UNEP Environmental Management Guidelines, No. 16

# ENVIRONMENTAL GUIDELINES FOR

# Flood Plain Management

UNITED NATIONS ENVIRONMENT PROGRAMME

*Environmental Management Guidelines*

1. Pesticide Use on Industrial Crops
2. Irrigation in Arid and Semi-Arid Areas
3. Watershed Development
4. Pulp and Paper Industry
5. Hides and Skins Industry
6. Coastal Tourism
7. Formulation of National Soils Policies
8. The Restoration and Rehabilitation of Land and Soils after Mining Activities
9. Afforestation Projects
10. Agricultural Mechanization
11. Agroforestry Projects
12. Farming Systems Research
13. Rural Roads
14. Domestic Wastewater Management
15. Rural Workcamps
16. Flood Plain Management
17. Coastal Protection Measures

# FLOOD PLAIN MANAGEMENT

United Nations Environment Programme
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CONTENTS

## FOREWORD TO THE SERIES

It has been our concern, shared by other bodies and agencies within and outside the United Nations family, that development projects and programmes should take account of basic environmental parameters and constraints. It is clear that broad-based sustainable development is not feasible, especially in the long-term, without sound environmental assessment and management.

There are many pitfalls to be avoided in initiating development activities and many opportunities that can be availed of without much additional cost. Experience during the last ten years has shown that remedial measures must be incorporated, if they are to be effective, in the conceptual and design stages of projects. The same applies to planning procedures. Later attempts may prove to be only cosmetic, as ecosystems are fragile and complex and may not recover from the stresses to which they are exposed.

Prepared by UNEP, in close consultation with the United Nations specialized agencies concerned, the first six guidelines were jointly financed by UNEP and UNDP. They were adopted by UNDP and distributed to the UNDP Resident Representatives. The remaining guidelines in the series have been prepared by UNEP to cover important areas of emerging concern.

The remedial or preventive measures outlines are meant to be illustrative rather than exhaustive in nature: there is no substitute for local experience, foresight and prudence. We have only attempted to draw attention to the kind of considerations which must be kept centrally in mind in undertaking development activities.

The objectives for which we strive in these guidelines are numerous and interrelated, requiring formidable array of diverse technologies and disciplines. Although the guidelines are essentially national in nature and scope, internationally co-operation and co-ordination to bring into play the different inputs required, may often be necessary.

I sincerely hope that the guidelines will be acceptable and meet practical needs, particularly in developing countries. Additional sectors will be examined and further guidelines prepared in collaboration with the UN specialized agencies, UNDP and other multilateral and bilateral development financing institutions, as appropriate, taking fully into consideration comments and advice which we expect to receive regarding this set of guidelines.

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## PREFACE TO THE SERIES

At an informal meeting held in Rome in September 1978 the Designated Officials for Environmental Matters (DOEM) of the United Nations Administrative Committee on Co-ordination recommended, on the basis of a report prepared by a consultant, Mr. O.M. Ashford, that UNEP undertake, in close collaboration with the UN specialized agencies, the preparation of environmental operational guidelines to assess and minimize the possible adverse environmental impacts of development activities. The report of the meeting states "that priority should be given to the preparation of guidelines aimed at improving the consideration of environmental aspects at all stages in the planning and execution of projects". It was recognized that the level of sophistication in such guidelines would depend on the audience for which they were intended. Much of the available material was of a general nature which would mainly be of interest to universities and senior international and national officials. At the other extreme, detailed guidelines based on indepth studies of specific projects would be very useful for specialists but difficulties were foreseen in obtaining the necessary information for such analyses, which would take a long time to complete. The meeting agreed that the primary need was for guidelines which would be useful at the operational level. For this purpose each of the major categories used in the consultant's report (e.g. agriculture) would have to be broken down into a number of subareas (e.g. crop pest control and rangeland management). A first list of subareas on which guidelines should be prepared soonest as agreed on as follows:

1. Pesticide use on industrial crops
2. Irrigation in arid and semi-arid areas
3. Watershed development
4. Pulp and paper industry
5. Hides and skins industry
6. Coastal tourism

At a subsequent meeting the DOEM determined that the operational guidelines should "avoid undue technicalities. They should be clear-cut statements of the environmental concerns, parameters and constraints arising in the area of interest. A distinction should be made between what would be useful for informed laymen, such as UNDP Resident Representatives or officials in the ministry of planning or ministry of economic affairs of a developing country, to reach a decision on the need for and nature of environmental considerations in a given project at a very early stage of its formulation on the one hand, and the analytical tools required by engineers, economists and other scientific consultants in the form of coefficients, etc., to implement a project on the other. The latter should not be a part of the operational guidelines but in manuals of implementation".

In the event, the guidelines that have been prepared vary in the nature of the material assembled and the technical details analysed. This has been done deliberately.

