THE CONTROL OF POLLUTION FROM HYDROGRAPHIC MODIFICATIONS

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
Washington, D.C. 20460

1973

FOREWORD

Degradation of the quality of fresh surface and ground waters caused by hydrographic modifications such as stream channel alterations or the impoundment of water is a common problem as man alters his environment. Such pollution is frequently an unintentional result associated with these activities.

The Federal Water Pollution Control Act, as amended (33 U.S.C. 1251 et seq.; 86 stat. 816 et seq.; P.L. 92-500) requires the Administrator of the Environmental Protection Agency to issue information on the identification and control of pollution caused by hydrographic modification (section 304(e)(1&2)(F)). This report is issued pursuant to that legislative mandate.

Russell E. Train
Administrator

THE CONTROL OF POLLUTION CAUSED BY

HYDROGRAPHIC MODIFICATIONS

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Preface

This report will present information including guidance for identifying and evaluating non-point sources of pollutants; and processes, procedures and methods to control pollution resulting from changes in the movement, flow or circulation of any navigable waters or ground waters, including changes caused by the construction of dams, levees, channels, or flow diversion facilities. This report is mandated in Section 304(e)(1)&(2) part (F) of The Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500.

An examination of the U.S. Senate Committee on Public Works Report which accompanied S. 2770 and the Report of the Committee on Public Works of the U.S. House of Representatives which accompanied H.R. 11896 was made to guide the report preparation. This legislative history was used in conjunction with the specific language contained in the law. (Public Law 92-500).

The type of informational guidance and procedures intended by the Senate Committee are described as "...the impact on water quality of hydrographic modification work,..." (p.49). The term water quality is defined by the

Senate Committee are described as "...the impact on water quality of hydrographic modification work,..." (p.49). The term water quality is defined by the Committee as "...to refer to the biological, chemical and physical parameters of aquatic ecosystems, and is intended to include reference to key species, natural temperature and current flow patterns...", (p.51). Thus, changes in flow patterns through channel modification, reservoir construction and other projects must be identified and if possible, methods to reverse or alleviate damages described.

The descriptions in the House of Representatives Committee Report were not as extensive as the Senate Committee's discussion for this section. The report directs the Administrator to be "...diligent in gathering and distribution of the guidelines for the identification and the information or processes, procedures, and methods for control of pollution from such non-point sources as... natural and manmade changes in the normal flow of surface and ground waters."

The pertinent part of the Act reads as follows: Sec 304(e)

"The Administrator...shall issue...within one year...information including (1) guidelines for identifying and evaluating the nature and extent of non-point sources of pollutants, and (2) processes, procedures, and methods to control pollution resulting from...(F) changes in the movement, flow or circulation of any navigable waters or ground waters, including changes caused by the construction of dams, levees, channels, causeways, or flow diversion facilities."

Part (1) requires development of informational guidelines for the identification and evaluation of pollution effects. Such an evaluation does not require EPA to identify and evaluate but only to provide guidance for such. Part (2) requires identification of available processes, procedures and methods for relieving or ameliorating the pollution resulting from changes in flow induced by stream hydrographic modification. The Act does not require the EPA to evaluate such methods, but only to identify those potentially applicable to control pollution from such hydrographic modification.

In the process of developing this report, potential problems are identified for each hydrographic modification technique which may not be applicable to many areas of the

country or which may occur only infrequently. In comprehensively evaluating the pollution effects of a project, many factors must be considered that investigation ultimately determines do not affect the environment. Therefore, only a few of all possible detrimental factors may need mitigation for any specific project.

Section 304(e) of Public Law 92-500 also requires the publication of additional material for the control of pollution from hydrographic modification from time to time after the initial report is published. For some areas which are not addressed by this report or for which additional coverage is necessary, supplementary reports will be issued.

I. Guidance for the Identification and Evaluation of Channel Modification Projects

Introduction

The definition and purpose of channelization projects are to increase the flood flow conveyance capacity of water courses through rural or urban flood prone areas, or to facilitate the drainage of what may be considered excessive surface and ground water from lands which can be used as other than natural wetlands.

This discussion will be limited to aspects of channelization where actual in-channel modifications occur. Consideration of other aspects of channelization will be covered under separate headings such as reservoirs.

The type of channel envisaged in this discussion is the small stream which frequently floods either urban or rural areas causing significant damage. In general such streams would be too small for commercial navigation purposes but would be of recreational benefit for canoeing and other activities. Also included are those drainage projects used

to render low-lying lands usable for agriculture or construction of suburban developments.

Current Governmental Involvement

Various governmental agencies, private groups and individuals are involved in designing and constructing channelization projects.

The Federal agencies principally concerned with channelization projects on a whole basin scale or major portions of basins are the Soil Conservation Service of the Department of Agriculture, U.S. Army Corps of Engineers of the Defense Department, the Bureau of Reclamation of the Interior Department and the Tennessee Valley Authority. Other agencies that may be involved on a smaller scale include the Federal Housing Administration in the Department of Housing and Urban Development, Veterans Administration and Federal Highway Administration of the Department of Transportation.

Contacts with the major Federal construction agencies should yield listings of projects completed, under planning and/or design and those being requested by various local governments or private interest groups. Such contacts

should provide information about the major projects in a given State or planning area.

State and local agencies involved in channelization projects are more difficult to identify in this type of report because of the various names such organizations use from State to State and locality to locality. Often these agencies will be identified in project reports prepared by the Federal agencies as participants in a given project. Organization names frequently used include a State Soil and Water Conservation Committee, Soil Conservation District, Drainage District, Watershed District, Conservancy District, Flood Control District or Irrigation District. These organizations provide local support and frequently partial funding of projects constructed under the auspices of a Federal program.

State and local governments frequently are directly involved in the financing of projects either on a partial basis conjunctively with Federal Agencies or in totality for Federally ineligible projects.

