VI. OPTIONS FOR WATERSHED MANAGEMENT AND HAZARD REDUCTION

A. Introduction

As has been explained in some detail in earlier chapters, and particularly in Chapters II and III, the problems of land degradation and the occurrence of water-based natural disasters are often interrelated. The natural balance of the soil, water and vegetation resources of a watershed can easily be disrupted by changes in land-use practices, by mismanagement or through poor land-use planning. Problems such as accelerated soil erosion and salinity can result from deforestation or other forms of interference with the natural balance of the catchment. The planning of land use and the careful management of soil, water and vegetation resources, through such means as the use of appropriate conservation practices and structural works, can retard run-off, increase the infiltration rate, improve production and enhance the productivity of the land. Land treatment measures which bind the soil and increase infiltration rates in the upper reaches of the watershed or on areas of degraded land can be effective in reducing the amount of run-off, especially during less intense storm events. Large-scale structural measures such as flood mitigation reservoirs, levees, channel modifications etc., when installed and operated in conjunction with a comprehensive programme of land management measures and land-use controls, can be effective in mitigating the impact of water-related natural disasters.

A wide variety of structural and non-structural options is available for the solution of watershed management problems. These may be employed either to control or to rehabilitate land degradation, to control or mitigate the occurrence or effects of water-based natural disasters, or to achieve both concurrently. The more commonly used of these options are briefly described below. More detailed information about them can be obtained from a variety of textbooks and manuals, some of which are listed in the Bibliography which follows this chapter.

B. Land management measures

1. Introduction

Land management measures for the control of land degradation and the mitigation of natural disasters may include a variety of structural and non-structural approaches. The structural approaches comprise a number of small and relatively low-cost mechanical devices whose function is to reduce run-off rates or volumes, to control or retard overland flow or to give protection against erosive or scouring forces. The non-structural measures comprise a variety of farming, cropping and cultivation techniques whose purposes are to maintain a protective vegetative cover, to increase infiltration and to impede overland flow. For the most effective results, a number of these approaches will generally be used in conjunction, utilizing a combination of structural and non-structural measures in an integrated fashion to achieve optimal management results.

2. Sheet and rill erosion

The most basic requirement for the control of sheet and rill erosion is to provide and maintain a dense, protective vegetative cover for as much of the time as possible. Special cropping methods and tillage practices can be employed to minimize the time periods during which the ground must be unprotected during land preparation and seed planting or after harvesting, or to reduce the total area of ground exposed to erosive rainfall at any time. In addition, farming practices or small-scale structural measures can be employed to improve infiltration, retard run-off and reduce the erosive energy of overland flow.

On cropping lands, low-till and no-till cultivation practices can be employed to reduce the breakdown of soil structure and avoid the necessity for leaving soil bare under fallow for long periods. These practices involve the use of selective herbicides for weed control and the employment of special cultivation implements such as sod seeders and chisel ploughs. The retention of crop residues and stubble, or the incorporation of vegetative mulches, undertaken in order to provide a protective soil surface cover, is commonly associated with these practices. Cover crops, mixed crops where one crop provides protection for the other during cultivation or germination, or the use of green manure crops for incorporation into the soil, are commonly used for erosion control, particularly where intense rainfalls are experienced during wet seasons or where crops must be grown on steep side slopes. Various forms of rotational cropping can be employed for the dual purposes of erosion control, soil moisture control and the enhancement of soil fertility. Strip cropping and alley cropping, where alternating strips of different crop types and different stages of the cropping cycle are planted, are effective methods of erosion control which act not only to maintain effective crop cover but also to retard overland flow and reduce the erosive energy of run-off. The application of techniques of this kind is usually termed "conservation farming".

Special cultivation techniques provide the simplest and cheapest means of structural erosion control. The simplest of these techniques is contour ploughing, which should be standard practice wherever mechanical cultivation is undertaken on sloping land. More effective erosion control can be achieved through supplementary cultivation in the form of listing or ridging, which involves the formation of alternating furrows and ridges on the cultivated land. This is most effective when the formation is undertaken strictly on the contour, where it serves not only to reduce soil erosion but also to reduce run-off and improve soil moisture conservation. In many parts of Asia, the ridges are formed by hand or with animal-drawn ridging devices; under these circumstances, care in aligning furrows and ridges accurately along the contour is particularly important. Water control can be more effectively achieved through the technique of basin listing or tied listing, which involves the additional formation of small dams along the furrow to produce a multitude of small water-holding basins. Basin listing can also be employed as an effective measure against wind erosion.

A wide variety of terrace-like structures is employed for erosion control under a range of topographic and farming conditions. In general terms, terraces are artificial earth embankments, or combined embankments and channels, which are constructed across sloping land, usually at fixed vertical intervals down the slope. They may be constructed for several purposes, which can include run-off diversion, run-off detention, the slowing-down of overland flow velocity, the reduction of erosive slope length, improved infiltration and soil moisture retention, slope stabilization or the retention of ponded water for irrigation, particularly for rice production.