In order to afford an opportunity to assess the practical utility of different approaches to the preparation of guidelines, it was considered necessary to establish models which could be compared and evaluated in terms of practical utility. UNEP would gratefully receive views on the analytical frameworks and approaches adopted in the different guidelines as well as suggestions for their improvement or amendment.

The environmental guidelines in this series are not intended to be prescriptions for corrective action or constraints on the methods, nature and scope of development activities. They are presented in the belief that dynamics and change induced by development aims are not without environmental hazards and risks. It is necessary to identify such hazards and risks where they arise and take early steps, in so far as circumstances permit, to contain or reduce them. It is necessary to take early steps, because later attempts at remedial action may be illusory, more costly than preventive action at the outset, and in some cases, may be so costly as to bringing into question the overall economic viability of the project.

We acknowledge with gratitude the contributions received from the UN specialized agencies, particularly the Food and Agriculture Organization (FAO), for preparing the guidelines. Without financial assistance from UNDP, the operational guidelines could not have been completed effectively within the time available. We are also dependent upon the assessment of the Resident Representatives and the Headquarters staff of UNDP on whether the guidelines meet specific needs in the field.

Within UNEP, a number of colleagues have assisted in the preparation and editing of the operational guidelines. I wish to thank in particular Mr. Nay Htun (for the guidelines on the pulp and paper industry and on the hides and skins industry) and Mr. Mohamed Tangi (for the guidelines on coastal tourism). Ms. Merran Van der Tak, Ms. Shahida Chaudhary and Mr. Mark Aeron-Thomas assisted in the research and editing of the first six guidelines in the series; the latest guidelines have benefited from the sustained efforts of Ms. Sophie Schlingemann and Ms. Gill Mayers.

UNEP's decision, to produce further guidelines, on issues currently on the international agenda for environmental action, has resulted in subsequent guidelines in the series. The first six have been complemented by the following:

1. Formulation of national soil policies
2. The restoration and rehabilitation of land and soils after mining activities
3. Afforestation projects
4. Agricultural mechanization
5. Agroforestry
6. Farming systems research
7. Environmental considerations in rural roads projects

The four latest ones are on:

8. Domestic Wastewater Management
9. Rural Workcamps
10. Flood Plain Management
11. Coastal Protection Measures

On the basis of reports received additional guidelines are under editorial consideration.

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# 1. INTRODUCTION

Floods are a natural and recurring event that are only a problem when man competes with rivers for the use of the high water channels of rivers or flood plains.

Flood-plain occupancy and use is based on the economic advantages of level ground, fertile soils, ease of access, and available water supplies despite flood risk. Full flood control often is not possible or economically feasible; yet, abandonment of the flood plain may not be reasonable because it is not only a valuable resource but in many areas it is the only means to support life. The nature and extent of flood-plain use should be compatible with risk involved and the degree of protection that would be practical.

The term "flood plain management" includes all measures for planning and action which are needed to determine, implement, revise, and update comprehensive plans for the wise use of flood plain lands and their related water resources. Flood plain management requires a coordinated effort by local, regional, and national officials and competent water resource engineers, land-use planners, economists, foresters, recreation specialists, naturalists, and others concerned with an overall comprehensive approach to flood plain problems.

The purpose of flood plain management policy can be stated in terms of two broad concepts. First, the immediate consequences of severe floods in a populated area must be dealt with; the loss of life, the physical hardships, and the destruction of an environment made more fragile through human use. Second, to achieve a long term plan for the optimum economical use of flood plains with due regard for environmental impact and socio-economic concerns. To accomplish this twofold purpose, policy makers must not only evaluate through physical and economic concepts the desirability of protecting investments already made; but also concern themselves with selecting the development alternatives that do not have an adverse environmental impact and that are beneficial for the welfare of the inhabitants of the flood plain.

In order to make informed decisions concerning flood plain management, the policy maker must be supplied with the basic concepts of flood plain management along with a rudimentary knowledge of floods and flood plains. These guidelines present the basic theories of flood plains and deals with those aspects of flood plains which are related to the safe management and development of the flood plain. The guidelines presented here are primarily for the guidance of the administrators and planners who are required to make a decision on the need and nature of the main environmental considerations whereas the development and management of flood plains are concerned.

## 2. FLOOD PLAIN MANAGEMENT

A comprehensive method of flood plain management would include:

- Determining the cause, frequency and extent of flooding;
- Determining the effect of public and private works on flood levels;
- Preparing relevant structural and non-structural proposals for flood alleviation; and
- Determining the areas that should be proclaimed floodprone.

Comprehensive flood plain management would be most beneficial at the earliest development of a flood plain. Historically, some countries have only looked at the advantages of being in close proximity to a flood plain—soil fertility, water supply for domestic stock and irrigation purposes. The hazards associated with flooding have not been considered until it is too late. Those responsible for flood plain management must have control over the development within a flood plain as well as the development of other flood control measures.

