DISCUSSION PAPER FOR THE FORMULATION OF ENVIRONMENTAL GUIDELINES FOR DRAINAGE AND SEDIMENT CONTROL

by
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INTRODUCTION

Past experience and observations have demonstrated that conversion of virgin or agricultural lands for urban and industrial uses may greatly alter the natural drainage characteristics and the sediment yield from the affected watershed areas. These changes may produce a variety of undesirable or damaging effects upon the environment not only within the boundaries of a site under development but also throughout the entire drainage system of the basin including the downstream receiving waters.

The effects of land development upon the natural runoff can manifest themselves in a number of ways. The runoff from comparable precipitation events may substantially increase the peak flow rates in the receiving stream exceeding more often the bankfull flow stage in the stream and increasing the probability of flood plain flooding. Higher peak flow rates increase the formative channel discharge and, in reconstructing its geometry in response to the new flow conditions, the stream may erode its bed or banks, alter its meander pattern and produce additional sediments for transport toward the receiving waters. The time from the start of a storm to the time of maximum runoff flow rate is generally reduced by the construction of impermeable surfaces such as pavements within the catchment basin. Less water is infiltrated into the sub-soil increasing the total volume of surface runoff and reducing the amount of water for ground water recharge. This may lower the ground water table and may affect the base flow characteristics of local streams. In extreme cases perennial streams may become ephemeral.

Earthwork activities associated with land development remove protective vegetal cover, expose the underlying soil to accelerated erosion and increase the sediment loads in the surface runoff waters. New sediment sources and artificial disturbances of the conditions controlling the overland movement of sediments downslope may alter the established sediment particle characteristics delivered into a receiving stream. The mode of sediment transport and the hydraulic roughness characteristics of the channel boundaries can be modified and can alter the dominant and environmentally important patterns of flow velocities, depths and hydraulic gradients of the stream.

The artificially induced disruptions of natural surface runoff and sediment movement in watersheds undergoing land use changes may be minimized or eliminated by available technical means. Effective and economical deployment of these countermeasures, however, depends upon the recognition of environmentally sensitive problem areas, the design and provision of control facilities or procedures, and the implementation of maintenance procedures to ensure the effectiveness of the control provisions during the construction and operation phases of the site development.

The objective of this brief is to outline the interrelated topics to be considered in the evolvement of environmental design guidelines for drainage and sediment control in watersheds undergoing land development. The brief deals with the physical aspects of the problem only. It considers the function and format of the guidelines that would best serve the designers' needs. It identifies basic design considerations for drainage and sediment control and suggests an approach for the establishment of environmental design criteria. Finally, it outlines field information requirements for the establishment of realistic design criteria and credible environmental standards.

The preparation of this brief has been prompted by proposals and future plans for the development of land sites for a variety of purposes. The suggestions and proposals contained in the brief do not differentiate between specific land uses because the basic surface drainage and sediment processes are the same on lands used for airports or townsites, or during the construction or the functional operation phases of a site development. Differences arise because development activities induce quantitative variations in the parameters which

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control these processes. Hence, in scope the brief is general and is not limited to any specific site.

THE FUNCTION AND FORMAT OF ENVIRONMENTAL GUIDELINES

The basic purpose of the guidelines should be to assist the drainage engineers by providing an outline of the various factors to be considered in the environmental design of drainage and sediment control facilities. They should, therefore, serve three main functions:

(1) To indicate the scope of the drainage and sediment related environmental problems in time and space.

(2) To provide a framework for the assessment of existing or reference conditions necessary for the establishment of environmental standards for a specific site.

(3) To identify or suggest design methods for the evaluation and selection of control facilities to meet the environmental criteria.

There appears to be no precedent to suggest the format which such environmental guidelines should have. However, because of their design function, consideration should be given to adopt for the guidelines some accepted form of engineering design specifications such as a "code" or a "recommended practice" format.

A "code" has the format of a "law". It defines minimum requirements against danger especially where public safety is involved. Sometimes it may attempt to identify and eliminate common errors from design procedures, but normally it does not specify the best practice.

A "recommended practice", on the other hand, attempts to define the best known design practice, and may state acceptable and satisfactory design assumptions and procedures. Sometimes it may include reasons as well as methods.