Privately constructed projects are even more difficult to identify. Usually, these projects are small and limited

to one individual's or at most a few individual's property These projects would generally be for drainage purposes to make land usable for agriculture or housing development. However, the effects of such projects may cause significant water quantity and quality changes in a given area. These projects may be located by examination of Department of Agriculture aerial photographs, examination of construction permits, inspection of recently constructed housing subdivisions or by contact with large housing or heavy equipment contractors in a local area.

Current Practices

Current practices can generally be subdivided into those principally flood control oriented or those principally drainage oriented. In combined projects, design is frequently dictated by flood control requirements. Several alternatives are generally available to accomplish the goals of a given project. Current practice is generally to use the method with the least cost to obtain the design objective unless some compelling reason overrides the economic justification.

CLEARING AND SNAGGING

Clearing and snagging operations may be used as an independent technique for increasing channel hydraulic capacity or it may in essence be a maintenance technique for maintaining a previously improved channel. The basic operation is the removal of obstructions from the channel which impede flow directly, which increase hydraulic friction, or which present obstructions that accumulate debris carried by the stream during high water conditions and thereby reduce the available area of flow.

Clearing and snagging operations are frequently used following high water to remove accumulated debris, logs, rocks, etc. and restore the hydraulic capacity of the channel. Equipment used consists of bulldozers, front loaders, cranes, draglines, clamshells, chain saws, and winches to physically remove the obstructions.

Although less expensive than channel resectioning for increasing the hydraulic capacity, clearing and snagging is also less effective. For restoring hydraulic capacity in a channel it may be the most efficient technique. However, improvements may be short lived. In certain types of basins

channel obstructions can re-occur within relatively short spans of time.

CHANNEL EXCAVATIONS

Channel excavating is principally of two types. In many cases the existing channel is enlarged and reshaped to increase hydraulic capacity. In other cases the existing channel is abandoned and a new channel is excavated. New channel construction has frequently been used for irrigation canals where no previous channel existed.

The design configuration and construction of the channel excavations depends on the purpose and physical setting of the new channel. In urban areas where land values are high and flood damage losses high, channels are frequently designed with a rectangular configuration to minimize land requirements and are concrete lined to achieve maximum hydraulic efficiency. In rural settings channels may be designed wider with a trapezoidal shape. Side slopes are determined by soil stability or by the final covering used such as grass, rip-rap or other channel liners. In situations where channel resectioning has resulted in excessively steep hydraulic slopes that cause excessively high water velocities which erode the channel bottom or side

slopes, grade control structures are used at frequent points along the channel to dissipate energy. An erosion resistant lining such as concrete or rip-rap may also be used.

The technique selected for excavation varies with the project size, whether "wet" or "dry" construction is possible, and the method of disposing of the spoil. In "dry" construction situations conventional drag lines, power shovels, clam shells or front end loaders are used; in "wet" construction situations some method of dredging is usually employed. The dredging method used depends on the material to be dredged.

CHANNEL REALIGNMENT

The purposes of channel realignment are principally to increase the hydraulic conductance when sufficient capacity is unavailable from the natural configuration and to eliminate the meandering of the stream over the flood plain. Without proper design, meanders frequently result in instabilities which cause changes in the channel section and which result in poor hydraulic efficiency. By realigning the channel into a straighter and therefore shorter length, costs of a channel improvement may be reduced when compared with resectioning the existing channel.

Physical constraints on realignment are existing roads and bridges and the existence of available land for right of way. Other constraints include costs, stability and environmental damage. Channel realignment is complicated by the problem of excavated material disposal and the destruction of the fish and wildlife habitat available in the old channel. Frequently, these "oxbows" are intentionally maintained with sufficient flow or backwater to maintain the habitat.

FLOODWAYS

Floodways are flow areas which are constructed to convey floodwaters around a protected area. These flow areas may be formed by protective dikes or be a separate channel. Floodways are constructed in lieu of modification to the existing channel or in conjunction with channel hydraulic improvements.

Such channels are designed to be dry until the water stage in the stream reaches a predetermined flood level and then to convey (in conjunction with the existing channel) flows greater than this amount. When flood flows recede, water is diverted from the floodway back into the principal channel.

Floodways that cut-off meanders are shorter than the natural channel and have greater hydraulic efficiency. Flood stages up-and-downstream may be affected by the use of such supplemental channels.

Since floodways are dry during normal stream flows, they may be used for other purposes such as pasture or as parkland. Maintenance is required to remove new growths of trees and brush and to maintain grass cover to minimize erosion during flood periods.

A flood control project using floodway channels requires more land than a channel resectioning project because of the dual channels and is therefore more expensive. Maintenance costs also can be high. Maintenance cost include removal of regrowth in the floodway and if non-permanent overflow devices are used, replacement of these periodically.

The principal benefits as related to water quality are the preservation of the natural fish and wildlife habitat in the natural channel and the maintenance of the natural appearance of the stream.

RETARDING BASINS

A retarding basin consists of a dam with an ungated outlet. The discharge of water from the dam is related to the height of water stored in the reservoir.

The purpose of these structures is the temporary storage of storm water. The stored water is gradually released when the channel capacity exists to pass the flow. The stream hydrograph reflects a reduced stage of increased duration. Flooding downstream is consequently reduced.

Consideration of such structures as part of a project is influenced by actual construction costs, land acquisition costs and the existence of acceptable terrain. The use of these basins rather than channel resectioning is preferred and incorporated in basin drainage plans when feasible.

DRAINAGE DITCHES

Drainage ditches are included in channelization project planning but seldom dictate the design channel capacity. Channel capacity normally is controlled by flood flow conditions. Drainage ditch projects usually involve

deepening previously constructed ditches or in constructing new ditches.