The alleviation or reduction of flood loss has been achieved traditionally through construction of protective works such as dams, levees, channel improvements and seawalls. These structural measures have partially reduced hazards and provided substantial protection in many areas. However, structural solutions alone can have a negative impact on the environment.

Policies on flood management are now reaching a balance between structural and regulatory controls. Flood plain management including land-use regulation, can effectively reduce flood losses. Land-use regulations can be used alone or in combination with protective works. Information on the extent of the flood hazard, land use, and development is essential for effective application of regulatory controls.

## 3. FLOODS AND FLOOD PLAINS

A flood plain is defined as the area adjoining the river or stream, which has been or may be hereafter covered by flood water. Along streams the flood plain may include the full width of narrow stream valleys or broad areas along the streams in wide, flat valleys. The floodway is defined as the channel of a river or stream and those portions of the flood plains adjoining the channel, which are reasonable required to carry and discharge the flood water or flood flow of any river or stream.

The principal characteristics of a stream valley are shown in Figure 1. The channel and flood-plain sections are integral parts of the natural conveyance system of a stream.

In many areas where flooding occurs, the rich fertile soils deposited by such overflows, and the replenishment of soil moisture, have sustained an abundant agriculture. In semi-arid areas such overflows may constitute the only source of enrichment and irrigation. Typically, a stream will overflow its normal channel about once in two or three years and invade low places on its flood plain. The overflow occurs when the volume of water entering a stream channel exceeds the hydraulic capacity of the channel. Greater floods occur at less frequent intervals in the area affected; but, only about once in a century or longer, a great flood will submerge all the alluvial deposits in the stream valley.

Floods vary in size, area inundated, duration, and frequency depending on natural and certain man-made conditions. The natural conditions include the total quantity, intensity, and geographical distribution of rainfall and snowmelt, storm patterns, antecedent moisture conditions, temperature, and season of the year, as well as the physical features of the watershed, such as topography, soils, geology, and drainage pattern. The man-made conditions include the various rural and urban land uses, storage, diversion, and regulation of stream flows, as well as changes in drainage and other factors that affect storm-water runoff.

Occupancy of the flood plain can thus result in two kinds of flood losses. An individual who uses the flood plain for any development invites flood losses to himself; the potential for loss depends on the vulnerability of his specific use. But, more importantly, his entry on the flood plain may create problems and costs to others by causing higher flood stages through impendance or obstruction of the normal pattern of floodflow and reduction of floodplain storage capacity. The increased flood depths

would affect not only his flood-plain neighbors but could also affect residents outside the area who would otherwise not be flooded. Hillside developments may also affect flood-loss potential as a result of accelerated runoff discharged to flood-plain areas downstream. The periodic inundation of flood-plains lands may result in losses to occupants including loss of life and property, hazards to health and safety disruption of commerce and governmental services, and expenditures for flood protection and relief. These losses may be caused by both the cumulative effect of obstructions in flood plains that cause increased flood heights and velocities, and uses of areas that are inadequately elevated or protected from flood damage. Any additional development on the fragile environment of the flood plain must be carefully managed to minimize the negative impacts and maximize the general benefits.

## 4. CHARACTERISTICS OF FLOODFLOWS

Two characteristics of floodflows: 1) the frequency of occurance and 2) the relation between the quantity of flow and the water-surface elevation (stage)—are of particular significance to the use of flood-plain lands. These characteristics are described below.

### 4.1 FLOOD FREQUENCY

In the evaluation of flood hazard or flood potential the probability of recurrence of floods of a given magnitude must be estimated. The probability of occurance of floods of various magnitudes at a site may be determined by statistical analysis of annual peak discharge for all years of record at the site, whether or not all of these events caused inundation. Peak discharge is the highest rate of flow in a stream and generally occurs coincident with the greatest water-surface elevation during a rise in the stream. The annual peak discharge, is the greatest flow in a twelve month period.

The magnitude of the annual peak discharge at a site varies from year to year. It is customary to compare those magnitudes in terms of their probability of occurance. A common practice is to refer to a peak discharge of a given magnitude in terms of its recurrence interval. The recurrence interval, or return period, is the average interval of time within which a given peak discharge will be exceeded once by the annual peak discharge. Thus, a peak discharge that has a 2 percent (1 in 50) chance or

probability of being exceeded in a year is a 50-year flood peak, while the peak discharge that has a one percent (1 in 100) chance is a 100-year flood peak.

Recurrence intervals are average periods based on historical data; because the occurrence of floods of this magnitude may occur several times during that period. A similar relation is true for a peak discharge of any given recurrence interval.