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Should the environmental design guidelines for drainage and sediment control take one of these two forms or should they have a distinct format of their own? Preliminary considerations, based upon present understanding of the various physical phenomena, suggest that some parts of the guidelines could take the format of a "code", while others should only contain suggestions for "recommended design practices". For example, the guidelines should explicitly require the assessment and consideration of all potential drainage and sediment induced effects upon the environment not only at the site of works alone but also throughout the entire drainage basin and the receiving waters affected by the land use changes. At present, however, even a moderate degree of refinement in the design criteria or procedures is not possible because the current understanding of the mechanics of flow in mobile boundary channels, and of the sediment erosion, transportation and deposition processes is still incomplete. Furthermore, the runoff and sediment phenomena are generated by precipitation events which depend upon the highly random nature of the climatic conditions as well as the variability of soil characteristics in the watershed. Hence, many of the land development induced drainage and sediment effects upon the environment are not understood or, perhaps, not even recognized. Therefore, the parts of the guidelines dealing with the design aspects of the drainage and sediment control facilities will have to adopt the "recommended practice" format and reflect the best available knowledge, however crude, to provide guidance for the design of effective, workable and economical drainage and sediment control facilities.

LOADING CRITERIA - DESIGN PRECIPITATION

The function of any site drainage system is to dispose of the surface runoff without damaging the drainage facilities, without unduly saturating the subsoil and without interrupting the normal site operations.

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Environmental considerations further augment these requirements by imposing limits upon the runoff discharge characteristics from land development sites into the natural drainage streams.

To meet its operational and environmental requirements a drainage system must be designed on the basis of factual quantitative information on the volume and the distribution of runoff which is to be controlled or disposed through the system. The design is usually based upon a selected "design precipitation" of an average frequency of occurrence rainfall and of such intensity-duration characteristics which give a maximum drain inlet discharge under watershed characteristics which govern the surface runoff.

Because of the probabilistic nature of storm events, the design precipitation recurrence interval indicates the average frequency with which the drainage system or any of its components operate under the full design capacity. This implies that the drainage systems are not designed to accommodate runoff from extreme rainfall events and that damages upon the system are not unforeseen. The selection of storm frequency for the design of airport drainage facilities, according to Hathaway (1), has to be based upon judgement with consideration for the purpose and the importance of the airfield and of various economic and engineering limitations as may exist.

The design of drainage facilities to satisfy environmental requirements will also have to be based upon a selected design precipitation of an average frequency of occurrence. An absolute adherence to imposed limitations would not be economical or realistic in view of the natural randomness of the events which generate the runoff. Although the possibility is not excluded that the design storm frequency selected for the operational site drainage system will be satisfactory, the guidelines should recommend that the design storm for the environmental requirements should be established independently of the operational requirements. It should be selected on the basis of site conditions,

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damage-benefit analysis throughout the entire drainage system and the recovery potential of damage susceptible environmental factors.

The environmental guidelines should also consider the recommendation of a design storm for drainage facilities during the initial phases of site development. Construction activities can substantially alter the natural watershed terrain, the runoff from a site and especially the sediment production by sheet erosion from exposed soil surfaces. Temporary facilities for drainage and sediment control must, therefore, also be provided during this period to meet the environmental standards, and must be designed, in principle, on the basis of some design storm. Because of the relatively short period of site construction activities and also the equipment which is normally available for emergency use during this period it may be feasible to accept the risks that the operational design storm will not occur during this time. This may permit the selection of a design storm of greater frequency of occurrence that produces a less severe loading on the drainage system and permit the use of less extensive and less costly temporary facilities than would otherwise be required under the operational design storm specifications.

ENVIRONMENTAL "STRESS-STRAIN" RELATIONSHIPS

Land development activities modify the runoff and sediment patterns entering into drainage channels, force the readjustment among the established hydraulic and channel morphological parameters and disturb the natural drainage system environment. The objective of this section is to suggest a mechanism for the evolvement of environmental safety criteria pertaining to drainage runoff and sediment input into natural streams from land development sites.

The basic problem concerns the relationships between the independent variables of flow, sediment load and sediment characteristics, and the dependent variables of channel width, depth of flow, hydraulic gradient, channel meander wavelength, meander belt width and sinuosity, and, hence, the flow velocity, water surface elevations along the stream length and the bed material composition. These dependent variables, in turn, determine the various environmental factors such as flooding, waterlogging, ground water levels, erosion of channel banks and production of new sediments, aggradation or degradation of stream bed, alteration of stream bed material characteristics, scour of bridge piers, destruction of aquatic life habitat and so on.