Where ditches are used to lower the water table and enhance drainage, the dry weather stream flows may be reduced in the main channel if the ditching project covers a sufficiently extensive area. Some increase in main channel peak flows may occur because of better interception of surface run-off and the more efficient hydraulic conveyance of such run-off than previously existed.

The depletion of ground waters and subsequent reduction of stream flows can impair quality in both surface and subsurface waters. In addition to the reduction of fish and wildife habitat, there is a decrease in dilution water for organic materials and a modified seasonal water temperature pattern. Ground water infiltration tends to increase stream temperatures during the winter season and decrease stream temperatures during the summer-season.

Sources of Pollution

Following the initial vegetative recovery after the various channel modifications are constructed, both direct and indirect sources of pollution are identifiable.

Realizing that the main purpose of channelization projects is either to increase hydraulic capacity to convey flood waters thus protecting adjacent property; or to provide drainage of land to increase its economic usefulness, the effects in terms of environmental pollution are apparent.

SCOUR FROM BOTTOM AND BANKS

In order to enhance the hydraulic efficiency of channels by resectioning, realignment or even clearing and snagging, the channel roughness is reduced. Such a reduction in roughness decreases friction losses and thereby increases the velocity of flow. If the channel is not properly designed, the increased flow velocities may exceed the stability velocities of the bottom or bank materials and cause erosion or scour. This in turn degrades the channel and furnishes sediment for stream transport, destroys natural habitats and detracts from the aesthetics of the stream.

Perhaps the worst offender in this regard is channel straightening and realignment. This process reduces channel lengths but not the decrease in elevation over which the water is lowered in traversing a stream section. The net result is a substantial increase in the stream gradient with

resulting substantial increases in stream velocities. Without extensive control measures for stabilization and the use of grade control structures, channel degradation can be extensive.

INCREASED POLLUTION FROM THE USE OF FLOOD PROTECTED AND DRAINED LAND

Following the implementation of both flood control and drainage projects, extensive amounts of land become available for higher economic production. Land formerly used for pasture or low return agricultural crops can be converted to high yield agricultural crops. Within municipal areas, property values are increased and uses with more economic return can be developed. With the increased land use there is potentially environmental degradation.

Enhanced agricultural use is accompanied by increased fertilizer, herbicide and pesticide use and by increased land tillage which may increase the erosional soil loss. The by-products of this agricultural use drains to the stream and causes various amounts and kinds of water quality impairment. The kind and amount of such pollutants entering the stream would be determined by the soil type, land slope and cropping practice.

Channelization projects which provide flood protection within urban areas frequently include the provision of lined channels. The effects on the water environment of these channels are both the destruction of fish and wildlife habitat and the destruction of aesthetic qualities.

ELIMINATION OF FISH AND WILDLIFE HABITAT AND AESTHETIC QUALITIES

The various channelization practices have varying effects on fish and wildlife habitats. In general, the more extensive the modification structurally the more damage is caused to habitat areas. For example, concrete lining of channels eliminates habitat areas for practical purposes whereas at the other extreme, clearing and snagging may not have a detectable effect. The effects of the project can only be determined by the use of before and after surveys designed to detect both drastic and subtle changes.

Aesthetic values for streams depend a great deal on the beholder. Swamp habitats may be quite disagreeable to a non-naturalist whereas parkland or pasture beside an improved channel may appear quite pleasing. To this extent aesthetics may be an acquired attribute in conjunction with strictly innate appreciation. Aesthetics is the most

difficult environmental factor to quantify and it may require the opinion of a representative cross section of the population before classification of a project as aesthetically acceptable.

Types of Pollutants

This discussion will be limited to the common pollutants both contributed directly and indirectly. Such pollutants are the common denominators to be anticipated from the majority of projects.

DIRECT EFFECTS

Sediment

Sediment is perhaps the most ubiquitous of all pollutants associated with channelization. The most pronounced effect on sediment occurrence and concentration is during the construction phase of the project. With bare soil banks and a non-stabilized channel, the natural stream flow itself and any rain that occurs flushes sediment into the stream discoloring the water and making it turbid. Following stabilization however, the stream frequently remains more turbid than before the project was constructed.

Every stream has an ability to naturally transport certain amounts of sediment. The amount transported is termed sediment load and is a definable stream characteristic. When channel hydraulic characteristics are changed by constraining the channel to a fixed location, by realignment, or by other means, the velocity of water flow is changed and consequently the ability to transmit sediment is likewise changed.

The effects of increased sediment on water quality are to reduce light penetration, to periodically blanket fish spawning areas, to periodically blanket and suffocate aquatic insect larvae used by fish as food, to create shoaling and instabilities in the channel itself, and to cause problems with sedimentation in unimproved channel sections downstream from the project section. In addition to these problems which directly affect instream water quality, increased costs are realized by water users including water suppliers and irrigators. Additionally, aesthetic quality is reduced to a substantial degree.

Thermal

The design of channelization projects for flood prevention requires increased channel dimensions. Because

of the enlarged channels, the dry weather flow is directed near the center of the channel. The stream flow is thus deprived of shade provided by trees along the banks and is exposed to solar radiation which heats the water. Previously in the natural channel, the presence of such trees along the banks provided shade for the flowing water and helped moderate stream temperatures.

In addition to reducing temperatures during daylight hours, the insulating effect of these trees is removed and night time temperatures are reduced to a greater extent than previously. Thus, a greater diurnal variation in temperature can result from a channelization project.

The temperature effects on fish and other aquatic life are caused by both the absolute temperature itself and the temperature variation. Both increased maximum temperatures and increased variation can have detrimental effects on fish and other aquatic life during various stages of their life cycle. Specie selection, availability of food, attendant life cycle chemistry and water quality changes are all phenomena that are temperature affected.

