa
22	17	17	3	0	0	6	0	Corbett Creek
23	18	18	1	0	0	2	4	Harbour Whitby
24	18A	60	1	0	0	0	4	Lasco Steel
25	19	19	3	0	0	0	0	Duffin Creek
26	20	20	2	0	0	0	0	Rouge River
27	21	21	3	0	0	0	0	Highland Creek
28	22	22	3	0	0	0	0	Scarborough
29	23	23	1	0	0	0	4	Industries Area, Toronto
30	24	24	2	0	0	0	0	Between Toronto Islands
31	25	25	4	0	0	0	0	STP, Toronto
32	26	26	2	0	0	0	0	Harbour, Toronto
33	27	27	5	0	0	0	0	Cherry St., Toronto
34	28	28	2	0	0	0	0	Ontario Place, Toronto
35	29	29	3	0	0	0	0	Sunnyside Beach, Toronto
36	30	30	3	0	0	0	0	Humber River, Toronto
37	31	31	4	5	4	0	0	STP outfall, Humber River
38	32	32	3	0	0	8	0	Mimico Creek
39	33	33	5	0	0	0	0	Etobikoke Creek
40	34	34	2	0	0	0	0	Lakeview Generator
41	35	35	3	0	0	6	0	Mouth of Credit River
42	37	37	2	0	0	0	0	Opposite Gulf Oil Plant

Table 2 continued: Sediment scores of data collected at 55 stations in Lake Ontario. The five sets of criteria used to rank the sites are 1) Fecal coliforms, 2) coprostanol, 3) cholesterol, 4) Microtox and 5) Genotoxicity.

43	39	39	2	0	0	0	0	16 Mile Creek
44	40	40	1	0	0	0	0	Bronte Creek
45	41	41	1	0	0	0	0	Petro Canada Pier
46	42	42	1	0	0	0	0	Spencer Smith Park
47	43	43	1	0	0	0	0	Entrance to Burlington Canal
48	44	44	1	0	0	0	0	Grimbsy Beach
49	45	45	1	0	0	0	0	Jordan Harbour
50	46	46	5	0	0	0	0	Mouth of Pourth Dalhousie
51	47	47	5	0	0	0	0	Inside of Bay, Port Dalhousie
52	48	48	3	0	0	0	0	Port Weller
53	49	49	2	0	0	0	0	Mouth of Niagara River
54	50	50	2	0	0	0	0	Mouth of Niagara River
55	51	51	2	0	0	0	0	Mouth of Niagara River

Table 3: Water scores of data collected at 26 stations in Lake Ontario. The five sets of criteria used to rank the sites are 1) Fecal coliforms, 2) *E. coli*, 3) coliphage concentrations, 4) cholesterol, and 5) coprostanol (see Table 1).