In terms of engineering time span (up to 100 years) the establishment of environmental safety criteria for a given stream appears to be a two-step problem. First, variations in the various hydraulic and morphologic parameters in response to a range of possible (new) formative flow discharges or sediment input loads must be determined. Second, the limits or ranges of environmentally permissible hydraulic or morphologic parameter values must be quantitatively assessed. The first step establishes a "stress-strain" relationship, and the second--an environmental failure limit (in terms of "strain"). For example, in a particular reach of a stream, waterlogging damage may occur when the water surface elevation m_1 exceeds a certain m_1/m_o value where m_o represents the baseline elevation. The relationship between discharge and water level elevation then provides an indication of the limiting permissible discharge Q_1 ("stress") upon which the design of the site drainage facilities can be based.

The establishment of the "stress-strain" relationships must be based upon comprehensive field information and a competent engineering analysis of stream behaviour in different reaches of a stream for various discharges (Q), sediment loads (G_s) and sediment size characteristics (D). In practical situations these independent variables may be increased or decreased from previously established values. For a case where D remains constant, four distinct combinations among Q and G_s are possible. Denoting an "increase of" by +, and a "decrease of" by -, the response of the dependent variable to these changes, according to Shumm (2), will be as follows:

$$Q^{+}, G_s^{+} \simeq b^{+}, d^{\pm}, \lambda^{+}, S^{\pm}, \left(\frac{b}{d}\right)^{+}, P^{-}$$

$$Q^{-}, G_s^{-} \simeq b^{-}, d^{\pm}, \lambda^{-}, S^{\pm}, \left(\frac{b}{d}\right)^{-}, P^{+}$$

$$Q^{+}, G_s^{-} \simeq b^{\pm}, d^{+}, \lambda^{\pm}, S^{-}, \left(\frac{b}{d}\right)^{-}, P^{+}$$

$$Q^{-}, G_s^{+} \simeq b^{\pm}, d^{-}, \lambda^{\pm}, S^{+}, \left(\frac{b}{d}\right)^{+}, P^{-}$$

where b = channel width
d = depth of flow
λ = meander wavelength
S = channel gradient
P = sinuosity

For practical engineering these effects have to be estimated quantitatively. Rough predictions of river behaviour trends can presently be made by techniques discussed by Blench (3,4), Cayade and Simons (5) and Leopold, Wolman and Miller (6) and others.

The establishment of the environmental strain limits has to be an interdisciplinary endeavour. For example, if the drainage streams are to provide a habitat for fish life, biologists should be consulted to determine the range of hydraulic and morphological characteristics conducive to fish life. Local water resource and agricultural requirements and long range land development plans especially in the flood plains of the receiving streams must also be considered.

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DRAINAGE AND SEDIMENT CONTROL MECHANISMS

The selection of design precipitation and the environmental failure conditions establishes the criteria which will govern design of site drainage and sediment control facilities. The objective of this section is to outline the fundamental surface runoff and sediment behaviour principles for the identification of potential control mechanisms and for the design of control facilities.

Surface Runoff Control

The principal physical components governing surface runoff phenomena are displayed in a continuity type relationship which also provides a model for an overall assessment of the disposition of rainfall.

$$Q = P - (F + L + S + E)$$

where Q= surface runoff

P= precipitation

F= infiltration

L= interception

S= storage

E= evaporation

Although it is conceivable that large scale land use alterations could alter the microclimate of a catchment area it is doubtful that this would be significant in airport or townsite development and change the selected design precipitation. The precipitation term in the equation may, therefore, be assumed to be independent of land use and fixed at the design value. The effects of land use changes upon the surface runoff are, therefore, dependent upon changes imposed by the various land development activities upon infiltration, interception, storage and evaporation. Some of these processes can be artificially manipulated to control runoff flow rates at different points in the drainage system.

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Infiltration generally depends upon surface entry, transmission through the soil and the availability of underground storage space. Under natural conditions, these factors are governed primarily by the characteristics of the soil. At land development sites infiltration is prevented by impermeable airport runway or highway pavements, or by buildings. The impact of raindrops upon soil surface exposed by excavation may also compact the soil particles and reduce surface layer permeability and infiltration.

Surface runoff regulation may be possible by artificial control of infiltration. Provided that the operational site design does not require substantial lowering of ground water level to avoid soil saturation, frost damage to pavements or unstable foundations, it may be feasible to construct highly permeable and porous gravel beds into which a part of total rainfall from a storm could rapidly infiltrate, and be temporarily stored.

Interception, or the part of storm precipitation which is stored on the vegetal cover depends mainly on the vegetation species, their composition and density, the season of the year and the atmospheric conditions. Although it may be insignificant in major storms it may nevertheless retain substantial amounts of initial precipitation for evaporation from the large surface of wetted foliage. The removal of vegetation from a site would thus reduce the contribution, however small, by interception toward the regulation of runoff. This effect can be minimized by the retention of existing vegetation for maximum length of time before stripping for construction or land development sites.