### 4.2 STAGE-DISCHARGE RELATION

For every peak discharge there is a corresponding peak stage, or water-surface elevation. The stage depends not only on the magnitude of the discharge, but also on the physical features of the stream valley. Pertinent physical features include ground or streambed slope in the direction of flow, cross-sectional size and shape of the stream channel and the valley, and the roughness alinement of the streambed, bans, and overflow area. The slope of the water-surface profile during periods of high water usually is approximately parallel to the average slope of the channel, with no abrupt changes in elevation in the water-surface profile if the flow is not obstructed constricted. However, some pronounced changes in cross-sectional size and shape are common in a reach or length of stream valley.

Stream valley, for example, may range from wide, flat flood plains to steep-sided canyons. Such pronounced differences in shape and ground elevation, combined with the relatively uniform water-surface levels, may cause wide variations in the extent of flooding and the depth of flow in the main channel and on the flood plain. This is illustrated in Figure 1, which shows two valley sections and the profiles of the streambed and of the water surface for the 10 and 100-year flood discharges in a reach. The sections show that the channel is more deeply incised at section A than at section B. Flow velocities in an unobstructed waterway are usually greater in the part of the section with the greater depths.

## 5. DELINEATION OF FLOOD PLAINS

Areas subject to flooding are commonly identified in reports on floods and in studies of measures for the alleviation or control of flooding. Reports on major floods prepared by various governmental agencies may include maps showing the extent of inundation from the floods. Studies of flood-

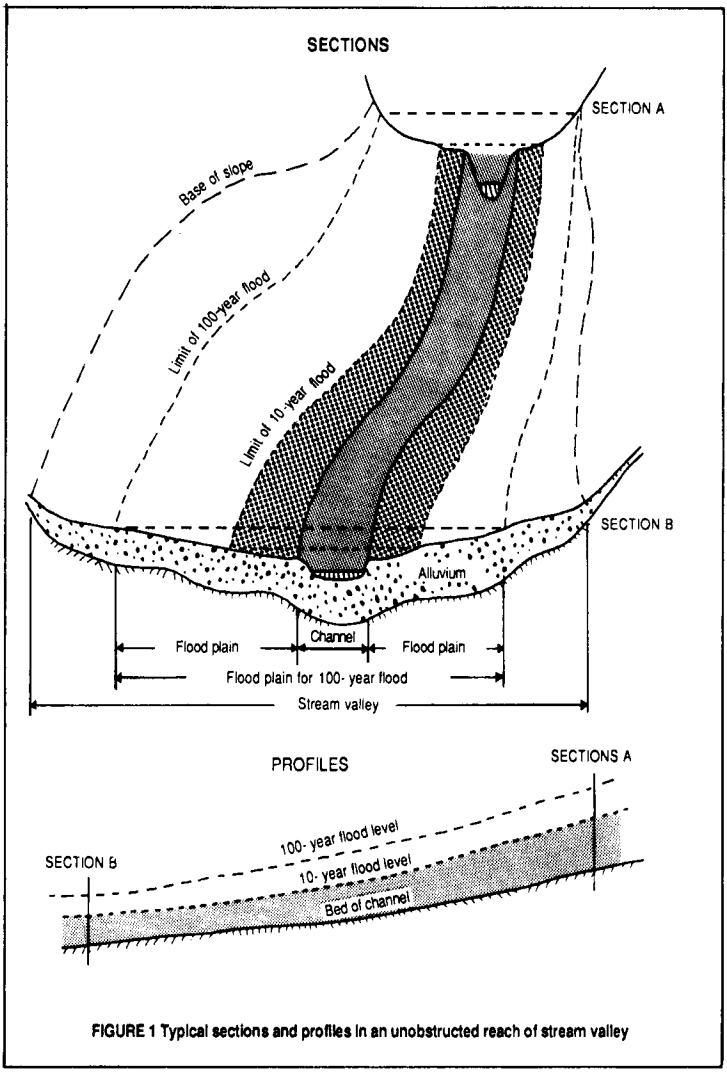


**FIGURE 1 Typical sections and profiles in an unobstructed reach of stream valley**

control or flood-management projects similarly include appraisals of the probable extent of the areas subject to inundation from floods of designated recurrence intervals before and after installation of the proposed measures. The delineation on suitable maps of areas susceptible to flooding can provide a means for identifying and evaluating flood risk.

For developing countries that may not have statistical data available on areas subject to inundation from floods, it is necessary to undertake studies which provide information on flood prone areas. An undertaking of this nature is necessary to establish a data base that will provide information from which the delineation of flood plains may be determined. Since statistical data on the extent of flooding may take decades to collect, it will be necessary to gather and evaluate what historical information on flood plains is available. This can be accomplished by interviewing residents living near rivers, reviewing local records of floods, and by scientists analyzing stream (alluvial) deposits surrounding a river basin. Once information on the frequency of floods has been collected, the extent of flood inundation may be determined by statistical methods.

