3. PREDICTION OF IMPACTS ON HEALTH

3.1 Introduction

3.1.1 Aims of Prediction

The next step in environmental health impact assessment is to predict the magnitude of the environmental health factors identified, and thus their likely effects on human health.

The aim of prediction is to provide information about the nature and extent of impacts resulting from an urban development project. This information allows us to assess the impacts of the project and if necessary to compare them with the impacts of other alternative developments or of taking no action.

3.1.2 The Process of Prediction

The process of prediction in EHIA may be one of gradual refinement. At first simple, approximate predictions are made to give an indication of whether or not an effect is likely to be significant. Later, more comprehensive predictions may be needed to give fuller information on important effects and to define proper mitigation measures.

In order to predict impacts it is necessary:

- o to describe the present state of the physical, biological and human environment, using available data, or based on surveys and monitoring;
- o and to predict how the physical, biological and human environment may change, and how these changes will affect environmental health factors.

Information on changes in environmental health factors may then be used as an input to Health Impact Assessment (HIA) which may comprise:

- o assessment of impacts in terms of effects on mortality and morbidity;
- o assessment of impacts in terms of particular "risk groups";
- o definition of the significance and acceptability of adverse health impacts.

Table 3.1(a) outlines the steps in prediction of the health impacts of urban development projects.

In the remainder of this section we discuss:

- o obtaining baseline information (3.2);
- o and for each main group of environmental health factors identified, prediction of changes to environmental health factors and human exposure to these factors (3 3 - 3 5)

Table 3.1(a)

Steps in Predicting the Health Effects of Urban Development Projects

1.	Obtaining baseline information	Description of the present state of the environment (see 3.2)	Description of present state of human health and exposure to disease (see 3.2)
2.	Predicting future changes (EHIA)	Prediction of how environmental health factors will change following the development (see 3.3-3.5)	Prediction of how human exposure to environmental health factors will change following the development (see 3.3-3.5)
3.	Predicting future changes in mortality and morbidity (HIA)	Prediction of total changes to mortality and morbidity, changes to size of high-risk groups	

3.2 Obtaining Baseline Information

3.2.1 Type of Information Required

Baseline information relevant to environmental health impacts has two main components:

- o information on the existing environment;
- o and information on existing levels of human health and exposure to disease.

Baseline information on the **existing environment** is needed to determine existing environmental health factors within an area (e.g. current levels of pollution, transmission pathways for existing disease problems).

Information on **human health** is needed to identify the pathways by which people are exposed to environmental health factors, for example:

- o the size, location and characteristics of the existing and incoming population, particularly the degree of contact with environmental health factors (e.g. water supply, sanitation arrangements, waste disposal practices, transportation, etc.);
- o current health problems, e.g. prevalent diseases and immunities in both the local population and incoming settlers.

Table 3.2(a) gives a checklist of baseline information on the environment and human health relevant to prediction of health effects.

In order to provide accurate information for prediction of environmental health impacts, it is essential that information obtained about the environment is site-specific. Information obtained in one area cannot be assumed to apply equally to a different, though superficially similar, area.

3.2.2 Methods of Obtaining Baseline Information

The first stage in obtaining baseline information is to establish what information may already be available from local or national government statistics, or from previous studies carried out within the area.

The extent and detail of such information may vary considerably as may the period of time over which it has been collected. Data aggregated at the national level may disguise important differences at the particular site; data which is several years old may be out of date because major changes have occurred. It is unlikely that data collected previously will answer exactly the questions posed by an EHIA. It may be necessary to use substitute measures (of health or environmental factors) rather than those which would ideally be required.

Table 3.2(a)

Checklist of Potentially Relevant Information on the Environment and Human Health

1. Review existing sources of information on the environment and human health.

   a. Climatic meteorological patterns: temperature, rainfall, wind, humidity, etc.

   b. Topographical maps, contours, location of roads, housing, industry, etc. in the region, plus detailed design plans of proposed project.

   c. Water: surface water and groundwater quantity, pollution, floods and droughts, seasonal variations.

   d. Soil: physical and chemical characteristics including permeability.

   e. Air: current levels of pollution.

   f. Current pollution sources: industrial, domestic, transportation, etc.

   g. Effects on health associated with current pollution levels.

   h. Current levels and types of occupational disease and accidents.

   i. Existence of any major hazards (man-made or natural) within the area.

   j. Current levels of injury and death from transportation accidents.

   k. Current levels and type of accidents in the home leading to injury or death.

   l. Current housing patterns, density levels, design and construction materials.

   m. Numbers and types of domestic and wild animals, especially disease vectors/carriers.

   n. Current water supply, excreta and waste disposal facilities.

   o. General epidemiology: morbidity and mortality rates, geographical distribution.

   p. Health and medical services: facilities, staff, degree of development, capacities and coverage.

continued

Table 3.2(a) (Continued)

Checklist of Potentially Relevant Information on the Environment and Human Health