On gently sloping agricultural or grazing lands, low channel-type terraces can be so constructed that crops or pastures can be planted on them and they cause little loss of productive land. On steeper country, terraces have to be more substantial structures and they make take significant areas of land out of production. On steep land, bench terraces become very substantial and expensive structures which completely alter the appearance of the landscape and serve not so much for erosion or moisture control but principally to permit farming and cultivation to be undertaken on country where agriculture would otherwise be quite impossible.

Channel terraces comprise a low, flat-sided earth bank with a shallow, similarly flat-sided channel formed on the uphill side. They are constructed by excavating the channel and using the spoil to form the embankment. Their purpose is to break up slope length and to retain a significant volume of water, which can either be diverted away from erosion-prone cropped or pastured areas or absorbed into the soil to improve soil moisture. Provided that the side slope is relatively flat, crops or pastures can be planted right across the terraces, which can be cultivated or harvested mechanically. On cropping lands, they are usually formed up following cultivation but before planting and destroyed and replaced during the following cultivation season. On grazing lands they may remain in place for a number of seasons.

Terraces which are built strictly on the contour, principally to retard overland flow and absorb moisture into the soil, are known as graded terraces or banks. They are most suitable in relatively low-rainfall areas. Terraces which have a slight fall or gradient and are designed to divert water to one side of the field in which they are constructed are called graded terraces or banks. These are used in areas of higher rainfall and their purpose is not only to reduce erosion slope length but to allow for the safe disposal of excess run-off , through a constructed waterway system into the nearest watercourse. Channel terraces are most suitable for use on relatively gentle slopes, not exceeding 20 per cent and preferably less, where farm sizes are large, cropping or livestock production is extensive, and suitable farm machinery for their construction and maintenance is readily available.

Bench terraces are relatively wide, flat terraces which convert sloping land into a series of platforms or steps. As indicated above, their purpose is to enable crops to be grown on very steep land where farming would otherwise not be possible. They are widely used in mountainous areas in many parts of Asia, particularly where population pressures are high and there is a scarcity of land suitable for cultivation.

Bench terraces are formed by placing soil behind substantial banks built across the slope, which may be constructed of stone, vegetated banks or bare earth according to local conditions and practice. They are expensive to build and maintain and require considerable care in lay out and construction. Relatively low-cost bench terraces can however be formed up over a long period of time – perhaps five to seven years – by growing barrier hedges of tall grasses across the slope and allowing them to develop gradually by siltation from erosion uphill. The process can be assisted by adding trash to the barriers and undertaking continuous downhill ploughing above them. The terraces may be long and narrow or formed as a series of irregular staggered platforms. They may be level or slightly graded according to their purpose. They are extensively used for irrigated rice production in China, Japan and the Philippines, where they may be built exactly on the contour, for still-water flood irrigation, or have a slight gradient for intermittent running water irrigation.

Bench terraces are most successful where the available soil is both deep and stable. They should be provided with a lip along the front and a slight back slope to prevent overtopping and facilitate drainage; when used for irrigation, a substantial bank along the front edge is essential. The retaining walls, if of earth construction, should have a slope not steeper that 1:1 and because of the limited depth of soil, vertical intervals between terraces are generally limited to the order of 1 metre. In practice, terrace design and construction methods vary widely according to soil type and depth, climate and slope, cropping purpose and local custom.

On grazing lands, ground cover can be improved by various measures, which include the careful management of stocking rates, the distribution of grazing pressures by installing more watering points, applying fertilizers, including trace elements for known deficiencies, and removing stock when ground cover levels fall below critical limits or if erosion levels are severe. The construction of works such as graded terraces and diversion banks to control surface run-off across bare areas and assist revegetation can also be effective. On timbered lands, sheet and rill erosion rates can be kept low by reducing the incidence of wildfire and maintaining a good ground cover of litter, grasses, herbs and shrubs.

3. Gully erosion

The control and rehabilitation of gully erosion is best undertaken in two phases. The first involves the introduction of land management measures and diversion structures upstream of the eroded gully area, to reduce the volume and velocity of run-off entering the eroded site. The second involves management and structural measures in the gully itself, aimed at controlling further erosion and promoting the stabilization and restoration of the gullied land. For the most effective results, an appropriate, integrated mix of these techniques should be employed.

Areas that have an extreme level of gully erosion are best treated by changing the land use. If they are currently used for cropping, they should be converted to grazing or rested completely and allowed to revert to native forest If they are currently used for grazing, they should be withdrawn from livestock production and natural reforestation allowed to take place.

Treatment of the land upstream of the gullied site may require any of the land treatment and structural measures described in the previous section, such as the maintenance of a dense vegetative cover, the use of farming techniques such as strip cropping, and the construction of graded terraces and grassed waterways to collect surface run-off and divert it around and away from the gullied zone.