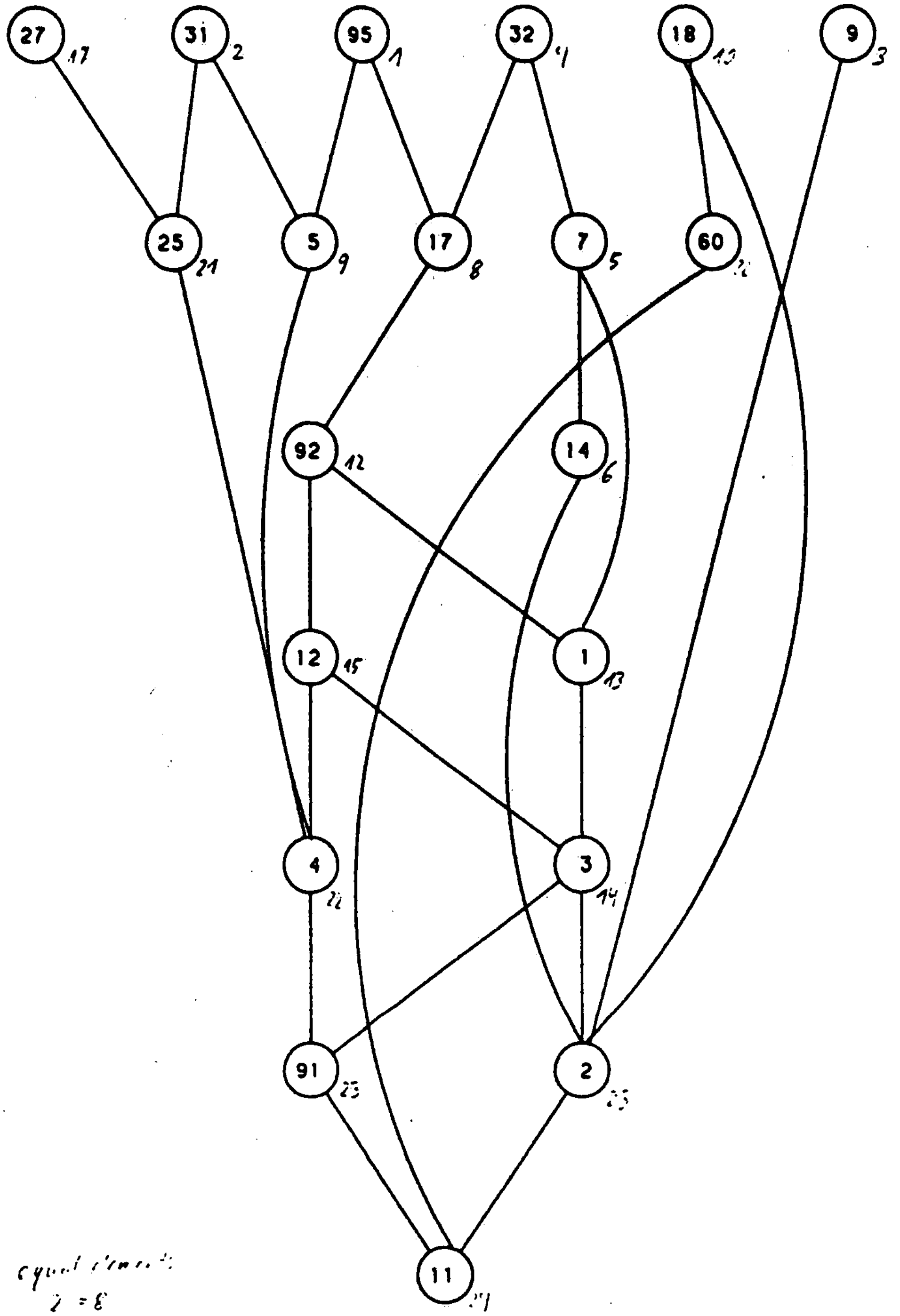
No.	station (Dutka label)	Hasse Diagram identifier	test results					Sampling Site
			1	2	3	4	5	
1	1	1	4	4	1	2	0	Cataraqui River, Kingston
2	5	5	2	2	1	3	0	Outfall area, Belleville STP
3	8	8	0	0	0	2	0	Coburg
4	9T	9	1	0	0	1	0	Harbour - Port Hope
5	20	20	0	0	0	1	0	Rouge River
6	21	21	1	1	0	2	0	Highland Creek
7	23	22	1	1	0	2	0	Industries Area, Toronto
8	25	25	1	1	3	3	7	STP, Toronto
9	26	26	1	1	1	2	1	Harbour, Toronto
10	28	28	1	1	2	1	0	Ontario Place, Toronto
11	29	29	2	2	2	1	1	Sunnyside Beach, Toronto
12	30	30	3	2	3	1	1	Humber River, Toronto
13	31	31	2	2	4	4	10	STP outfall, Humber River
14	32	32	2	1	2	2	3	Mimico Creek
15	33	33	3	3	3	1	0	Etobikoke Creek
16	35	35	3	2	3	1	0	Mouth of Credit River
17	40	40	2	2	1	1	0	Bronte Creek
18	42	42	1	1	1	1	0	Spencer Smith Park
19	44	44	0	0	0	1	0	Grimbsy Beach
20	45	45	0	0	0	1	0	Jordan Harbour
21	46	46	1	1	2	1	0	Mouth of Port Dalhousie
22	47	47	4	3	2	1	0	Inside of Bay, Port Dalhousie
23	48	48	2	1	2	1	0	Port Weller
24	49	49	1	1	0	1	0	Mouth of Niagara River
25	50	50	1	0	1	3	0	Mouth of Niagara River
26	51	51	1	1	1	1	0	Mouth of Niagara River

FIGURE LEGENDS

1) Hasse diagram ranking 55 stations in Lake Ontario according to the five criteria (Fecal coliforms, concentration of coprostanol, concentration of cholesterol, Microtox and Genotoxicity test) shown in Table 2. These criteria are tests performed in the bottom sediments. The numbers within each circle identify a station. At the bottom of the picture stations that occupy the same position in the Hasse diagram are identified. The small numbers near the circles show the ranking computed by Dutka et al. (1986). Location of sampling locations is presented in Table 2.