2. Carry out surveys to check existing information or fill gaps in knowledge; requires expert assistance.

   a. Engineering and operational reconnaissance for geological, hydrological or soil studies.

   b. Detailed monitoring of climatic conditions at site, particular wind direction and speeds, frequency of inversions, etc.

   c. Detailed monitoring of water flows, both surface and groundwater, replenishment, run-off from surface.

   d. Monitoring at site and surrounding area of current pollution levels: air, water (surface and groundwater), soil, noise.

   e. Detailed investigation of current sanitation and waste disposal practices, including degree of human contact involved.

   f. Investigation of working practices within existing industry.

   g. Detailed specifications of proposed new development. General plans and layout, population size, age distribution, socio-cultural pattern, residential areas design and location, transportation, industrial development, water supply, sanitation and waste disposal plans, social facilities and health services, source of incoming settlers.

   h. Study of local economy: present status and prospects for future development.

   i. Detailed epidemiological study of existing major diseases and associated environmental health factors.

   j. Contact with agencies operating in the project area, to establish their range of activities and the possibility of assistance and co-ordination.

Once data from existing sources has been examined, a decision can be taken on whether further information should be collected through surveys and monitoring:

- o such information collection can provide accurate, up-to-date information specific to the study;
- o however, it can be expensive and time consuming, particularly where measurement by experts over a period of time is required (e.g. to cover wind data or water quality data over seasonal variations).

It is often the case, as with the prediction process as a whole, that the decision to go ahead with detailed data collection is taken only when it becomes apparent that a particular issue may be significant. For example, if emissions of nitrogen oxides from a factory seem likely to give high NO_x levels in a residential area, detailed monitoring of existing NO_x levels (from traffic, etc.) may be justified.

If it is decided that a comprehensive survey for the area is required, this may require input from a range of specialists, for example experts in medicine, environmental health, ecology, meteorology, hydrology, waste disposal, socio-economic studies.

The survey programme should be designed specifically for each different location, taking account of local conditions, seasonal variations and the level of information already available. It should be geared specifically to the type of problems likely to be encountered in the proposed development, so that the results of monitoring and surveys are presented in a way which allows them to be readily incorporated into the prediction process.

A summary of points to remember in obtaining baseline informatin is given in Table 3.2(b).

3.2.3 Problems of Measuring Health

Whilst appropriate measures of environmental health factors can often be readily determined, useful measures of human health are less easy to define. Published mortality statistics based on death registration, statistics on notifiable diseases and on hospital patients suffer from various defects because of under-reporting, incomplete geographical coverage, unreliable diagnosis, insufficient breakdown and publication delays.

In order to overcome these problems, a number of organisations have suggested the development of **health indices,** based on a number of measures of health, which may be used as part of an environmental health monitoring system. As with other monitoring systems, full application of the system may be costly and time-consuming, particularly where data collection on health is poorly developed. However, the indices described in Figures 3.2(c) and 3.2(d) represent ideals towards which health monitoring systems should aim.

Table 3.2(b)	
Summary of Points to Remember on Obtaining Baseline Information	
o	What are the major health problems current in the population (both existing and incoming); what are the levels of ill-health and degree of susceptibility?
o	What are the major environmental health factors important in these problems?
o	What are the main pathways in exposure of the population to these factors?
o	What are the numbers, locations and characteristics of existing populations?
o	What existing information is available on local environmental and social conditions?
o	What time-period and geographical coverage are necessary for a survey of existing conditions to cover important temporal and spatial variations?

Figure 3.2(c)

Health and Epidemiological Indices for Environmental Health Monitoring Systems

Real time indices and data

Indices of physiological status: height, weight, strength, reaction time, blood chemistry, karyotype, and chromosomal abnormalities.

Broad demographic data: short-term data on mortality rates, and all available specific morbidity rates, including those for communicable diseases and respiratory and nervous disorders.

Accidents, poisonings: comprehensive data on a short-term basis on casualty admissions to clinics and hospitals, and on deaths due to accident.

Intermediate indices and data

Complications of pregnancy, childbirth and the puerperium, and infancy: antenatal, perinatal, infant, and maternal mortality rates, and rates for congenital abnormalities and aberrations.

Historical indices and data

Cause-specific mortality and (where possible) morbidity rates under the following headings:

(*a*) neoplasms: particularly of lungs, stomach, liver, bladder, and bone marrow (leukaemias);

(*b*) neurological, mental, and behavioural disorders, including alcoholism and drug dependence;

(*c*) circulatory disorders, particularly ischaemic heart disease, arteriosclerosis, and pulmonary hypertension;

(*d*) respiratory diseases, particularly asthma, bronchitis, emphysema, and pneumonia;

(*e*) diseases of the digestive system, particularly cirrhosis of the liver;

(*f*) renal diseases, particularly nephritis and nephrosis.

Source: World Health Organisation; "Health Hazards of the Human Environment". Geneva, WHO, 1972.