If gully erosion is not severe, and the upstream treatment just described is effective in controlling erosive inflows, the gullied section can be stabilized and reclaimed by fencing it to keep out stock and allowing natural vegetation to re-establish. In more severe cases, the planting of grasses, shrubs or trees which are appropriate to or adaptable to the local soil and climate can be undertaken. Rehabilitation may be assisted by cutting back the steep gully sides and filling in the gully floor, which can be undertaken by hand or using farming or earthmoving machinery as appropriate. This serves to control further erosion and scouring and to facilitate revegetation, whilst enabling the gully to function safely and effectively as a waterway under intense rainfall conditions.

Where gully cutting is deep and gully floors are steeply inclined, structural works become necessary. There is a very wide range of such devices in use, depending upon available funds, local customs and practice, and the ingenuity of the designer. With very severe and deep gully heads, the construction of expensive concrete drop spillways, chute spillways or flumes may be necessary. Alternatively, a variety of low-cost gully head control structures may be constructed from such materials as rock, sawn timber, logs, sandbags, galvanized iron, gabions, sprayed or formless cement or geotechnical fabrics. The purpose of such devices is to control gully head scouring and undercutting by conveying and discharging inflowing run-off over and away from the active erosion site and protecting the site itself from further scouring by providing some form of armouring and energy dissipation.

Downstream of the active gully head, a further wide variety of devices might be used to form check dams or weirs which serve to reduce erosive velocities, reduce further scouring, promote siltation and facilitate revegetation. These may be constructed from such materials as gabions, rocks, sawn timber, logs, brush, wire or timber fencing, earthworks, dense, rapidly-growing vegetation such as willows or vines, or even waste or trash materials such as old tyres and motor car bodies. Hydraulically, these structures should be designed to function as broad-crested weirs. Once they have served their purpose they may be removed or covered with earth or sediment and vegetated over.

A useful alternative, when gully erosion is severe but gully floor gradients are not unduly steep, is to construct large earthwork dams across the gully at intervals down the slope to form a series of ponds or reservoirs. The stored water acts to control erosive velocities and promote sedimentation. Under conditions of very heavy erosion, the ponds may eventually fill entirely with silt and provide useful additional land for cultivation. Alternatively, the reservoirs may provide a useful water supply for domestic, stock or irrigation purposes or make possible fish farming and other forms of aquaculture. This approach is used with considerable success in China.

4. Wind erosion

As is the case with broad-scale water erosion, the single most effective solution to the problem of wind erosion is to provide and maintain a good vegetative cover. There are times and circumstances where this is not possible, such as during long fallow periods on cropping lands or following a long period of severe drought on grazing lands. In such cases, additional measures must be taken.

At the watershed scale, wind erosion control is most effectively achieved through land-use planning and control. In areas which, because of climate, soil type, farming practices or conditions or other factors are particularly susceptible to damage from wind erosion, land-use controls must be applied to restrict farming activities to those which are sustainable under the prevailing conditions. Depending upon the circumstances, this may require the changing of crop types or farming practices, the replacement of arable farming with pastoral activities, the prevention of large-scale clearing of natural vegetation, or the prevention of any kind of intensive land use.

At the farm scale, measures for the control of wind erosion can be considered in two broad categories. The first involve the use of vegetative "structural" devices to reduce wind velocities and control erosive forces. The second involve the use of special tillage and farming practices aimed at reducing wind erosion by managing the aerodynamic nature of the ground surface.

Devices which fall into the first category include windbreaks and various forms of strip cropping. The most effective windbreaks are formed from several rows of shrubs and trees, designed to provide optimal downwind protection without increasing turbulence to leeward. These devices have the disadvantage that they take a significant area of land out of production and they are only really effective if climatic conditions are such that the severe prevailing winds come predominantly from one direction. An alternative is to use strip or alley cropping methods, in which farming is undertaken in alternative strips of crop and fallow, or of high value shrubs and crops, oriented at right angles to the direction of the prevailing wind. Again, these devices are only really effective if the prevailing winds blow predominantly from one direction.

A variety of conservation farming methods and techniques has been developed for wind erosion control on croplands. These involve stubble retention techniques, which seek to maintain some vegetative ground cover for as much of the time as possible, along with cultivation techniques which enable weed control, seedbed preparation and planting to be undertaken with minimal disturbance to the vegetative cover and maintain the roughness of the soil surface. This may involve chemical weed control and the use of special farming implements, such as stubble and sod seeders and chisel-type ploughs, which permit the cultivation of vegetated surfaces and maintain a rough, well-textured surface. Under extreme conditions, special cultivation techniques such as basin listing may be employed to form a special surface which not only resists wind erosion but serves also to trap and absorb rainfall. These conservation farming techniques are similar to those which are used to control water erosion, and may be equally effective for both purposes.