Water quality is directly affected by increased temperature. Dissolved oxygen is removed more rapidly by

temperature. Dissolved oxygen is removed more rapidly by temperature-mediated bacterial oxidation of soluble and suspended organic materials. This problem is compounded by the reduced solubility of oxygen at higher temperatures so that a resulting decline in stream dissolved oxygen concentrations results. Decreased dissolved oxygen concentrations stress aquatic life dependent on this constituent.

Movement of Pollution Effects Downstream

In channel relocation or realignment projects where channel lengths are substantially reduced, the effect of increased water velocity can be pronounced. One effect of increased velocities on surface water quality is to increase the length of stream affected by pollutants whose effects are time dependent. The organic materials in discharged wastes and the drainage of natural organics from swampy areas along the stream are bacterially degraded and oxidized in the course of moving downstream. With an increased water velocity these materials move much farther in distance for the equivalent period of time required for completion of the biochemical reactions. Thus the effects of reduced dissolved oxygen levels extends farther downstream than previously.

In the case of dissolved oxygen the effect of extending the reaction over a greater channel length may be beneficial. The increased water velocity also increases reaeration which counteracts the decrease in dissolved oxygen concentrations caused by biochemical oxidation reactions. This effect may be sufficient to prevent dissolved oxygen concentrations from decreasing to previous low levels and thereby enhance water quality.

In contrast, the effects on feces-associated bacterial levels downstream from a discharge would be to expand the distance over which a health hazard would exist. The die-away reaction for these bacteria is also time related. The extension of such a health hazard is detrimental to water quality.

Increased water velocities also are capable of transporting increased sediment loads which may be deposited in non-channelized areas downstream. The phenomenon of sediment deposition tends to migrate upstream clogging channels and defeating the channelization improvement unless removed during maintenance operations.

In addition to simply transporting more sediment, increased velocities will, if large enough, make streams

more aggressive in eroding channels and stream banks which destroys much of the usefulness of the stream for other purposes.

Fish and Wildlife Habitat Alteration

Almost any modification of a channel alters the existing habitat for fish and wildlife. Not all such changes are detrimental however, provision of water storage for example may provide increased habitat areas but perhaps for a different than pre-project biological assemblage.

Most in-channel modifications do remove obstructions that are used by fish for protection from predators, for fish food habitats and for backwater breeding areas. Removal of trees and brush along stream banks removes protective cover and food sources for various water-related wildlife.

Many of these effects can be mitigated by incorporating proper factors into project design. For example, maintenance of water in cut-off oxbows helps retain available fish and wildlife habitats.

INDIRECT EFFECTS

Destruction of Aesthetics

Channelization projects have frequently been criticized for the destruction of aesthetic values of natural streams. The creation of geometrical shaped channels with highway-type alignment is not conducive to aesthetic appreciation by naturalists or the general public. It is possible to mitigate much of the aesthetic destruction by use of proper design techniques. For example, those techniques which only alter one stream bank or which provide a replanting program to establish vegetation similar to that existing prior to construction can be used. Other similar measures can be included to minimize the reduction of aesthetic values.

It should be mentioned also that aesthetic values can be enhanced for many people by various channelization-related projects. In many instances public accessibility to water courses is improved and parks or other recreation facilities can be incorporated into the right-of-way acquired for the project.

In-stream techniques can also be applied to maintain fish and wildlife habitat. Construction of pool and riffle

areas is one technique available. Use of more natural alignment and other design features are available to project planners.

Hydrology

Many of the effects on basin hydrology of a channelization project can be anticipated. The major effect is to increase the hydraulic capacity of the principal channel and the smaller channels which drain into the principal channel. The principal effect of this change is to move water more rapidly through the channel. Downstream from the channelization project these increased flows may cause increased flooding by shortening the time of concentration of peak runoff following heavy rains.

Drainage projects may aggravate this problem by allowing higher valued operations on the drained land. If the higher valued use is urbanization, then the paved areas, including roof areas, drain water to storm drains which convey water to the water course even more quickly than previously occurred and increase peak flow rates and subsequent flooding.

Drainage facilities also tend to lower the water table during wet periods of the year and deprive streams of the critical base flow required during dry weather periods of the year.

Methods of Pollutant Transport

The methods of pollutant transport in channelized stream basins are essentially the same as in the unaltered stream basin. Certain transport mechanisms are either increased or decreased by the effects of the alteration.

SEDIMENT LOAD

As indicated previously, sediment load is the amount of sediment characteristically carried by a particular water course. It consists of suspended and bedload sediments. Bedload sediment is sediment that is transported in a stream by rolling, sliding, or skipping along the bed very close to it; that is, within the bed layer. Sediment load is related to several factors but principally the hydraulic characteristics of the stream and the soil and geologic characteristics of the stream channel and drainage basin.

The effects of a channelization project is generally to cause an increased amount of sediment load. Improved hydraulic conveyance produces increased water velocities which in turn increase sediment transport capability. If the streambed is improperly stabilized following construction, this increased sediment load can be dramatic. Even though proper stabilization techniques are used, concentrations of sediment generally increase except in the special case of complete channel lining with concrete or other paving materials. Downstream from the channelization section, these materials can settle and fill the channel with excess sediment destroying hydraulic efficiency and stream biology and increasing the potential for stream meander formation.

Indirect effects of channelization are to enhance land for higher economic uses such as increased agricultural production or urban and commercial development. Many of the pollutants generated by these new uses become adsorbed with soil grains. Such organics as pesticides are particularly susceptible to such adsorption. When these soil particles are flushed into the stream, the adsorbed materials are likewise carried along for later deposition downstream. Following such deposition, these materials can enter the life cycle of the stream. Biological concentration in the

aquatic food chain may cause significant ecological disturbances.

The increased sediment load can be visible as increased turbidity of the stream water. The principal effect is to decrease the aesthetic value of a stream. On larger streams used for water supply purposes, increased turbidity causes increased treatment costs for potable or industrial water users.