Figure 3.2(d)

Summary Health Indicator Developed by Cayolla da Motta (1979)

The Summary Health Indicator (SHI) is the weighted average of the values of 9 single health indicators:

- maternal mortality, - infant mortality, - 1-4 yrs. mortality, - tuberculosis mortality rate, - gastritis and enteritis mortality rate, - infectious and parasitic diseases mortality rate, - pneumonia mortality rate,	Crude picture of health situation
- % deliveries without medical assistance, - % deaths without medical certification.	Indicator of medical coverage

Once identified, the indicators are standardised by conversion to a "conventional value". A coefficient or weight is assigned to each, by the researcher and these combine to give the SHI.

Source: UNESCO; "Approaches to the Study of the Environmental Implications of Contemporary Urbanisation". MAB Technical Notes 14, 1983.

3.3 Predicting Impacts of Pollution

3.3.1 Predicting Changes to Pollution Levels

In Section 2 we identified the following types of pollution arising from urban development projects which could give rise to health effects:

- air pollution,
- water pollution,
- soil pollution,
- noise,
- occupational exposure.

In order to predict the impacts of an urban development on health it is first necessary to predict the changes in levels and types of pollution which will arise from the development. To carry out this step it will be necessary to use detailed information on:

o the proposed development (sources of pollution, types of pollutant, emission rates, location of sources and receptors);

o and on the existing environment (geographical, climatological, hydrological, current levels of pollution).

This information will be available from the baseline survey (see 3.2).

Predictions of changes in levels and types of pollution may be made on the basis of:

o historical records of the levels of pollution produced by similar developments in the past;

o expert judgement of likely levels of pollution by specialists experienced in this type of development;

o experimentation in the environment, for example to predict the transportation of air and water pollution using inert substances;

o physical models representing certain aspects of the environment at a reduced scale;

o mathematical models of varying complexity which represent certain aspects of the environment.

Each approach has advantages and drawbacks, for example:

o historical data on pollution levels may relate to situations which are different in some significant way to the development proposed;

- expert judgement places considerable reliance on the interpretation of one person (or a group of people) who may not have experienced exactly similar situations in the past, although expert judgement allows for inclusion of a wider range of knowledge than just historical data;

- experimentation is only possible in limited circumstances and gives limited information unless very complex and costly experiments are developed;

- physical models may be extremely costly to develop and may pose considerable problems in scaling to give an accurate representation of a real-world effect;

- formal mathematical models are often of a theoretical nature, based on limited data sets, and may not have been widely tested in practice. They may require high levels of data input, be applicable only to limited situations and be costly and time consuming to use.

No single prediction method will prove the most suitable for every problem. Choice of method will depend on the resources available and the particular circumstances of the EHIA. However, some methods are more suited to certain types of problem;

- **Mathematical models** are best developed for predicting **air** and **water** pollution and **noise** levels. For these factors a number of relatively simple models are available which have been widely tested in practice, and can be applied within limited cost and time levels. However, they may still need considerable adaptation to the specific conditions of a particular urban development project.

- **Physical models** have been used to predict **transportation** of **water** and **air** pollutants in complex conditions where other forms of modelling are unreliable. Simple physical models are available for predicting **noise** levels in restricted circumstances.

- **Experimentation** is generally used in limited circumstances, to check predictions made by other methods. Balloon release may be used to check mathematical predictions of air pollutant transport, and simple markers used to check predictions of water transportation. In both these cases the movement of physical objects through air or water is mapped to see how well it fits with predicted movement.

- **Historical data** has been used as a basis for prediction where considerable data is available and other prediction methods are less feasible, for example concerning occupational exposure to chemicals and soil pollution. It is often used, formally or informally, in conjunction with expert judgement.

- o **Expert judgement** may be called upon either in conjunction with other types of prediction or where other methods are not feasible. The judgement of experts, based on their practical experience, is particularly helpful where prediction is complex, for example soil pollution related to waste disposal.

A number of sources of advice on pollution prediction methods are available; major sources are listed in the bibliography. Basically, the choice of prediction method will depend upon a trade-off between:

- o the resources available (time, money, information);
- o and the likely importance of the level of pollution to human health.

Thus prediction may be a cyclical process beginning with expert judgement or historical data on pollution levels, and moving on to mathematical or physical modelling if a particular form of pollution appears likely to be critical.

Table 3.3(a) lists points to remember in prediction of changes to pollution levels.

Table 3.3(a)
Points to Remember in Prediction of Changes to Pollution Levels
o Different changes to pollution levels may arise during construction, and after completion of urban development projects.
o Sources of pollution, whether industrial, domestic or transportation, may not always operate at design capacity.
o Fuel and raw material composition may change over time.
o Pollutant emissions may not be constant over a daily, weekly, monthly or annual cycle. There may be peaks and troughs.
o Similarly environmental conditions affecting pollutant transportation (such as temperature, rainfall, air stability) may vary over time.
o Measures of pollution level changes must be appropriate to EHIA, e.g. annual average and maxima rather than mean daily levels.