On grazing lands, wind erosion control is effected principally through management of vegetative cover and management of stocking rates. Stocking rates in particular must be carefully managed to maintain sufficient vegetative cover, particularly during drought conditions, and prevent overgrazing and denudation. In severe circumstances, this may require destocking or even total cessation of livestock production. Control of vegetative cover can be assisted by the strategic location of fencing, the use of portable or temporary fencing and the strategic location and management of watering points. The control of feral animals and grazing wildlife, including the use of appropriate of fencing and the restriction of these animals from water sources, may also be necessary for wind erosion control, particularly during severe drought conditions.

5. Mass movement

As is the case with all forms of land degradation, a range of non-structural and structural or mechanical means is available for the avoidance of mass movement disasters and the mitigation of their effects.

Photo 7: Although the area disturbed by individual landslides is usually small, these can be disastrous. The event depicted in this photograph occurred in Shanxi Province, China

Photo 8: Mud and rock flows occur when unstable foundation material is associated with poor drainage conditions

Photo 9: Dry terracing is an effective gully control measure. It is used here in the loess hills of China

Photo 10: Structural gully control works are an effective means for the control of sediment movement

Where it is economically and socially acceptable, and population pressures and the demand for additional productive land allow it, land-use zoning provides the most effective and least costly solution. This simply requires the prohibition or restriction of agricultural development or urban settlement in locations which are particularly susceptible to land instability. Where this is not feasible, land-use controls might still be employed to restrict the use of the land to activities which are compatible with potential instability or result in minimal damage and loss of life should disaster events occur. This might include such means as the prohibition or restriction of clearing or logging, the restriction of cropping, or the prohibition of urban settlement from land areas at hazard. It might also include the requirement for precautionary land management practices and farming techniques which minimize disaster potential.

There is a variety of structural or mechanical measures which can be applied to reduce the potential for land instability in areas where occupation cannot be prohibited. These measures might include the following:

- preventing or diverting run-off flows around critical sites
- de-watering sites using drainage systems
- planting trees or shrubs which remove sub-surface water by transpiration
- planting deep-rooted vegetation to bind sub-soil material
- underpinning foundations to stable rock
- battering slopes to stable grades
- constructing retaining walls along the toes of critical slopes

6. Dryland salinity

As has been explained in some detail in Chapter II, dryland salinity is essentially the consequence of inappropriate alteration to site hydrology, and particularly the removal of vegetation which otherwise would function to maintain water table levels at a safe depth and prevent the discharge of saline groundwater along critical zones.

To avoid the future development of this form of land degradation, land-use controls need to be applied in locations where geological and hydrological conditions, sub-soil salinity and groundwater salinity levels indicate that a potential problem exists. Such controls should prevent extensive clearing on susceptible sites, or at least ensure that excessive clearing is not undertaken in critical sections of the watershed, particularly in upland groundwater recharge zones.

Where dryland salinity problems already exist, various land management measures can be taken. These include the following:

(a) Fencing off salt outbreaks;

(b) Reducing stocking rates or totally excluding stock;

(c) Using salt-tolerant vegetation on the saline areas,

(d) Undertaking surface tillage and deep ripping of the site to assist plant germination;

(e) Installing subsurface drainage;

(f) Installing interceptor banks to divert water away from the site;

(g) Introducing strategic soil conservation works to control the soil erosion hazard on salt-damaged areas;

(h) Changing the management of the sub-catchment to promote high rates of groundwater usage by pastures or deep-rooted crops;

(i) Regenerating vegetative cover on groundwater intake zones using deep-rooted trees or shrubs.

7. Irrigation salinity

The possible future development of irrigation salinity problems can largely be overcome by ensuring that proposals for new irrigation areas are thoroughly investigated. This requires a careful study of such aspects as irrigation water quality, soil types, sub-soil conditions, watertable depths and drainage conditions, undertaken in sufficient detail that problem areas or conditions can be identified and land-use zoning plans devised to prevent or control development on hazardous areas.

New irrigation schemes must be carefully designed to ensure that efficient control of water application rates is available and to ensure that tailwater and sub-surface drainage provisions are adequate. Farmer education and the provision of extension and advisory services are essential to ensure that sound irrigation methods are employed and the development of high water table, salinization or waterlogging problems is avoided.

On existing irrigation areas there are many non-structural and structural measures which can be taken to maintain sustainability of production and avoid the development of land degradation problems. Appropriate land management techniques and land-use controls might include the following:

(a) The restriction of crop types, cropping practices and farming methods to those which are sustainable on the site;

(b) The use of water application techniques which provide optimal water use efficiency and prevent the development of rising water table or waterlogging problems;

(c) The introduction of improved land preparation techniques to ensure uniform and efficient water application;

(d) Changing where necessary to alternative irrigation methods or equipment which utilize less water and apply it more efficiently;

(e) Ensuring that adequate leaching practices are employed by irrigators;

(f) Improving irrigation distribution systems and water ordering or rostering procedures to minimize water loss and wastage.