Storage plays a leading role in the surface runoff disposition. In a typical watershed, a large part of the initial precipitation is stored in surface depressions from which it infiltrates underground or is evaporated. After the depressions are filled, the entire soil surface becomes covered with a finite depth of water that flows overland toward the natural drainage channels. Substantial amounts of the total available precipitation are temporarily detained minimizing the peak flow rates

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and redistributing runoff over longer periods of time.

Storage is dependent upon the topography of the catchment area--especially the surface gradients and their lengths, the presence of depressions, lakes, ponds or swamps, and the hydraulic characteristics of the land surface over which overland flows occur. Land development activities disturb many of these factors and may significantly affect the runoff from a site. An assessment of these disturbances is imperative in evaluating the changes in runoff and in the design of runoff control facilities.

Artificial storage provides an effective surface runoff control mechanism. Temporary ponding facilities to reduce peak flows in drainage channels have been successfully employed in many different drainage design situations in the past.

Evaporation is governed by a variety of factors including vegetation, humidity, temperature, wind and nature of evaporative surface. However, its effect upon drainage system design, especially in small basins, is likely to be insignificant in comparison to other factors which govern storm runoff.

Erosion and Sediment Control

Land erosion takes place by soil particle detachment due to the impact of falling raindrops or by the forces generated at the water-soil interface by the flow of water which also transports and deposits sediments at various downslope locations in the drainage basin.

The control of sediments to prevent environmental damages in the natural drainage streams receiving runoff from land development sites is possible, in principle, by artificial interruption or modification of the processes of local soil erosion or of sediment transportation or deposition at various points in the drainage system. The design of the control facilities must, however, be based upon factual quantitative

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information for estimating of the capacity requirements for control works and upon sound relationships describing the physical behaviour of sediments in the two-phase systems.

According to Meyer (7) the rates of soil erosion can be predicted using the empirical Universal Soil Loss Equation

$$A = R\ K\ L\ S\ C\ P$$

which relates the loss of soil (A) from an area in a given time period with factors which account for rainfall erosivity (R), soil erodibility (K), land gradient (S), length of the gradient (L), land cropping (C) and supplemental practices (P). It has been developed primarily for use in agriculture, but recently Wishmeier (8) has indicated that it is adaptable also for estimating of soil losses from land areas undergoing construction or urbanization.

This equation is limited for use in predicting soil losses by sheet or rill erosion but cannot predict sediment deposition because it does not include factors which account for sediment storage and yield in the transport phase between the site of erosion and the receiving stream and does not include sediment contributions from gully erosion. However, it is useful in the design of sediment control works because its dependent variables display the possible erosion prevention mechanisms. Furthermore, it provides a quantitative information on the availability of sediments for transport. This, when used in conjunction with sediment transport information, provides an indication of local sediment control facilities size requirements.

The rainfall index (R) measures the erosivity of rainfall and has an average value depending upon the rainfall intensity-duration-frequency characteristics of a location. Hence it is fixed and not subject to artificial control except indirectly. It may be possible to reduce the exposure of soil to rainfall by a variety of surface or vegetation coverings to absorb raindrop impact energy, or to reduce the exposure time to a practical minimum, or to limit the exposure to a specific season of the year when critical rainfall is less likely.

The soil erodibility factor (K) measures the susceptibility of soil to erosion. It accounts for the combined effects of the soils' water intake and its ability to resist detachment by raindrop impact or surface runoff. This factor depends upon local soil characteristics and may be altered by chemical soil stabilizers and, perhaps, by freezing.

Sheet and rill erosion are highly dependent upon the physiographic characteristics of land gradient and its length. These are considered by the slope steepness factor S which accounts for the increased velocity of runoff on steeper slopes, and the slope-length factor L which accounts for the increased quantity of runoff when the distance from the top of the slope lengthens. Both, the land slope and its length, may be artificially controlled especially during the construction activities and by design of final land topography. The length of slopes can be reduced by terraces and diversions. Maximum slopes can be specified for any temporary earth stockpiles or permanent earth slopes for rapid reestablishment of vegetative cover.

The above four factors determine the basic soil erosion potential of a given site. The last two--the land cropping and management factor (C) and the supplemental practices factor (S) represent local artificial effects due to agricultural conservation practices and may be viewed as the modifiers of the basic R, K, L and S factors.

When flow is permitted to concentrate in areas of moderate to steep topography over land which has a thick soil mantle, severe gully erosion may occur. As it is generally assumed that entrainment of soil particles by flowing water is a function of flow shear upon the boundary materials, any means which alter the shear stress,such as diversion of runoff from critical areas, or conversion of concentrated flows back into sheet flows may be employed to reduce erosion by flowing water.