3.3.2 Predicting Exposure to Pollution Factors

The increased exposure of the population to pollution following the development will depend upon:

- o baseline levels of pollution at different locations;
- o predicted future levels of pollution at these locations;
- o numbers and time of residence of people at the locations.

In general, predictions of future levels of pollution are made for specific geographical areas where high numbers of people will be concentrated, and also to determine the geographical areas where the highest pollution levels will be found. However, in some cases, annual averages over a whole area may be used.

Exposure to pollution levels will also be affected by the behavioural characteristics of the population; for example:

- o how much time is spent in the home, at work, in travel?
- o what are the levels of contact with particular sources of pollution (e.g. visits to water bodies particular hygiene habits, children's play on waste dumps, keeping of domestic animals)?
- o how does the timing of activities causing exposure relate to the timing of high pollution levels?
- o does the pattern of activity vary for different risk groups?

Data on factors affecting exposure may be available from the baseline survey. However, predicting the effect of the development on behavioural characteristics and thus on exposure is extremely complex. We are not aware of any specific prediction methods which take account of such factors in predicting exposure levels to air pollutants. Instead, use may be made both of expert judgement and of the various criteria for pollution levels which have been developed on the basis of past experience.

3.3.3 Quality Criteria for Pollutants

Quality criteria for different pollutants in relation to different situations of human exposure (e.g. water, for drinking and bathing, or for fisheries and shellfisheries uses) have been drawn up by WHO and other international and national organisations. The basis of these criteria is that if levels of different pollutants are limited to those specified, people will not be exposed to a risk of damage to health. It is therefore not necessary to predict the exact level of pollutant which will be absorbed by individuals, only to ensure that the overall level of pollutants remains below the damaging level.

The criteria are drawn up on the basis of a range of epidemiological and toxicological studies. Such studies have certain problems in relation to environmental health effects; these are described in Table 3.3(b). Examples of quality criteria for air, water and noise are given in Annex 3.

Quality criteria are regularly revised in the light of increased scientific knowledge. In predicting the effects of pollution on health, expected pollution levels should therefore be compared with the most recent criteria available. In some countries, such criteria have been adopted into national or local law (see 4.2). Elsewhere they may be seen as a source of general guidance rather than strictly adhered to.

3.3.4 Occupational Exposure Criteria

A particular type of quality criteria, limit values, has been developed for occupational exposure to pollutants. Limit values may take the form of either atmospheric limit values for air pollutants (often known as TLV's - Threshold Limit Values or MAC's - Maximum Allowable Concentrations), or biological limit values which specify the maximum level of certain substances within human organs (e.g. liver, blood). Again limit values have been drawn up by many national and international agencies and may be advisory or compulsory. Definitions of limit values from certain European and US sources are given in Table 3.3(c). Examples of limit values are also given in Annex 3.

One advantage of limit values is that they have been drawn up for a wider range of chemical substances than environmental quality criteria. However, care should be taken with applying limit values to an environmental context. Limit values generally relate only to an 8-hour daily exposure of healthy adult males. Exposure at a certain level may have more serious consequences where longer exposure times or higher risk-groups are concerned.(1)

Where appropriate limit values or quality criteria have not been developed, and a potentially serious pollution effect is concerned it may be necessary to undertake a further analysis of the health impact of exposure to an environmental health factor. This procedure is known as 'risk assessment', and involves the systematic evaluation of likely exposure levels in relation to data on exposure response levels. This procedure may be costly in time and resources, and is most widely used in situations where potential exposure levels are high and there is a considerable degree of uncertainty. The risk assessment procedure for major hazards is described in section 3.4.1.

3.3.5 Predicting pollution effects on disease vectors

Where environmental health factors involve enhanced transmission of disease, for example pollution of water by sewage, or soil pollution by human or animal faeces, predicting human exposure is complicated

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(1) Safety factors applied to convert occupational exposure criteria to community exposure criteria have ranged from 10 to 100 (the limit value is first converted to a 24-hour basis by multiplying by $^{8}/_{24}$).

Table 3.3(b)

Sources of Information on the Link Between Pollution Levels and Health and their Problems

A. **Epidemiological Studies** are concerned with effects occurring in human populations exposed under natural conditions. Studies can either be retrospective, based on historical data on health and pollution levels, or prospective, involving setting up of health and pollution monitoring.

The major difficulties with epidemiological studies are:

- o lack of controls; observed changes in health levels may be due to unknown factors which have not been measured. An observed correlation between health and an environmental factor does not necessarily imply causality;
- o non-specificity of observed effects. For example, the major indicators of air pollution effects - bronchitis, asthma, emphysema, lung cancer - can be caused by a wide variety of agents;
- o multiple exposure; it may be particularly difficult to separate the effects of exposure to one agent from the effects of simultaneous exposure to many other factors;
- o differential sensitivity; information is rarely available on the sensitivity of the population exposed or the conditions of exposure, such as presence of risk groups, general state of nutrition and health, concurrent exposure, existing disease, temperature and humidity at the time of exposure.