Structural measures that might be undertaken to control irrigation salinity problems include the following:

(a) Installation of adequate surface drainage systems to provide for effective disposal of tailwater, excess irrigation water or run-off from irrigated fields;

(b) Installation of adequate sub-surface drainage facilities to maintain appropriate water table depths, with appropriate provision for the safe collection and disposal of drainage water;

(c) The installation where necessary of groundwater pumping networks using tubewells, spearpoints and similar dewatering techniques to control groundwater accumulation;

(d) Provision where appropriate for the safe disposal of drainage waters, such as pumping to safe disposal areas or processing in evaporation basins or vegetated transpiration fields.

C. Land-use control measures

As has already been explained in Chapters II and III, land degradation can cause significant changes to watershed ecosystems. These changes usually produce adverse effects upon the natural hydrology of the watershed, which can lead to degradation of the natural resources of the watershed and an increase in the intensity of natural disasters.

The vulnerability of watersheds to land degradation and water-related natural disasters can be reduced by structural works and land treatment measures. The potential impact of these adverse developments or events can be further reduced by the imposition of land-use controls, designed to manage degradation and minimize exposure to the risk of disasters which cannot be avoided. To achieve this objective, legislative controls which empower the relevant government authorities to direct land-use planning policies and practices related to watershed management should be adopted and implemented. These controls should strive to ensure that an effective and comprehensive legal and administrative system is adopted which addresses the problems of land degradation, environmental protection, and the maintenance of ecosystems and is consistent with the principles of sustainable resource development. Such a system requires an integrated approach to the management and protection of natural resources, including land, water, vegetation and human activity, undertaken on the basis of the total watershed. This approach recognized that changes to the natural environment in the upper watershed will influence conditions in the downstream areas.

Legalization should establish national standards for watershed management which relate to the use, development and protection of land in a way which will minimize the risk to populations during the occurrence of water related natural disasters and the degradation of natural resources. Activities within a watershed should be controlled and protected through a comprehensive watershed management plan which places restrictions on those activities which can increase the risk of damage. Under this type of legislation, consent would be required for:

- large-scale land clearing
- rural land development and use
- forestry, mining and extractive industries
- rezoning of land for urban use
- occupation of flood plain land, steep slopes and other hazardous areas

D. Large-scale structural or engineering measures

1. Levees and flood walls

The principal purpose of levees and floodwalls is to confine floodwaters to the stream channel and a selected portion of the floodplain. These barriers protect only the land area immediately behind them, and are effective only against flood depths up to the chosen level for which they were designed.

A major advantage of levees and floodwalls is the flexibility they offer to protect either a specific site or a larger area. For example, they can be used to protect a single community or a portion of a community. However, they may create a false sense of security about the degree of protection provided. Floods exceeding the levels for which the levees and floodwalls are designed can cause disastrous losses of life and property.

Levees and floodwalls may increase flooding in other areas unless they are designed to form part of a comprehensive programme. If they restrict the extent of flooding, levees and floodwalls tend to increase water surface elevation, velocity and maximum discharge within the confined stream reaches and also to increase the rate of flood wave travel downstream. These structures may also have undesirable environmental aspects, such as destruction of natural habitat and the loss of scenic views.

The requirements for the design and construction of levees and floodwalls are governed by degree of hazard to life and property within the protected area and by site conditions. Levees are normally constructed of earth and require significant space to accommodate the required base width. Floodwalls are usually constructed of concrete or steel and take up far less room. They are more suitable for use in congested areas.

The intensity of investigation for levees and floodwalls depends upon the importance and economic value of the land being protected from flooding. Items covered by the investigation should include levee location, determination of design water level, foundation conditions and embankment materials. Investigations undertaken for levees should also incorporate geotechnical investigations of suitable borrow pits for embankment material.

Because levees and floodwalls can fail by overtopping, undermining, slumping and excessive seepage, the design of these structures should attempt to reduce the possibility of failure from these causes. Ample freeboard, which takes into account the settlement of levees, wave action, sedimentation of the river channel and inaccuracies in estimation of flood levels, reduces the possibility of overtopping of levees or floodwalls. Undermining is minimized by locating levees or floodwalls far enough away from channels to eliminate exposure to high velocity or scour. Proper side slopes and construction methods minimize slumping of earth levees. Excessive seepage can be reduced by the provision of seepage protection works. Damage can also be caused by termites and burrowing animals. Regular inspections are necessary to locate and remedy the damage in an early stage of development.

Levees and floodwalls complicate the drainage of land they protect and provision must be made for the discharge of internal drainage water unless adequate storage is available. Discharge through levees or floodwalls can be achieved by gravity flow through pipes equipped with gates. When prolonged flood stages prevent gravity outflow, the internal drainage water must be stored temporarily, removed by pumping or disposed of using a combination of these methods.

To be effective levees should be subjected to proper maintenance. Such maintenance should include regular inspections as well as periodical patrols during and immediately after severe floods. Vegetation, grazing and traffic on earth levees should be controlled. Proper attention to any defects will help ensure against levee failure.