Excess channel scour can cause increased sediment loads and downstream deposition, adsorbed pollutant transport, and direct detrimental effects to water suppliers and stream aesthetic values.

DIRECT DRAINAGE

The increased uses of land adjacent to streams following the provision of flood protection and drained arable land provide sources of pollution which directly drain into the water course. Many of the pollutants arise as the normal product of urbanization or farming practices. Others arise because of the removal of natural mechanisms which trap contaminants directly or provide detention time for the adverse effects to decay to acceptable levels.

With time, many pollutants are degraded into innocuous substances. Nature provides detention time in natural backwaters and in sluggish meandering streams. Pollutants in solid form or which naturally flocculate and settle are assimilated and may be destroyed in the bottom sediments by microbiological activity. Phosphorus is chemically removed as an insoluble salt while nitrogen and sulfur compounds are removed by conversion to gaseous forms which evolve to the atmosphere. Following channelization and drainage projects these natural places of detention are by-passed or removed which has the effect of increasing pollutant concentrations in the flowing waters. The effects of these pollutants are then transferred downstream decreasing water quality while in passage.

SOLAR RADIATION

The light provided by the sun provides the energy for the biology of natural waters. The so-called "food web" begins with primary production by algae which are capable of photosynthetic production and continues up through the consumer species including aquatic insects and fish. Too little solar radiation produces too few algae, little primary production, and sparse fishery. Too much sunlight heats the water, provides a competitive advantage for

undesirable biological species and an unsatisfactory fishery. The effects of solar radiation are both on the water quality itself and on the biological response and effects to that water quality.

In many streams light penetration extends essentially to the stream bottom and provides energy for attached algae which provide both food and oxygen for animal life. In streams characterized by alternating pool and riffle areas, these productive areas are near the edge of the stream extending toward deeper water until the incident light is extinguished to less than photosynthetically usable levels. Following channelization, the stream channels are frequently made deeper reducing light penetration from former levels. Thus the habitat is altered and a different biological assemblage develops. Frequently, the new assemblage is composed of less desirable species.

Thermal effects become evident when shade trees and brush are removed allowing both more time and increased surface area of exposure to sunlight. Coldwater species of fish can not tolerate the elevated water temperatures and are replaced by warm water species. The direct effect of increased solar radiation may indirectly change the stream fishery.

Magnitude and Variation

Available statistics for defining the national magnitude and variation of channelization projects indicates that perhaps 200,000 miles of waterways have been altered in the last 150 years in the United States. Since the initiation of Federal projects in the early 1940's planning for and development of about 34,240 miles of waterways in 1,630 projects have been initiated under the Federally-assisted local protection and small project programs of the U.S. Army Corps of Engineers and watershed programs of the Soil Conservation Service. Additional projects have been initiated by the Bureau of Reclamation, the Tennessee Valley Authority and other Federal, State and local agencies.

The Corps of Engineers have assisted in 889 projects of which 47 percent involve channelization and 53 percent involve levees. Of these projects 6,180 miles (56%) are completed, 3,896 miles (35%) are under construction and 1,001 miles (9%) are planned. The median size for these projects is about 4 miles with two thirds under 5 miles and 80 percent less than 10 miles.

The Soil Conservation Service assisted in 558 projects of which virtually all involved channelization. Of these

projects 4,209 miles (25%) were completed by 1971 and 12,426 miles (75%) still remaining to be completed. The median size of the projects is about 18 miles with 38.7 percent less than 10 miles and 24 percent less than 5 miles.

COUNCIL ON ENVIRONMENTAL QUALITY REPORT

The Council on Environmental Quality's report (Ref. 1) discusses 42 different projects of 4 different Federal agencies. Each project was analyzed among other things for the basis of project formulation, physical effects of the completed project and the biological effects on the aquatic and terrestrial systems. The methodology used in preparing this report is an excellent guide for those evaluating additional projects.

ENVIRONMENTAL ASSESSMENT REPORTS

Since the enactment of the National Environmental Policy Act of 1969 (Public Law 91-190) each Federal agency participating in a proposed channelization project that significantly affects the quality of the human environment must prepare an environmental impact statement. These statements must assess the following for the project: (Title 42 U.S.C., Sec. 4332)

"(i) the environmental impact of the proposed action

(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented

(iii) alternatives to the proposed action

(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long term productivity, and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented."

In accordance with NEPA all proposed projects significantly affecting the environment have such reports prepared. These reports are made available for review and comment in draft form. Final reports incorporating comments of reviewers are submitted to CEQ and are available upon request from the preparing Federal agency.

The environmental effects of a project are comprehensively covered in these reports. Whether or not the agency is able to mitigate the adverse effects identified in the environmental assessment, discussion of these effects is included. For most projects these assessments are invaluable in evaluating a project.

It should also be pointed out that several States have also enacted statutes patterned after NEPA which require an environmental impact statement before the expenditure of State funds or in some cases before permits are issued to private interests for project construction.

Prediction Methods

Methods to predict the effects of channelization projects will not be directly presented in this report. A tremendous volume of literature exists discussing the effects on water quality caused by various physical modifications of streams. Several sources of information will be mentioned as convenient and comprehensive starting places for project evaluation including the mitigation as much as possible of the inevitable adverse effects.

The CEQ report on channel modification (Ref. 1) presents the results of extensive biological investigations conducted by the Philadelphia Academy of Natural Sciences. Chapter 5 of Volume I of this report entitled, "Effects of Channel Modifications on Fish and Wildlife Resources, Habitat, Species Diversity, and Productivity" directly addresses the biological effects observed in 21 channelization projects analyzed. The same or similar effects therefore are to be anticipated in other projects under comparable conditions. Discussion includes the effects of channelization projects which cause erosion, consequent sediment accumulations and unstable stream beds, remove solid substrates, or decrease light penetration which may affect the biological population by disturbing the number of species, the populations of each, or the productivity of the stream, and alternatives to channel construction which will avoid adverse effects altogether.