Upland erosion produces loose sediments that become available for further transportation by water. However, not all of the detached soil particles are immediately transported downslope toward receiving streams. The amounts delivered to any point in the system depend upon the competence of the overland or small channel flow to sustain the movement of the sediments. Therefore, the downslope transport of the eroded soil particles can be controlled and their deposition can be enhanced by redirecting the overland flow over grassed areas, or by constructing sediment retention reservoirs which increase the cross-sectional area of the sediment carrying flow, reduce velocities and shear and cause the settlement of soil particles.

Sediment production and yields are likely to be most severe during the construction activities. It is imperative that the environmental guidelines explicitly identify the temporary as well as the permanent areas of environmental concern and recommend design procedures to satisfactorily alleviate the sediment problems during all phases of site development.

For more extensive discussion of erosion, sediments and their control refer to Meyer (7), Barnes (9), Wischmeier (8), - (10), - (11), Thronson (12), and Swerdon and Kountz (13).

RUNOFF AND SEDIMENT SIMULATION MODELS

The determination of the changes in the natural runoff and sediment climate in watersheds by land use change activities involves a study of the interrelated hydrologic and sediment erosion-transportation-deposition. Various surface runoff and sediment parameters at any point in the watershed in time must be determined for the assessment of the impact of the changes upon the environment, in the establishment of environmental "stress" limits, and for the design of effective and economical countermeasures to offset any damaging effects.

The problem of the assessment, however, is very complex because a large number of physical processes must be considered simultaneously and because the controlling variables in nature exhibit highly statistical properties. Presently, the integration of the component theories to realistically model the complex interrelationships between the different processes and to provide system response and prediction capabilities under different loadings is possible, in principle, through computer simulation techniques.

Numerous models have been developed, to date, for surface runoff simulation. The environmental guidelines should provide or suggest one or more acceptable simulation models for surface runoff facilities design. However, because none of the existing surface runoff models have been universally accepted as superior to others, the limitations and applicability of individual models for specific purposes should be investigated and considered before recommendation for use of a specific model is included in the guidelines.

Unlike models in hydrology, the models for sediment problems are far less advanced. The state-of-the-art on sediment erosion-transportation-deposition simulation is discussed by Fleming (14) who points out that a substantial effort in research and development is still necessary before a comprehensive model for sediment problems, especially those in which bed movement has to be considered, becomes a working design tool.

FIELD INFORMATION REQUIREMENTS

The effects of land use changes and the alterations of runoff and sediment regimes will be superimposed upon the established natural drainage systems. Information on the existing conditions is therefore required for all environmentally related drainage and sediment design aspects. The basic information needs are as follows:

1. Geographical information - topographic maps and airphotos of drainage areas.
2. Hydrologic data - water discharge hydrographs, stage information, flood occurrence and magnitude.
3. Sediment data - suspended and bed load measurement data.
4. Ice information - especially effects upon flooding, thickness of ice cover, seasonal effects, potential damages.

5. Hydraulic data - channel cross-sections, channel profile, identification of homogeneous channel sections, flow velocities, hydraulic roughness.
6. Alluvial materials' characteristics - channel bed materials, bank and flood-plain materials, sub-bed materials.
7. Channel processes - channel shifting information, bed-forms and their movement, scour.

The above abbreviated summary of information requirements must be reviewed in detail to correspond to local site conditions. As more detailed list of information needs is provided by Neill (15).

SUMMARY

This brief presents a proposal for the formulation of environmental design guidelines for the disposal of runoff and for sediment control from land development sites. It considers the function which the guidelines should serve and the format in which they should be presented. It outlines the three main categories of information which should be provided in the guidelines for the environmental design of runoff and sediment control. It presents a short list of site information requirements for the establishment of environmental safety criteria or the design of control facilities, and reviews briefly the state-of-the-art of runoff and sediment simulation modelling.

The brief emphasizes the engineering aspects of the problem. In the three categories of design considerations it discusses the design precipitation which provides factual quantitative information on the storm generated runoff to be disposed through the drainage system, the environmental "strain" limits which impose permissible ranges of runoff flow rates and sediment loads or characteristics in the environmentally sensitive parts of the drainage system, and the control mechanisms which identify various alternative methods for the environmentally safe disposal of

design runoff or in the control of sediment problems.

The approach outlined in the brief may not be unique. It may present, however, the initial step toward the formulation of environmental design code for runoff and sediment control.

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