B. **Toxicological Studies** are experimental studies of the effects of pollutants on man or animals under controlled conditions. Their major problems are:

- o experiments on man can only be carried out in limited circumstances;
- o results obtained on animals are not necessarily applicable to humans;
- o it is generally not possible to reproduce all contributing factors (or mitigating factors) in the laboratory;
- o studies can be very costly and time-consuming.

Table 3.3(c)

Definitions of Limit Values from European and US Sources

Denmark

o Hygienic Limit Values: damage or irritation will not occur if normal, healthy workers are exposed to the limits for 8 hours per day over a working lifetime. (Maximum values are also established for substances with a rapid acute effect).

Germany

o MAK (maximum permissible concentration) values: according to current knowledge, health of workers will not be impaired, or undue annoyance caused, by repeated exposure to the limits for an average of 8 hours per day and 40 hours per week over a long period, or 42 hours per week for shift work.

o TRK (technical guiding concentration) values: because of lack of knowledge avoidance of damage cannot be guaranteed but risk to health will be reduced if a worker is exposed to no more than the limits for 8 hours per day and 40 hours per week over one year.

Italy

o Exposure Limit Values: workers' health will not be endangered by exposure to the limits except in cases of hypersensitivity or predisposition.

Netherlands

o MAC (maximum accepted concentration) values: as far as is known as present, detrimental effects to the health of normal, healthy workers and their offspring (by genetic damage) will not occur after repeated exposure to the limits for 8 hours per day and 40 hours per week over a working lifetime. Safety cannot be guaranteed. (Maximum values are also established for substances with a rapid, acute effect).

o TAG (temporarily accepted concentration) values are set for substances where social, economic or technical reasons make the application of medically acceptable MAC values inappropriate or impossible.

Table 3.3(c) (Continued)	
Definitions of Limit Values from European and US Sources	
USA	
o	**Threshold Limit Values:** it is believed that nearly all workers may be repeatedly exposed day after day to these levels without adverse effect. If these levels are exceeded a potential hazard is presumed to exist. These values do not indicate a sharp dividing line between 'safe' and 'dangerous' concentrations; best working practice is to reduce concentrations as far below the TLV as possible. They are based on exposure for five 8 hour shifts per week, if exposure time exceeds this, a pro rata reduction in the TLV should be made, taking due account of the material in question.
Source:	Environmental Resources Ltd.; "The Law and Practice Concerning Occupational Health in the Member States of the European Community". London: Graham & Trotman, 1985 (in press).

by the need to consider the effects of environmental change on the disease organisms; for example:

- the ability of the organism to exist outside its host. This may be short or long, for example salmonella can live up to 70 days in soil irrigated with sewage under moist conditions;

- the effect of environmental change on secondary hosts; for example slow-flowing water will favour snail populations and thus aid transmission of schistosomiasis; fast-flowing water will aid breeding of simulium flies and the transmission of onchocerciasis;

- the effect of environmental change on carriers of disease, including domestic animals, insects, rodent pests; urban development may provide increased habitats for carriers, such as stagnant water pools for insect breeding, piles of rubbish to sustain rodents, or domestic animals in close proximity to man (including pets).

Predicting how changes in the environment will affect disease vector life cycles is a complex procedure requiring a thorough understanding of the specific vector and lifestyle concerned. The current state of ecological knowledge is generally inadequate for the development of widely applicable methods for predicting effects of environmental changes on particular species with any accuracy. Instead it is necessary to make an expert judgement, based on as full information as possible about the particular environment and species concerned.

3.3.6 Checklist for Prediction

Table 3.3(d) gives a checklist of points to consider in predicting exposure to pollution factors.

3.4 Predicting Accidental Effects and their Consequences

3.4.1 The Risk Assessment Procedure

Accidents are by their nature unexpected events and thus difficult to predict with any certainty. However systematic examination of different sectors within an urban development project, and analysis of historical data on faults etc, enables experts to make some predictions of the likely occurance of accidental effects. Once accident levels have been predicted, they need to be related to likely human exposures in order to predict their consequences for human health. The procedure used is known as 'risk assesment'. It's use is not limited to assessing the effects of accidents, but can form a wide framework for predicting impacts of environmental changes on human health.

Table 3.3(d)

Checklist for Predicting Exposure to Pollution Factors

- Over what area will pollution levels be increased? What will be the average and maximum concentrations? Will there be variations over time?

- Are highest concentrations likely to be encountered in the home, the workplace, during travel or elsewhere? Are particular activities (e.g. swimming, play on waste dumps) likely to lead to high exposures?

- Which groups of the population (e.g. industrial workers, housewives, children) are likely to experience high exposure levels. Are any of these groups likely to be particularly susceptible to the effects of disease?