Methods to predict the effects of channelization projects are included in a volume produced by the Soil Conservation Service entitled, "Planning and Design of Open Channels" (Ref. 2). This document comprehensively presents available information on channel design including the estimation of anticipated flows; location, alignment and hydraulic design; and channel stability design. A recently

added chapter 7 (1971) includes environmental considerations. The technical methodology presented in this document is sufficient to predict the effects of the hydraulic changes caused by a channelization project including any increases in sediment transport.

Increases in the stream temperature and the diurnal variation are not so readily predicted. These calculations can only be made by estimating the amount of protective shade removed, changes in depth and changes in channel length in conjunction with tables of solar radiation values. Such calculations will probably only yield approximate semi-quantitative amounts of change.

The best technique for evaluating potential effects of channelization on a stream is the field survey of a nearby stream which has undergone the changes projected for the stream of interest. Comparison of this type of information establishes a more rational basis for predicting the various physical, chemical and biological changes to be anticipated. In the absence of such a situation, predictive techniques from the sources suggested above and in the companion report entitled, "Methods, Processes and Procedures to Control Pollution Resulting from Channel Modification Projects" are available for use.

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II. Methods, Processes and Procedures to Control Pollution Resulting from Channel Modification Projects

This discussion will be limited to those design changes in the actual channel modification project that can be incorporated to enhance and mitigate undesirable by-products. A brief discussion will be directed to consideration of alternatives to channel modification such as flood plain zoning regulations. Discussion of other structural alternatives including upstream storage reservoirs are covered under separate headings.

Design Modifications to Minimize Adverse Channelization Impacts

CHANNEL ALIGNMENT

Channel improvement projects generally are designed to follow existing stream alignment with the exception of situations where stability or cost factors force an alternative course. Also, changes are often made to provide larger parcels of flood free land. In stream sections passing through highly erodable soils for example, an

alternative course may be desirable if an alignment through more stable soils exists. Relocation may also be desirable to avoid passage through otherwise valuable lowland areas which serve as fish and wildlife habitats.

In the design for channel construction the alignment generally should follow a natural pattern which should consider the type of existing stream, the required hydraulic capacity and comparison with upstream and downstream sections of the particular water course or a similar nearby water course. The use of such design techniques avoids the unnatural appearance of a modified channel thus improving aesthetic appeal. In many cases such design may aid channel stability by not changing the channel gradient excessively.

Special features along the stream should be protected to enhance aesthetic appeal. By proper design of channel alignment the existence of particularly striking features can be preserved and perhaps enhanced which adds to the public appreciation of the projects. Design should incorporate provisions to protect these features including

special stream and streambank stabilizing measures, land treatment methods and grade adjustments.

CHANNEL CAPACITY

Channelized streams should convey water discharges ranging from base flow to the design flood flow without damage to the channel itself. The low flow channel cross section should approach the natural stream condition. The bottom width and side slopes can be designed to simulate the natural channel so that it will blend with upstream and downstream sections of the natural channel and avoid a monotonous appearance. At bends, the channel side slope can be steepened on the outside of the channel bend and flattened on the inside to simulate natural waterways. Use of naturally occurring rocks and boulders can be placed at selected points for aesthetic appeal, energy dissipation and fish-habitat development. The bottom width of the channel can be varied in conjunction with the channel slope to develop pool and riffle areas to aid fish and wildlife yet maintain hydraulic capacity. The use of rip-rap made from native rock improves the aesthetics, offers hiding places for crustaceans, small fish and other aquatic biota, and gives the banks and channel bottom stability in an otherwise erosive channel. Inclusion of these devices however

requires the careful attention of the designer, the on-site inspection personnel and especially the contractor.

CHANNEL GRADE

Within the topographic constraints of a given project, the channel gradient can be varied between stream reaches to achieve naturally appearing pool and riffle areas, cascades or other such features. To accommodate the existence of highly erosive soils in certain reaches, gradients can be flattened. Conversely, in erosion resistant soils gradients can be steepened. All such changes must remain within the natural topographic constraints of channel elevations at the beginning and end of channel sections. The use of such grade variations not only enhances aesthetic appeal but increases protection against meander development, increases channel stability and minimizes sediment from channel and bank erosion.

Adjustment of the channel gradient to develop pool and riffle areas can also provide increased atmospheric reaeration capacity in the stream. Reaeration increases with increased velocity and decreased stream depth. Riffle areas provide additional turbulence which also tends to increase reaeration. The increased dissolved oxygen

supplied by the increased reaeration improves the habitat for fish and aquatic life. It also provides additional capacity to satisfy the demands exerted for the oxidation of naturally occurring or man-contributed organic material before damage to aquatic life occurs.

SPOIL PLACEMENT

The on-site placement of excavated spoil material should be accomplished so as to minimize the amount of clearing required or other land disturbing activities. Spoil should be placed in such a fashion so as to minimize the potential for the erosion of the material back into the stream. Placement of spoil should also be made so as to minimize the adverse effects on wildlife habitats and may be concentrated at selected locations along the stream section to accomplish this goal. Through proper re-vegetation and planning the spoil may be used to create scenic overlooks and other contrasting features which may enhance the aesthetic appeal of a project and avoid the monotony of continuous spoil banks beside the stream.