The following disadvantages are associated with levees and should be recognized:

(a) Economic and other constraints limit the height to which levees are constructed and it is usually statistically certain that rare flooding will result in overtopping;

(b) Levees can create a false sense of security;

(c) If overtopping does occur the resulting damage can be far in excess of that which would have occurred if the levee had not been constructed;

(d) Levees tend to promote increased development in the areas protected which in turn leads to even greater damage if overtopping occurs;

(e) Levees can be unsightly and can divide communities.

For safety purposes, earth levees should be constructed with gentle backslopes to reduce the risk of scour and failure if they are overtopped by a large flood. Consideration should be given to the provision of measures which allow controlled overtopping and thus minimize damage if the design height of the levee is exceeded.

2. Channel modification including river training works

Most natural watercourses have a river channel of limited capacity, which may be exceeded annually, with excess floodwater overflowing onto the floodplain. Hydraulic improvements to the watercourse or to the floodplain, and/or flood channels constructed within the floodplain, enable flood waters to be passed at a lower level than would occur naturally. In urban areas, such works also permit the optimization of land use through improved residual drainage.

The various types of channel modification include:

- straightening, deepening or widening of the channel
- removing vegetation or debris
- lining the channel
- raising or enlarging bridges and culverts which restrict flow
- removing barriers which interfere with flow
- installing river training works

All of these modifications contribute towards reducing the height of a flood. It is sometimes possible, by extensively reconstructing a stream channel, to contain major floods within the banks. Caution should be exercised, however, as channel modifications can facilitate the transfer of floodwaters downstream and may impose problems on downstream communities

Channel modifications are similar to levees and floodwalls in that they can be used to protect a specific site or region. They can also provide the community with other positive benefits, such as improved navigation and recreation.

Channel deepening is not very well suited to major streams, because sediments can quickly fill the excavated area. Frequent re-dredging is often necessary to maintain the deeper channels and this can involve a significant maintenance cost.

Channel modifications are likely to be most effective on steeper, smaller streams with overgrown banks and narrow floodplains. Channel modifications are unlikely to have any significant effect in flooding situations where there are extensive areas of overbank flooding, or where flooding effects are dominated by tide levels.

River training works are structural measures of various kinds which are undertaken in order to provide a more effective channel for the passage of flood flows and sediment loads. Such works may be designed either to retard flow rates along a river bank, in order to reduce erosive velocities and increase the deposition of sediments, or to provide protection for the bank against erosion or scouring

Permeable groynes and revetments, constructed of piling, rock, concrete, fencing materials, vegetation or other materials, are generally used for these purposes Groynes protrude into the channel and are designed to divert flow away from the bank, whilst at the same time causing an accumulation of sediment along the toe of the bank and on the downstream side of the groyne structure. Revetments, on the other hand, are constructed along or parallel to the bank. where they serve to reduce the velocity of flow along the bank, thus reducing bank erosion and allowing the river bank to stabilize.

Which of these devices should be used in a given situation depends upon characteristics of the stream channel and the extent and nature of the existing erosion damage. Whichever kind of device is employed, its satisfactory long-term performance will be very much dependent upon its continuing maintenance.

Disadvantages which are related to the use of channel modifications include the costs of proper maintenance, the destruction of riverine habitat for fish and wildlife, and the potential for the aggravation of channel scouring and bank erosion if the structures are not intelligently designed, well constructed and carefully maintained.

3. By-pass floodways

These structures serve two functions in flood mitigation. Firstly they create large, shallow reservoirs which store a portion of the flood water and hence decrease the flow in the main channel below the diversion. Secondly, they provide an additional outlet for water from upstream, improving flow characteristics and decreasing water levels for some distance below the diversion. Opportunities for the construction of floodways are limited by the topography of the area and the availability of low-value land which can be used for the floodway.

There are two types of by-pass floodways, natural and constructed. A natural floodway follows the course of an existing cross-country depression and carries floodwaters that can no longer be carried within the river channel. The land in the floodway is generally not different from other farmland, except that it may be low-lying. Some floodways have control banks constructed across them, or may be bordered by levees, in order to control the spread of floodwater. Restrictions are usually placed on land development in floodways to ensure that future loss and damage from major floods is reduced to a minimum and to ensure that the floodway functions as designed.

When required, controls in the form of spillways and gates are provided at the entrance to a floodway. Spillways take the form of a lowered and protected section of levee which is designed to control the amount of floodwater diverted into the floodway from the river. As spillways can be overtopped for long periods by high velocity floodwater, they have to be specially designed to avoid failure. Protection can be provided by rock gabions or, where appropriate, by building the spillway with gentle backslopes which are well grassed.

If the floodway possesses comparatively steep bed-slopes, control banks may be built perpendicular to the direction of flow at intervals along the length of the floodway. These banks are similar in design to the entrance spillway, and form a series of basins which reduce the water velocity by dropping the floodwater in progressive steps down the floodway alignment.