## 5.1 FLOOD-PLAIN INUNDATION MAPS

Flood-plain inundation maps provide basic information useful in developing land-use plans and policies for flood plains and adjacent areas and in formulating regulation for managing flood plains. There are two types of flood-plain inundation maps. These are: maps of flood-prone areas and flood-hazard maps. Maps of flood-prone areas show the areas likely to be flooded by virtue of their proximity to a river, stream, bay, ocean, or other water-course or water body as determined by available information. Flood-hazard maps show the extent of inundation as determined from a thorough technical study of flooding in a given locality. The detail and accuracy may be sufficient for readily identifying the relation of special flood hazards to individual areas.

### 5.1.1 Maps of flood-prone areas.

Flood prone area maps are prepared to assist in minimizing flood losses by quickly identifying areas of potential flood hazards. These maps are prepared on topographic maps to include showing the elevation of the land surface. The areas subject to flooding are delineated from available information for quick appraisal rather than by detailed field surveys. The

information includes data on flood inundation, flood frequency, peak stage and discharge, and the results of some hydrologic and hydraulic studies. Estimated 100-year flood levels are used to identify flood limits at specific points along the margin of the flood plain. Lines denoting the limit of inundation are then drawn in general conformance with the stream slope and the topographic contours of the land surface.

A regional flood-prone map provides the regional and county-level planners and decision-makers with useful information in formulating broad policies to guide the future development of flood plains. The inundation map may be used, for example, in conjunction with a regional map of present land use and other information in developing a regional land-use plan. The map may also serve to identify problem areas where detailed study of flood hazard would be desirable; thus the map may also be an aid in local planning.

### 5.1.2 Flood-hazard maps.

A flood-hazard map, is a detailed map based on a thorough technical study depicting the extent of areas subject to potential hazard from severe floods. The cost of a flood-hazard map and the associated study increases greatly with map scale and corresponding refinement of the study. Thus, cost may preclude preparing maps at large scale for all flood plains in a large area. The larger-scale maps may be essential, however, for areas where the existing or potential development on the flood plain is significant. Where little structural development exists or is planned the smaller maps scales may be adequate. Then, individual sites or local areas can be studied and mapped in greater detail for definition of the potential hazard with respect to depth and duration of inundation and flow velocity.

## 6. FLOOD-LOSS PREVENTION AND REDUCTION MEASURES

Measures flood-loss prevention and reduction measures will generally fall into two broad categories—structural and nonstructural. Structural measures include reservoirs, levees, floodways, channel improvements, and overflow basins; nonstructural measures (flood-plain management practices) generally include flood-plain regulation or control of land use.

The purpose of flood-plain regulation is to promote beneficial use of flood plains with a minimum of flood damage and expense for flood

protection. Nonstructural (regulatory) measures may be used effectively in combination with structural measures to achieve maximum benefits and provide relief from existing and potential flood problems. Effective programs for flood-loss prevention should be based on an adopted comprehensive plan, although individual methods and devices are often applied without a plan. Any flood-loss reduction is most effective if based on an adopted comprehensive plan or flood plain management program that is being firmly implemented.

## 6.1 STRUCTURAL FLOOD-CONTROL MEASURES

Constructing and operating dams and reservoirs for water supply, flood control, power, irrigation, and conservation, developing and operating watershed-management programs, and constructing channel improvements for flood control and navigation all have an influence on flood discharge and stage. The general positive impact of these operations and measures is a reduction in the magnitude of floodflows.

### 6.1.1 Reservoirs and dams.

Flood-control dams and reservoirs occur in all sizes, are located in diverse topographic environments, and may be constructed of earth or concrete. Many serve multipurpose needs, designed not only for flood protection, but also for furnishing water for irrigation, generation of electric power, and recreation.

Flood-control reservoirs require management procedures different from reservoirs used primarily for water supply, power generation, or recreation. Whereas these three purposes require that the reservoir be kept full to provide water during drought periods; for flood control, the reservoir should be kept at low levels to provide storage for floodwaters. The uncertainties of occurance of droughts and floods make management difficult. To add to the flood-control problems, a typical river system may include a number of reservoirs of different functions.

A distinction must be made between dams that protect established cities from floods and dams that keep water out of largely undeveloped flood plains so that they can be urbanized. Current ideologies support maintain undeveloped flood-plains as natural overflow areas.

### 6.1.2 Channel improvements.

Channel improvements for flood control include dredging, straightening, smoothing, protecting the banks from erosion, and clearing the channel of debris. These modifications increase channel capacity by increasing the cross-sectional area of stream channel or the stream velocity. The increase of the effective cross-sectional area has a great effect in the increase in velocity through reduction of flow-retarding influences.

The velocity of flow may be increased in many instances without reducing the cross-sectional area. Straightening and realigning the channel and eliminating bed and bank irregularities will remove impediments to flow. Eliminating bends (meanders) contributes to flood control in two ways. First, it eliminates overbanks floods on the outside of cures, against which the swiftest current is thrown and where the water surface rises highest. Secondly, the shortened course increases the gradient and velocity, and the floodwaters erode and deepen the channel, thereby increasing its flood capacity. The sediment from the induced erosion does not present noticeable problems, but the containment of flood waters at one place increases the flood hazard downstream.