The amount of spoil can also be minimized by the use of one-sided or single stream bank construction where appropriate (Figure 1). Other spoil reducing measures can

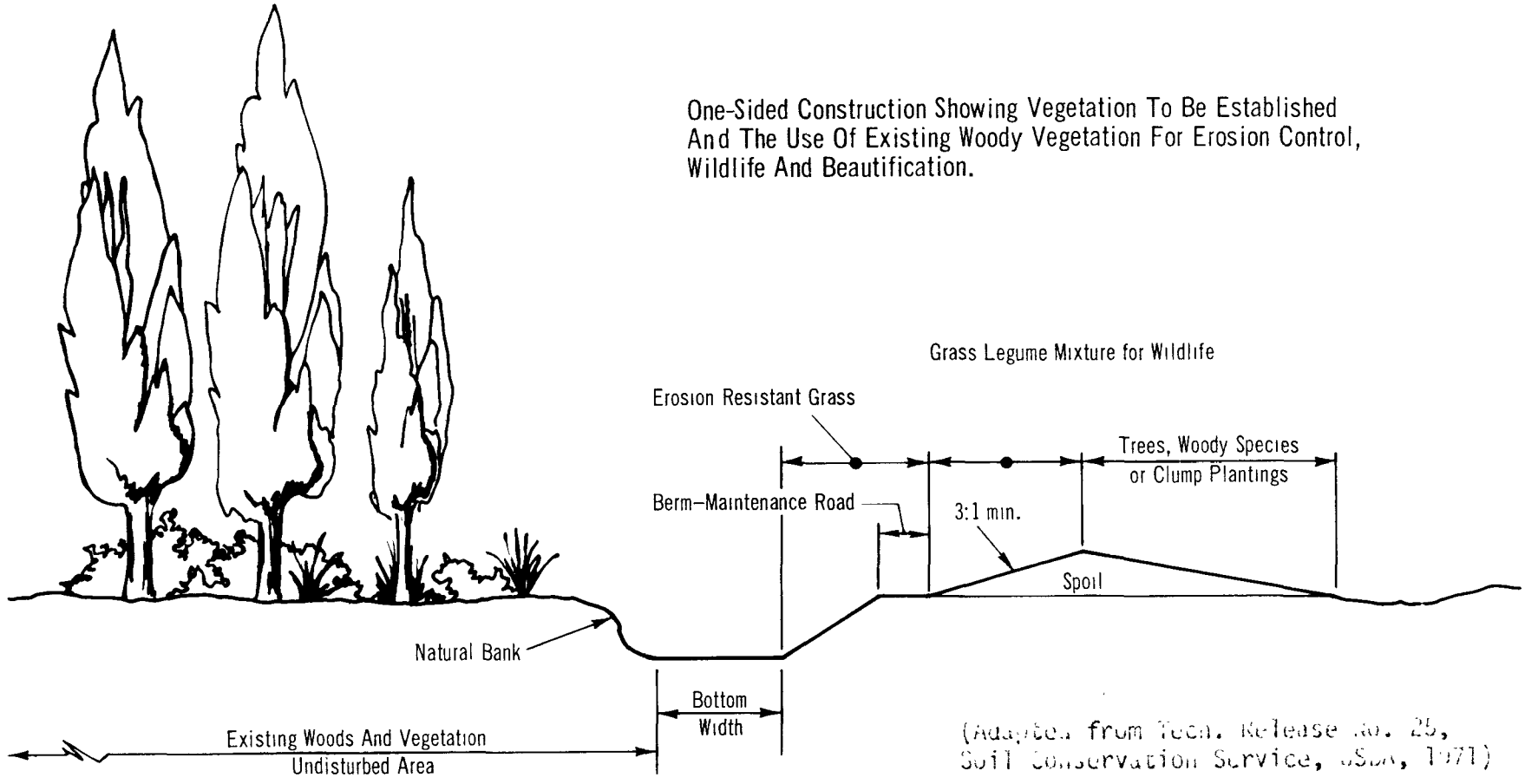


Figure 1 One-sided Channelization Construction

be included by the use of non-structural alternatives totally or partially in lieu of actual channel modification.

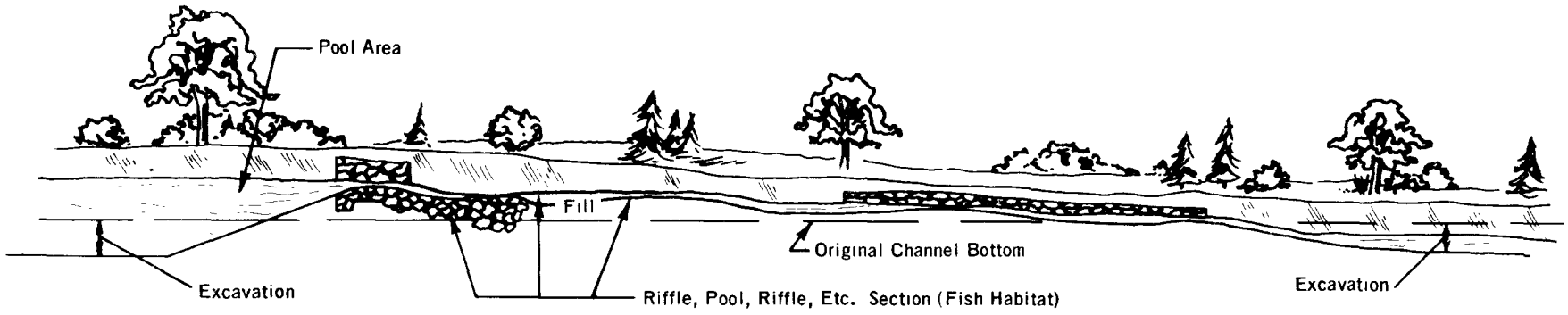
STRUCTURAL MEASURES

Structural measures can be included in a channel modification project to maintain stability by alleviating problems of excessive grade. Structural measures can also be applied to side stream entry points to control the introduction of sediment, debris or other pollutants or effects.

For channels with excessive slopes which would otherwise erode and produce sediment, typical structual measures include drop structures, chutes, steepened rock-armored sections and cascade structures. Each of these structural modifications provides resistance to high velocity flows and allows the use of stable, moderate gradients upstream and downstream.