- Do sectors of the exposed population already have health problems which may be exacerbated by pollution (e.g. existing lung diseases)?

- Is the health effect of pollution affected by the presence of secondary hosts/carriers?

- Have any specific epidemiological/toxicological studies been carried out for the pollutant which seem relevant to the proposed development?

The process of prediction of the likelihood of accidents occurring in particular circumstances and their likely consequences can be defined as "a probabilistic objective activity based upon observations, experiments, epidemiology, theoretical considerations and mathematical-statistical methods".(1)

Risk assessment can be more-or-less complex depending upon the circumstances of the development being assessed. In general terms risk assessment comprises 5 main stages:

a)	hazard identification	Prediction of the likelihood of accidents occurring
b)	hazard analysis	
c)	consequence analysis	Prediction of the likelihood and magnitude of health effects arising from these accidents
d)	risk determination	
e)	assessment of results	

Figure 3.4(a) gives an example of how risk assessment may be applied to predict the effects on health of an accidental leak of hazardous materials. Although this example concerns a single industrial plant, similar techniques can be used to assess risks posed by a number of different plants within an urban area. Simpler risk assessments may be carried out based on:

- expert judgement of the likely frequency of accidental events;
- simple predictions of the distance of travel of pollutants etc.;
- estimates of the numbers of people within the polluted area.

It should be noted that risk assessment is an inexact science, involving many uncertainties. The main reason is that events creating major risk, such as explosions or major chemical releases, are more or less rare in statistical terms, and it is therefore very difficult to check by actual experience whether predictions for a particular situation are correct. Small-scale discrete risks, such as injury through traffic accidents, are more common and risk assessment procedures can be based on observed frequencies of occurance.

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(1) ZAPPONI, G.A.; "Assessment of risk and hazard". International Seminar on Environmental Impact Assessment, Aberdeen, 1984.

Figure 3.4(a)

A Quantitative Risk Assessment Method

Stage 1 Quantitative Plant Description

- location and layout of site
- process flow schemes
- equipment list
- inventories and normal conditions
- number and diameters of pipework connections
- remote operated valves

Stage 2 Identification of Failure Cases

- from hazard and operability study (systematic questioning of every part of the process and utility plant)
- from technical audit (study of design, construction and operating procedures)
- from examination of the historical record

Stage 3 Estimation of Primary Failure Frequencies

- probability that plant failures postulated will occur in a given period of time
- methods
  - o fault tree analysis - analysis of probabilities of failure case based on probabilities of contributory events
  - o historical experience

Stage 4 Prediction of Discharges

- quantity, speed and form of hazardous material escapes

Stage 5 Prediction of Dispersion

- modelling of dispersion characteristics of released material

Stage 6 Calculation of Impact and Hazard Distances

- flammable materials
  - distance to lower flammable limits
  - ignition probability
- toxic materials
  - distance to toxic threshold criterion, taking into account duration of exposure

Stage 7 Risk Contour Plots

- hazard distances corresponding to selected damage levels and associated probabilities for each failure case
- assessment of probability of domino damage
- superimposition of risk contour plots onto a population map of the area

Source: Based on RAMSAY, C.G.; "Assessment of Hazard and Risk". In CLARK, B.D. and others. Perspectives on Environmental Impact Assessment. Dordrecht: D. Reidel, 1984.

3.4.2 Predicting the Likelihood of Accidents

The first stage in risk assessment is to identify those components of the urban development which oculd give rise to accidents.

Hazard identification comprises two steps:

- o identification of hazardous agents;
- o identification of hazardous events.

Identification of hazardous agents requires a compilation of the quantities and use of agents which have been identified as hazardous.(1) This should be carried out as part of the baseline survey.

Identification of hazardous events requires the risk 'assessor' to envisage those events which could lead to the hazard being realised and which in turn could produce specified undesired consequences.

The major uncertainty in hazard identification is the ability of the 'assessor' to guarantee that all hazardous agents and events have been identified.

- o For example, a chemical plant may handle a liquid organic hydrocarbon which at first sight appears 'harmless'. It may later be discovered that there is a possibility of a large fire occurring nearby and the consequence analysis reveals that the liquid organic hydrocarbon would be heated to a sufficient temperature by such a fire to cause a breakdown of the hydrocarbon with the release of toxic fumes.

It is thus important to consider how agents could behave in abnormal conditions.

Similarly, the nature of the environment around the hazardous operation may change so that events which were originally considered to be non-hazardous could become hazardous. A common problem is housing being built closer and closer to an existing hazardous installation so that a reduced quantity of material release would constitute a hazard.

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(1) It should be recognised that in some cases the material may not be inherently hazardous, but is only hazardous because of the situation in which it is put, for example, water behind a dam.

Once potential hazards have been identified, the likelihood of a hazard actually leading to an accident must be analysed.