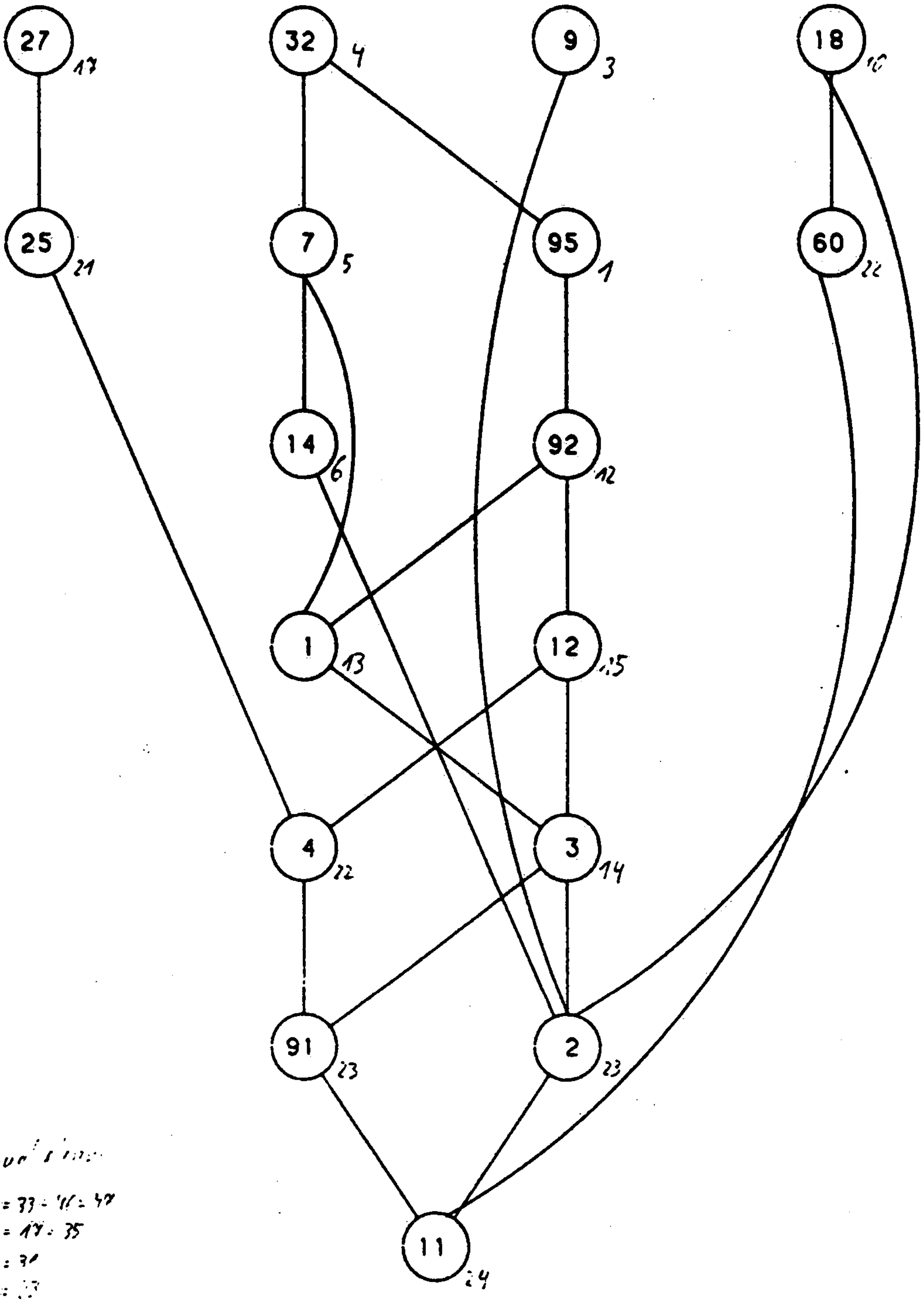
2) Hasse diagram ranking 55 stations in Lake Ontario according to three criteria as explained in the text. These criteria are tests performed in the bottom sediments and they are are Fecal coliform concentrations, Microtox and Genotoxicity tests. The numbers within each circle identify a station. At the bottom of the picture stations that occupy the same position in the Hasse diagram are identified. The small numbers near the circles show the ranking computed by Dutka et al. (1986). Location of sampling locations is presented in Table 2.

3) Hasse diagram ranking 26 stations in Lake Ontario according to four criteria shown in Table 3. These criteria are tests performed in the bottom sediments and they are *E. coli*, coliphage concentrations, concentration of cholesterol, and concentration of coprostanol. The numbers within each circle identify a station. At the bottom of the picture stations that occupy the same position in the Hasse diagram are identified. The small numbers near the circles show the ranking computed by Dutka et al. (1986). Location of sampling locations is presented in Table 3.



equal elements:
2 = 8
11 = 1[illegible] = 4[illegible] = 41 = 4[illegible]
= 44 = [illegible]
27 = 3[illegible] = 4[illegible] = [illegible]
17 = 35
60 = 73
4 = 6 = 9 = 10 = 13
= 19 = 21 = 22 = 29
= 36 = 45
91 = [illegible] = [illegible] = 14 = 16 = 64 = [illegible]
= 28 = 3[illegible] = [illegible] = 39 = 51