Diversions are works constructed to intercept flood flows upstream of a damage-prone area and route them around the area through an artificial channel. Diversions may either completely re-rout a stream or collect and transport only those flows that would cause damage.

Diversions sometimes offer the advantage that they can be located to protect several nearby communities with one major facility. They are, of course, subject to surcharging if floods exceed their design capacity.

Diversions are particularly well suited for protecting developed areas, because they do not usually require land acquisition or construction within the protected area. However, opportunities for diversions are often limited by the nature of local land formations and soil conditions. There must also be a receiving water body or stream channel with sufficient capacity to carry the flow bypassed through the diversion without causing flooding.

4. Retarding basins and flood storage areas

Flood storage and retardation involves the deliberate, controlled flooding of designated areas in order to minimize overall flood losses. It permits floods exceeding a specified magnitude to spread over low-lying lands situated behind levees in a controlled fashion, accomplished by the operation of gated structures or spillway sections incorporated in the levees. The diversion of floodwater, when carefully controlled, will reduce the flood peak at downstream locations and confine flooding to within the flood control system.

Areas selected for flood storage and retardation are traditionally low-lying locations which have a history of flooding. By the formulation of proper controls it is possible to utilize these areas for habitation and agricultural purposes, on the understanding that they will be flooded periodically. This calls for the preparation of a comprehensive programme of flood operation, a knowledge of the depth and extent of area inundated, the imposition of controls to ensure predictable flood behaviour and the implementation of a reliable flood forecasting and warning system to ensure timely and safe evacuation. Special provisions are also required for the protection of emergency services and for flood refuge areas.

To reduce the damages associated with controlled flooding, it is necessary to provide drainage works capable of emptying the flood storage area as quickly as possible after the cessation of main river flooding.

Retarding basins reduce downstream flood flows in both mainstream and urban drainage situations. They allow small flows to pass unimpeded but trap a portion of larger flows. In urban areas, retarding basins are most suitable for small streams which respond quickly to rainfall and/or stormwater flooding. However, they introduce a number of inherent problems, which should be carefully evaluated for each particular situation. These may include the following:

(a) Basins may require a substantial area to achieve the necessary storage;

(b) Long duration or multi-peak storms (when the basin is filled from a previous peak) can increase the risk of overtopping or breaching,

(c) The impact on floods larger than those for which they are designed is limited.

Although such basins can be very useful in reducing the flood problems of both proposed and existing development, it is particularly important to make provision for downstream management of the resulting floodwater if the capacity of the basin is exceeded.

Sites for retarding basins in developed urban areas are generally limited. Available sites are usually restricted to established recreational areas, such as parks, playing fields and parking lots. In new urban developments or re-developments, the incorporation of a system of retarding basins at the planning stage can result in effective flood protection for those areas.

Retarding basins are sometimes constructed by building an earth embankment across the watercourse and providing outlet facilities to control releases appropriate for the capacity of the downstream channel. The outlet facility usually takes the form of a box or pipe culvert. If earthworks are used for the construction of the basin embankment, the provision of adequate spillway capacity is essential to protect the basin from failure by overtopping if flows exceed the design flood.

Retarding basins can play a role in the improvement of water quality by the removal of floating rubbish and the collection of sediment. When they are used for this purpose, they require continuous maintenance.

Land along the river and natural depressions on the floodplain can be utilized for the off-river storage of floodwaters. Flood flows are diverted into them in order to reduce flood peaks downstream. The efficiency of operation of such storages can usually be improved by providing them with suitable intake structures for controlled filling and outlet structures arranged to permit controlled releases when downstream conditions allow.

5. Flood mitigation reservoirs

In appropriate circumstances dams can be constructed to create reservoirs which control major flood flows by temporarily storing flood waters and releasing them at a safe flow rate. Such devices may be used to control floods arising from existing catchment conditions or to offset the impact of proposed land-use changes. The amount of storage required depends upon the degree of protection needed and the downstream channel capacity.

The degree of mitigation provided by a flood control reservoir depends on the combination of dam storage, spillway capacity and the pattern of flood inflows. The effect of storage is to decrease the flood peak without reducing the total volume of floodwater. The reduction of the flood peak is achieved at the expense of an increased duration of dam releases at lower rates. For dams equipped with gates or valves, the way in which these controls are operated will determine the rate of release and the degree of downstream mitigation.

The protection afforded by a surface reservoir is greatest in the area immediately downstream of the dam. Protection further downstream is reduced by tributary flows and by run-off from land adjacent to the river. Protection may also decrease over time if the reservoir capacity is diminished by siltation. Surface reservoirs have the greatest potential to mitigate floods when they are empty.