Hazard analysis also comprises two steps:

- o description of the sequences of events which could lead to the previously identified accidents;
- o quantification of the likelihood of the events taking place.

Description of events which lead to accidents may be aided by 'fault tree construction'. Normally, this process begins with an accident and then examines ways in which the accident could be caused, i.e. to identify the 'precursor' events.

There are also procedures by which "initiating events" can be identified before the accidents they relate to have been defined. For example, small sections of a process, plant or operation are examined in a systematic manner, by a series of 'What if ...' questions. In each case, the question provides a possible initiating event and the immediate consequences are considered to determine if such events could lead to an accident.

Whichever procedure is adopted, the purpose of this stage of the assessment is to present a comprehensive range of possible accident sequences which are in a form to be quantified.

The aim of quantification is to predict the likelihood (or expected frequency) of the various accidents. It involves quantifying the likelihood of each of the sequence of events and combining this information to predict the overall likelihood. Quantification may be based on technical data concerning reliability and failure probability of single components within the system.

For smaller-scale discrete risks such as traffic accidents or accidents at work quantification may be based on suitable historic data of the frequency of accidents in different circumstances.

3.4.3 Effects of Accidents on Human Health

Once the likelihood of certain types of accidents, or "hazardous events" occurring has been determined, the next stage is to predict potential effects of these on human health. Again this involves a number of steps.

Consequence analysis comprises four steps:

- o Examination of possible impacts on identified targets (e.g. local residents, workers).
- o Examination of the sequence of events from the accidents to their impact on the target.

- o Estimation of probability of particular health consequences given the occurrence of the accident.
- o Assessing the impacts.

Figure 3.4(c) gives an example of this procedure.

Figure 3.4(c)

Example of Consequence Analysis

The identified accident is a large fire and the specified consequence of concern is injuries to local residents. The consequence analysis consists of:

a. Finding data relating human injuries at various levels and exposure times to heat.

b. Prediction of likely fire temperature, duration and size in order to determine likely temperatures at nearby houses in the event of fire.

c. Consideration of a series of scenarios of the form: given fire 'A', the temperature at the houses will be X. Such heat will cause burns after 1 minute. An escape probability (i.e. likelihood that house occupants will escape within 1 minute) of 0.5 is assumed. Therefore given fire 'A' there will be an individual casualty probability of 0.5.

d. From this information an estimate of the total expected numbers of caualties for each fire scenario can be developed.

Some aspects of consequence analysis have been subject to intense research over the last decade or so. These include the effects of unconfined vapour cloud explosions and the dispersion of denser-than-air gases. However, closely related topics remain under-researched, and in particular there is a lack of information about toxic effects of even common chemicals such as ammonia on human health.

At the stage of **risk determination** the results of the hazard and consequence analyses are combined to generate risk values. Figure 3.4(d) illustrates this process, continuing the example of Figure 3.4(c).

Figure 3.4(d)

Example of Risk Determination

If the specified consequence is 'injuries to people as an immediate and direct consequence of an accident at installation X which handles ammonia', the results might appear as follows:

- likelihood of a major ammonia release is 2×10^{-4} yr^{-1};
- probability that a given individual is at home at location A is 0.8;
- probability of an individual at location A becoming a casualty is 0.06;
- individual risk of the given individual is $2 \times 10^{-4} \times 0.8 \times 0.06 = 1 \times 10^{-5}$/yr;
- population at location A at any particular time is 200;
- conditional probability of injury 80 is 0.15;
- the societal risk is $2 \times 10^{-4} \times 0.15 = 3 \times 10^{-5}$/yr; of injuring 80 people.

Individual risks could also be calculated for other locations B, C and D and the societal risks could be totalled over the population at risk at all locations. Similar calculations could also be formulated for different specified consequences.

Assessment of safety and acceptability of risk is the final stage in risk assessment and entails a degree of controversy. For example, most people would accept that the likelihood of a serious accident at a nuclear power station is low, although this is largely based upon prediction rather than historical data. This in turn means that the risk to a given individual near the power station is also low which leads to statements of the form:

'living near a nuclear power station is safer than...'.

The difficulty is that this argument cannot be extended to the statement 'nuclear power is safe'. The reason is that a serious accident could have very severe consequences altnough the likelihood of this happening is low. Similar arguments are valid for large storage tanks containing flammable/toxic gases liquefied under pressure or refrigeration.

Although attempts have been made to define "acceptable" risk levels none have proved fully successful, and the acceptability of certain risk levels is a question for negotiation between decision-makers and others.

3.5 Predicting Effects on Disease Transmission

We have discussed above (section 3.3.5) the prediction of effects of pollution on disease vectors and thus on disease incidence. Prediction of the effects of overcrowding, building design and similar factors on transmission of diseases is less well developed.

Whilst various studies have indicated an increased propensity for disease transmission in crowded conditions, no quantitative relationships between the two have been established and other factors such as poverty, nutrition and occupation have also been implicated. Evidence of other links between disease transmission and changes in population distribution and lifestyle are similarly qualitative and even anecdotal.