The smoothing of channels reduces friction and increases flow. Irregularities that retard flow increase flood heights upstream. The smoothing involves removal of projections, filling of revetments, and removal of vegetation.

Deepening a channel by dredging will increase the hydraulic capacity more than widening and will also increase the velocity, thus effectively reducing water elevation. Dredging is expensive, and the construction of levees is preferred. Also, the disposal of dredging spoils may create problems.

Protection against bank erosion, especially on the outside of curves, is provided by revetments. These are protective armors to shield the banks and sides of levees. They may consist of mats of willow or other brush, lumber, dumped or fitted rock fragments, concrete blocks, or other materials.

Clearing of channels of loose debris, mostly trees and other vegetation, reduces the chances of their snagging and forming growing obstructions. Any obstacle to free flow will act like a partial dam and raise the flood level upstream.

In some instances improving the channel may have adverse effects. Straightening an alluvial channel by removing bends, and possibly increasing flow velocities, for example, may result in erosion and sedimentation problems. Paved channels could provide the ultimate in eliminating flow-retarding influences, but the measure may not be fully acceptable because of esthetic, ecological, and other environmental considerations, such as interference with natural alluvial deposition and ground water recharge. Although channel modifications may benefit lands adjacent to the treated reach, they will tend to pass the flood problems on downstream.

### 6.1.3 Levees.

The construction of artificial levees, or the improvement of natural levees, is designed to enlarge channel capacity and contain all but the exceptional flood. Protection of bottom lands from floods cannot be undertaken as piecemeal projects by individual communities or landowners. Individual property owners or communities cannot finance as effective flood-control measures as regional agencies can. Even though a community has the means to construct and maintain adequate levees, floods may overtop less adequate structures upstream and come in behind the "adequate" levees. Furthermore, the prevention of overflow in adequately protected stretches, means that increasing volumes of floodwater are passed on downvalley to flood less adequately protected areas.

### 6.1.4 Overflow basins.

Overflow basins are usually backswamp areas confined by levees of the master and tributary streams and the valley sides. Some natural basins may be continuously occupied by floodwaters; other are dewatered to provide sunken agricultural land. In some instances, artificial construction has enclosed a low area to form a basin. During floods, waters are diverted into these basins, deminishing the volume continuing downvalley.

### 6.1.5 Foodways.

Floodways are emergency escape routes for floodwaters at densely populated centers. To protect an urban area, and to reduce flood heights, a diversion route can be built to accommodate the flood water. A levee is used to divert the water to a man-made channel, or an abandoned channel.

or into neighboring rivers. At a point downstream the flood waters may be redirected back to the river from which it originated. Controlled openings through the levee must be provided at the points of diversion and reentry.

## 6.2 LIMITATIONS OF FLOOD-CONTROL MEASURES

The construction of flood-control works can be self-defeating if: (1) regulatory measures are not enforced; (2) there is an adverse environmental impact, (3) measures are not taken to reduce the flood hazard at its source by preventing excess runoff; and (4) flood plain management measures are not developed and implemented.

Actions and improvements by upstream communities often impose expenditures on downstream communities for flood-control works. Channel improvements, for example, may increase flood peaks downstream and require public expenditures for downstream stream flood-control works. Some facilities for flood control, such as dams and levees, may encourage development of flood plains in anticipation of additional works being constructed. The public may believe that the flood problem has been eliminated, rather than simply abated, by newly constructed works. The intelligent management and regulation of the flood plain is still required in conjunction with flood-control works.

### 6.2.1 Adverse environmental impact.

The construction of dams and reservoirs may have long-range effects on the environment. Soil compaction may increase runoff in the area near a dam, causing soil erosion and the elimination of protective plant cover. The soil erosion may accelerate sedimentation which in turn may cause damage downstream. By changing the normal pattern of seasonal flooding, the areas downstream are deprived of the soil nutrients and thus, agriculture may be affected. The flooding of the area behind a dam or reservoir may lead to the loss of forest products including commercial timber.

The use of other structural flood-control measures such as levees and channel improvements generally have the same adverse environmental impacts. Increased water velocity caused by these control measures will lead to accelerated sedimentation, which may have many damaging effects downstream. Not only is the physical shape of the stream changed by flood-control structures, the ecosystem dependent on the stream is changed.

### 6.2.2 Excessive runoff.

Several measures can be taken to prevent excessive runoff from contributing to a flood hazard. One cause of excessive runoff is destruction of forest cover by natural or humanly created fires and over harvesting of trees. Lightening-induced fires cannot be prevented, but it is becoming increasingly necessary to prohibit human entry into forested areas during dry seasons and to encourage wise tree harvest practices. Responsible agricultural practices, such as contour plowing and the prevention of overgrazing, also help to reduce surface runoff.