Flood mitigation reservoirs are mostly used on small and moderate-sized streams. The large areas of land required to store the flood flows of major rivers are generally no longer available, especially where they involve the flooding of valuable agricultural lands. Many sites that are geologically and topographically suitable may require very considerable and expensive land acquisition and the displacement of large populations. The cost of large reservoirs can generally only be justified where they protect heavily developed urban areas and are the only practical means for significantly reducing flood damages. It is usual practice to reserve a component of the available storage capacity in multi-purpose dams for flood mitigation purposes. In such cases, careful coordination is necessary to permit flood mitigation reservoirs to serve also for water supply or irrigation purposes.

A major disadvantage of flood mitigation reservoirs is that downstream residents often do not appreciate that they can only control floods up to the peak rate for which they were designed. Complementary land-use controls need therefore to be enforced to prevent unsafe development and encroachment on the downstream floodplain.

6. Drainage evacuation systems

Drainage water produced by storm run-off from within the protected area behind levees or floodwalls may be disposed of by various means, which include:

(a) Gravity release through pipes fitted with gates during periods of low river flow;

(b) Temporary accumulation of drainage flow in storage areas;

(c) Pumping of interior drainage water during periods when gravity drainage outflow is restricted by backwater.

Pumping is usually required for the disposal of interior drainage water whenever sufficient discharge by gravity flow cannot be achieved, which may be because of limited outlet capacity, insufficient storage capacity or the effects of backwater caused by flooding.

The design of drainage works for the removal of flood waters accumulating within the low-lying areas behind levees or floodwalls requires consideration of the entire drainage network servicing the protected area. Coordinated use of storage areas, channels, pipe systems and gravity outlets is needed so that the pump capacity, size and period of operation can be optimized. The efficient planning and design of pumping plants will involve careful selection of the required water removal rate, the auxiliary drainage facilities needed to minimize the pumping requirements and the location of the pumping plant to provide an effective outlet to the entire drainage system.

The required capacity of the pumping plant should be determined on the basis of direct hydraulic analysis. This analysis should give consideration to such factors as the size of the area served; the amount, rate and timing of rainfall and run-off; and the period of flooding when gravity flow is restricted. For protected areas in coastal plains which are located along rivers, the effect of tides should also be taken into account

The period of pumping may be reduced by increasing the amount of available storage. This may be achieved by excavation. Where this is not practical, adequate pumping capacity must be installed to safely discharge any drainage inflow volume in excess of the available storage capacity.

Pumps installed for drainage evacuation systems must be selected to operate efficiently whilst moving large quantities of water at low heads. They may also be required to handle substantial amounts of sediment and rubbish in the drainage effluent. Axial flow, mixed flow or radial flow centrifugal pumps are best suited to this application. It is advantageous to install two or more pumps, in order to provide efficient pumping over a wide range of pumping rates and ensure that the breakdown of one pump will not stop all pumping. Discharge of drainage water by gravity flow is achieved more efficiently by using a battery of small gates, rather than by one or two large gates.

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ANNEX

CONTACTS FOR COMPUTER MODEL PROGRAMMES

HEC series models:
US Army Corps of Engineers (USACE)
Hydrologic Engineering Centre
609 Second St
Davis CA 905616 USA

SSARR:
US ARMY Corps of Engineers (USACE)
North Pacific Division
Attn: CENDP-EN-WM-HES
PO Box 2870
Portland OR 97208-2870 USA

USACE Water Quality Models:
Environmental Laboratory
US Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg MS 39180 USA

HSPF, SWMM, SYMPTOX3, QUAL2E, WASP5:
Environmental Protection Agency (EPA)
Center for Exposure Assessment Modelling (CEAM)
960 College Station Road
Athens GA 30605-2720 USA

CREAMS, GLEAMS:
US Department of Agriculture (USDA)
Agricultural Research Service (ARS)
Southeast Watershed Research Lab
PO Box 946
Tifton GA 31793 USA

SWRRB:
US Department of Agriculture ARS
Attn: Dr. J. Arnold
808 East Blackland Road
Temple TX 76502 USA

ANSWERS:
University of Georgia
Department of Agricultural Engineering
Coastal Plains Experiment Station
PO Box 748
Tifton GA 317973 USA

Information about US Federal Government agency models and their availability can also be obtained from
National Technical Information Service
US Department of Commerce
5285 Port Royal Road
Springfield VA 22161 USA

WALLINGFORD series and other UK models:
Wallingford Software
HR Wallingford Limited
Howbery Park
Wallingford, Oxfordshire
OX108BA United Kingdom

MOUSE and other Danish models:
Danish Hydraulic Institute
Agern Alle 5
DK2970
Horsholm, Denmark

NOTE: that many of the agencies listed above have Internet sites, from some of which model programmes can be downloaded (e.g. all the EPA programmes listed above). They can be located using search engines such as AltaVista and Yahoo. The following home pages provide a good starting point:

US Corps of Engineers: http://www.usac.army.mil/
US Environmental Protection Agency: http://www.epa.gov/
US Department of Agriculture: http://www.usda.gov/