Given these circumstances, it is probably unrealistic to attempt quantitative predictions of effects of urban development on disease transmission through crowding and lifestyle change. However, useful information may still be gained through qualitative investigation. This may include collection of data on:

- current population densities within the area and amongst any groups expected to be a source of migrants to the development;
- prevalence of density-related diseases amongst these populations (e.g colds, influenza, streptococcal diseases);
- expected population densities in proposed development;
- experiences elsewhere in the region of effects of increased population density on disease;
- significant differences in lifestyle between current residents and likely in-migrants which may affect disease transmission;
- potential changes to lifestyles expected to occur following urban development; including introduction of new building styles such as high-rise.

Together with analysis of relevant historical data and expert advice, some indication of the likelihood of increased disease transmission following development may be derived from this information.

3.6 Predicting Social/Psychological Effects

3.6.1 The Problem of Measurement

Unlike prediction of levels of pollution or likelihood of accidents, there are no generally accepted measures for the social and psychological effects associated with increased stress from physical changes to the environment.

Perception of what is "overcrowded", for example, depends considerably on both past experience and future expectations. Whilst many organisations have drawn up housing standards which reflect views on desirable population density, these are "at best the expression of the judgement of some authority, or were based on limited observations made under the conditions with which that authority was concerned".(1) When such standards are imported from one country to another, particularly from the west to developing countries, they have often proved impractical in cost terms and irrelevant to local lifestyles. It is now recognised that a thorough knowledge of local human requirements is essential for the development of such standards.

Similarly the terminologies and concepts associated with different lifestyles are complex, the subject of some controversy, and do not readily lend themselves to empirical description.

Neither are there currently available practical methods for measuring mental health on a broad base.

> "At the moment, no psychological tests are available that can be administered quickly to a large population, scored efficiently and interpreted with a minimum amount of professional time. There are a variety of psychometric tools available that measure intellectual functioning, personality dynamics and organic disfunctions... Most of them are administered on an individual basis and are not suitable for large populations. Furthermore, administration, scoring and interpretation of these instruments takes a considerable amount of time and requires a highly skilled clinician for their interpretation."(2)

Given these measurement difficulties, there has been relatively little systematic work carried out on the prediction of social/psychological impacts of urban development projects.

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(1) World Health Organisation; "Health Hazards of the Human Environment". WHO: Geneva, 1972.

(2) ROBINSON, J.D. et al; "Assessing Environmental Impacts on Health: A Role for Behavioural Science". In EIA Review 411.

3.6.2 Predicting Effects on Mental Health

The effects of urbanisation on mental health are the subject of considerable controversy. Different studies have given conflicting evidence on effects which might be expected. Whilst some animal and epidemiological studies have related increased living densities to high stress levels, the mechanism by which the effect occurs is poorly understood, and it is difficult to separate the effect of density from other factors.

Historical data also indicates a link between major changes in lifestyle and increased stress, but again the evidence is largely qualitative and the relationship not well understood.

Again the most useful course for prediction at present is to examine current population densities and lifestyles amongst the potential population of the development and, based on plans for the development and relevant experience elsewhere, use expert judgement to indicate whether stress effects may be expected, and what the nature of these may be.

3.7 Predicting Future Mortality and Morbidity Rates (Health Impact Assessment)

As we noted in 1.3, the aim of environmental health impact assessment (EHIA) is to overcome the problems of lack of knowledge and sensitivity associated with Health Impact Assessment.

In general, formal methods are not available for predicting future mortality and morbidity due to environmental changes. As we have noted above, prediction of health effects generally ceases with prediction of likely levels of exposure of the population to environmental health factors, often related to general health criteria. Such criteria, as described in section 3.3, represent the most widely accepted method of describing the likely impact of predicted environmental health factors on human health. Data is often presented in terms of the expected levels of pollutant x at location y in comparison to International Standards for acceptable pollutant concentration.

However, it should be remembered that such criteria and standards are likely to relate to the health of the general public. High risk groups, for example people in hospitals, young children, those with particular illnesses, may be sensitive to much lower levels of effect. The baseline survey should indicate the likely presence of such groups in the area of the development, and where environmental health factors appear likely to be significant, they should be investigated further in relation to their impact on high-risk groups. This is an area where relatively little structured guidance is available. The most useful approach within EHIA is to enroll the assistance of an expert once preliminary prediction indicates that significant impacts on high risk groups may arise.

Nevertheless certain prediction methods, particularly those incorporating risk assessment, do allow for prediction of mortality and morbidity levels in probabilistic terms as illustrated in section 3.4.3. That is, they give the likelihood of a certain level of ill-health or death arising from certain environmental conditions. Whilst such predictions have a high level of uncertainty associated with them, they may provide a useful source of information to decision makers. It is important, however, that when such data is presented, its limitations and uncertainty are made explicit. We discuss presentation of information further in Section 5.