Where considerable ground is covered during urbanization, the resulting increased runoff must be controlled. This may involve enlarging natural drainageways, straightening courses, clearing brush, building levees, or constructing drainage tunnels.

Where possible, strict zoning regulations should be established to control flood-plain urbanization. These would restrict urbanization of flood plains in favour of agricultural and recreational uses.

## 7. REGULATION OF FLOOD-PLAIN USES

It is costly to undertake flood-control programs for the protection of development, difficult to remove or convert existing development, and unrealistic to assume that all future development on a flood plain will be discouraged by indirect action. Prohibiting and regulating uses vulnerable to flood loss provides an efficient and economical method for preventing or reducing flood loss.

Devices for prohibiting or regulating flood-plain development include establishing regulatory zones compatible with the flood hazards involved and incorporating flood-plain regulations in zoning, subdivision, sanitary, and building ordinances.

A basic feature of flood-plain regulation is the establishment of a regulatory flood discharge, commonly the 100-year flood. The topography of the flood plain, the magnitude of the floodflow, and the corresponding water-surface elevation and profile would determine the areal extent of the inundation. The part of the flood plain affected by this discharge can be described as the regulatory flood plain. It would include the channel, floodway, and fringe area required to transport the regulatory flood discharge. Figure 2 shows the flood-hazard areas of a regulatory flood plain along a river.

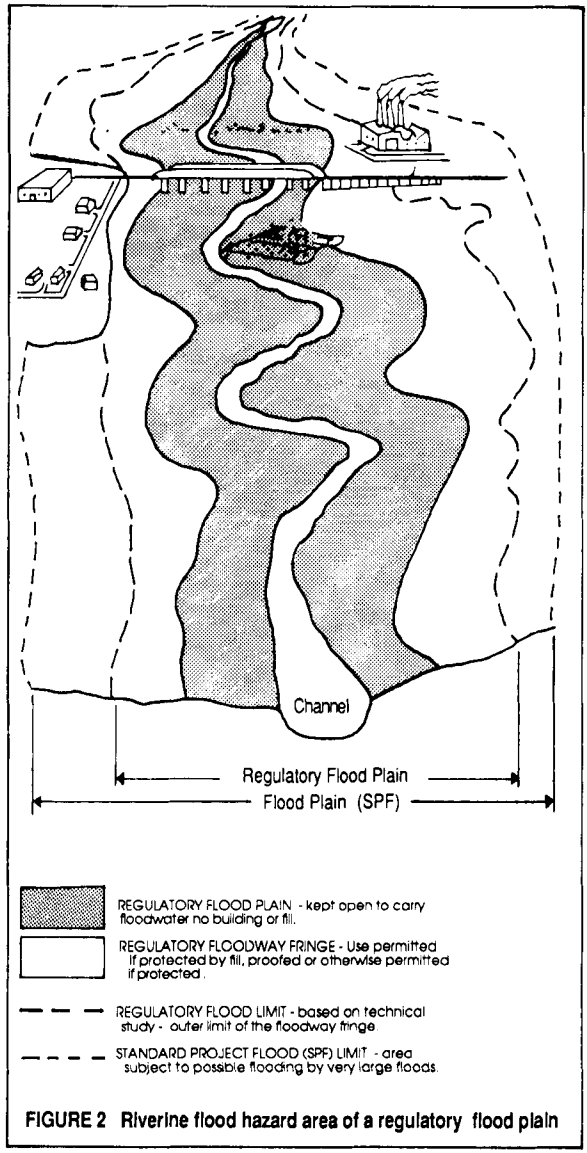


**FIGURE 2 Riverine flood hazard area of a regulatory flood plain**

## 7.1 ZONING ORDINANCE DISTRICTS

Zoning ordinances, adopted and administered by local governmental agencies, can regulate and restrict the use of land, water, air, and structures in the public interest. Zoning is an effective technique for controlling flood-plain development. This device can provide direct benefits by restricting future development of vacant lands in flood plain to avert potential damage and by limiting expansion of existing development in flood-hazard areas.

The most common general zoning districts which contain uses compatible with flood hazards are agricultural, open-space conservancy, and park districts. These districts permit such uses as general farming, woodlands, wildlife refuges, and public and private recreation. The general zoning regulations can be supplemented by incorporating flood-plain regulations into the zoning ordinance text to prohibit those agricultural, open-space, conservancy, and park uses which would be vulnerable to flood damage. For example, the use of flood plains for agricultural purposes can be regulated to prohibit farm dwellings, the permanent sheltering or restrictive confinement of animals, and tillage of the flood-ways without soil conservation practices.