DU3
S104F5 [illegible]
[illegible]



equ[illegible]

27 = 33 - 40 = 47

95 = 17 - 35

25 = 31

60 = [illegible]

92 = 15

0 = 5 [illegible] = 94 = 1[illegible] . 1[illegible] = 19

= 14 - 1[illegible] = 79 = [illegible] 4[illegible]

2 = 5

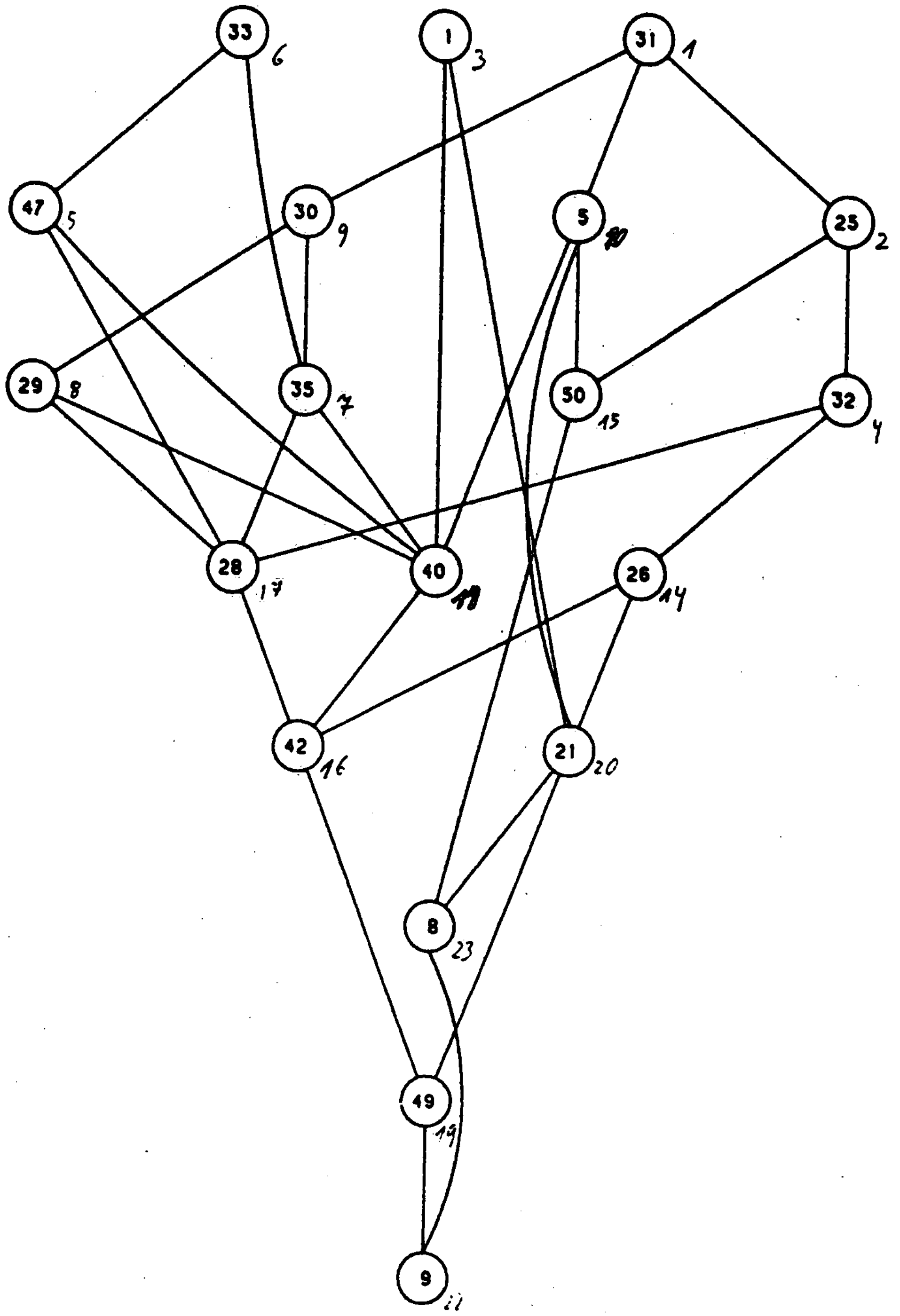
91 = 93 - 2[illegible] = 7[illegible] [illegible] 7[illegible] - 51

= [illegible] 5[illegible] = [illegible] = 53 = 5[illegible]

[illegible] = 1[illegible] [illegible] 4[illegible] = 4[illegible] = 1[illegible]

[illegible] 4

[illegible]



Equivalences
28 = 46 = 48
[illegible] = [illegible]
[illegible] = 22
9 = 26 = [illegible] 45