## 7.2 SPECIAL FLOOD-PLAIN REGULATIONS

Regulations in zoning ordinances concerning the use of flood-plain supplement the basic use and site regulations and can be designed to:

- prohibit flood-vulnerable uses and structures within the flood plain and its floodways, including on-site sewage disposal facilities, residential uses, sheltering and confining of animals, and the storing of buoyant, toxic, flammable, and explosive materials.
- regulate other uses and structures within the flood plain to require floodproofing without impending drainage, reducing storage capacity, increasing flood peaks, or raising flood stages.
- prohibit uses and structures within the floodway, including filling, dumping, bridge embankments, permanent structures, and private roads that would obstruct the floodway, raise flood stages, increase flood velocities, or retard the movement of floodwaters.

### 7.3 SUBDIVISION ORDINANCES

Regulating the design and improvement of subdivisions is a less frequently used method for controlling flood-plains development. These ordinances may prohibit subdividing lands not suited to the intended uses, subdividing flood plains, and altering flood plains and floodways. They may require flood-protection measures for building sites and improvements of streets and building sites prior to dedication and sale. Subdivision ordinances should be designed to:

- prohibit the creation of building sites on flood plains subject to the 100-year flood.
- require the delineation and designation of flood-prone areas on subdivision plats and certified survey maps.
- require dedication or reservation of flood-prone lands for public or private parks or other community purposes.
- require that public and private roads, bridges, and other facilities be designed and constructed to withstand flood velocities; prevent isolation, utility outages, and disruption of transportation; and not obstruct the movement of floodwaters, increase flood velocities, or raise flood stages.
- require dedication of, or easements along, those drainageways necessary for adequate watershed drainage.

### 7.4 SANITARY ORDINANCES

Sanitary ordinances can be used to eliminate the health problems resulting from the disruption of private sewage-disposal systems or contamination of private sewage-disposal systems caused by flood inundation. On-site soil absorption systems, for example, including septic tanks, absorption fields, and seepage beds and pits, do not function during floods and may become inoperative or clogged after floodwaters have receded. Such problems can be avoided by a sanitary ordinance that is designed to:

- require a permit prior to installing any system or constructing or modifying any building, and require the application for such permit to show the flood-plain boundaries.
- prohibit on-site soil absorption sewage-disposal systems and private water-supply systems on lands subject to flooding.
- require the replacement of on-site soil absorption sewage-disposal systems on flood plains with alternate sewage or floodproofed holding tanks.

### 7.5 BUILDING ORDINANCES

Building ordinances can be used to ensure that the structures and their contents are protected from flood loss, do not aggravate flood problems, and provide sound and safe occupancy during floods. The opportunity to protect structures from flood loss can be increased by a building ordinance that requires:

- foundations, base supports, footings and other anchorages that can withstand flood velocities and hydrostatic pressures.
- use of materials that will not be damaged if submerged.
- elevation of floors and electrical equipment at least 0.6 meters above the level of the 100-year flood. In addition, the ground level around buildings should be at least 0.3 meters above the 100-year flood for at least 4.6 meters out from the exterior walls.
- appropriate floodproofing measures, including structural modifications and installation of special equipment.
- bridge and culvert openings adequate to pass high-flood discharges and designed for maximum passage of debris.

## 8. FLOOD-PRONE AREAS—PLANNING FOR APPROPRIATE LAND USES

In planning for flood-loss reduction, the local and regional land-use planner is particularly concerned with defining appropriate land uses for flood-prone areas. The determination of appropriate land uses is a technical-political process involving personal and industry's aspirations and legal rights, as well as public goals and objectives. A well-conceived and implemented land-use plan can lead to significant reduction in flood losses with relatively small public cost, and little negative environmental impact, particularly in areas where little or no development of the flood plain has occurred.

More is at stake in deciding land uses in flood-prone areas than the potential reduction of flood losses. The flood plain is an important environmental and ecological resource meriting attention its own right. Flood-prone areas often provide wild-life habitats, water-recharge areas, fertile soils, scenic areas, and lands suitable for recreation and park uses. Thus, the land-use planner must evaluate proposed land uses in terms of both the potential flood risk and the beneficial use of the natural attributes of the flood plain.

## 9. CONCLUSION

Flood plain management is most effective if a comprehensive plan is developed and implemented. This plan should consider the social as well as environmental impacts of flood-loss reduction and prevention measures.

The first step of flood plain management is to determine the frequency and extent of flooding for a given area. The next step is to establish a development program to include wise land use. After these two steps have been implemented, the effects of the combined use of structural and regulatory flood-control measures should be considered. Once a flood plain management program has been put to action, the final step is to study the effectiveness of the flood-loss reduction and prevention measures that have been used.

The guidelines for redemial or preventive measures which have been presented in this study are meant to be illustrative rather than exhaustive in character; there are no substitutes for local experience, foresight, and prudence. It should also be noted that although the guidelines presented here are essentially national in nature and scope, international co-operation and co-ordination may be necessary to access the different required inputs.

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