For channels with sufficiently flat gradients so that channel and bank stability are not problems, designs can be incorporated using the pond, riffle and pool sequence. The inclusion of ponding provides sufficient excess elevation that succeeding pool and riffles can be maintained. Besides protecting fish habitat, aesthetic appeal is increased (Figure 2).

Side channel structures include pipe drops, lined chutes and drop spillways. These structures can be used in conjunction with sediment basins and debris traps to retard the input of these materials into the main channel. The principal purpose of these structures is to prevent the loss of vegetation from stream banks at the point of entry, slumping of the main channel bank or the cutting of a deeper tributary channel. All of these effects contribute sediment to the main channel and reduce channel stability.



CHANNEL PROFILE – BUILT IN GRADE AND BOTTOM CONFIGURATION

(Adapted from Tech. Report No. 25,
Soil Conservation Service, USDA, 1971)

Figure 2 Channel Profile - Built In Grade and Bottom Configuration

VEGETATION

The early re-establishment of vegetative cover following in-channel modifications is most important to prevent extensive erosion and damage to the hydraulically improved channel. The selection of the plantings should incorporate both an initially quick growth to stabilize the bank and the subsequent development of a cover which will blend with or simulate the natural cover.

Use of proper erosion resistant cover will keep sediment concentrations and adverse water quality impacts to a minimum. Proper selection of trees and bushes will enhance biological productivity within the stream itself and the associated wildlife. Shade provides against excessive solar radiation which helps maintain temperatures within allowable tolerances and insulate against excessive diurnal thermal variations.

Use of acquired right of way for parks, hiking paths or the provision of access for fishing is also enhanced aesthetically for public use by the use of suitable re-vegetation practices.

EFFECTS ON GROUND WATER

Any channel modification may alter the natural circulation of the ground water. Natural recharge to the ground water may be increased or decreased depending upon location, depth, and other characteristics of the new channel. Thorough investigation of possible effects on both the quantity and quality of ground water should be made before undertaking a channelization project.

An important distinction in terms of their effect on ground water quality is whether channels are lined or unlined. A lined channel, constructed of an impermeable material such as concrete, may prevent the natural interchange of streamflow with ground water. Such a lining may be required to provide flood protection in an area with unstable soils.

In areas where such recharge is important, water can be artificially recharged to the ground water. This can be done by installation of ditches or basins for artificial recharge in the vicinity of the lined channel. High-quality water diverted from the stream or derived from some other source and released into these structures would infiltrate

to the ground water and thus compensate for the loss of natural streambed recharge.

In unlined channels, a primary effect is that produced by changing the water table elevation in the area adjacent to the channel. If a channel is dredged in an area where the water table is close to the land's surface, the new channel acts as a drain and lowers the water table. If the water table elevation needs to be maintained at pre-channelization levels, the effect of lowering the level can be negated by lining the channel with an impermeable material. This will prevent dewatering of the upper portion of the aquifer and hence maintain the original natural conditions of ground water quality. Some drainage to prevent uplift of the channel lining may be necessary.

There may be some loss of bank storage of water even with unlined channels if the hydraulic characteristics are improved and the gradient steepened, resulting in higher velocities. The effects on ground water quality are the same as for lined channels. Artificial recharge can be used to compensate for the loss.

Unlined channels may allow polluted water to enter the ground water if there is no impermeable barrier between the bottom of the channel and the ground water body.

In some coastal areas natural channels have been deepened or new channels excavated. These have sometimes cut deeply into or through the underlying clay formation which originally acted as a natural barrier and prevented the downward movement of saline water into the underlying freshwater aquifers. Serious ground water pollution has resulted. Such channels should be located, designed, and constructed with care so that the natural barriers to saline water intrusion will not be impaired. If this is not possible, the channels must be artificially lined.

Structural Alternatives to In-Channel Modifications

In many cases in-channel modifications can be reduced substantially or avoided altogether by the use of various alternative designs involving construction of off-stream facilities. Such facilities as levees, floodways, retarding basins, building flood proofing and land treatment can be incorporated into projects to avoid actual channel modification.

LEVEES

Levees are generally low structures located along the edges of surface water bodies such as rivers, reservoirs, lakes, and the sea to prevent inundation of land behind the levees during periods of high water levels resulting from floods, storms, or tides. Levees also may be constructed to form a controlled channel. A floodwall serves the same purpose as a levee but is constructed of concrete or masonry to save on right-of-way acquisition. Only in rare instances do levees or floodwalls extend deeply enough into the subsurface to form a barrier to ground water flow.

In coastal areas levees prevent the flooding of land by seawater. As a result, the quality of ground water in the aquifers behind these levees is protected.

Occasionally a harmful effect of a levee on ground water quality may occur in floodplain aquifers near streams. The dissolved mineral concentration of most floodwaters is lower than that of ground water. During periodic inundations of floodplains, some of the water infiltrates to the floodplain aquifer and acts to improve its quality by dilution. Where a levee prevents this action and reduces the natural recharge, the mineral quality of the aquifer

will tend to change with time. The existence of such localized flood plain aquifers is confined to special geological situations and is not a common problem throughout the country.

The effect on surface water quality of levees located along a channel is principally the encouragement of erosion and channel scour during high water periods which contribute sediment and increase water turbidity. Since the stream is confined by the levee to a smaller than natural flood channel, water velocities are increased above natural conditions causing channel scour. The increased scour can subject underlying less resistant geological formations to attack and perhaps even breach aquitards opening aquifers to pollution by contaminated surface waters.

Control methods include use of wider spacing between levees to provide additional area of flow and the use of stabilization techniques on the levees themselves and in the flood plain such as plantings or rip-rap. Levee maintenance is important to continue both the protection against floods and to reduce the production of sediment caused by erosion and scour.

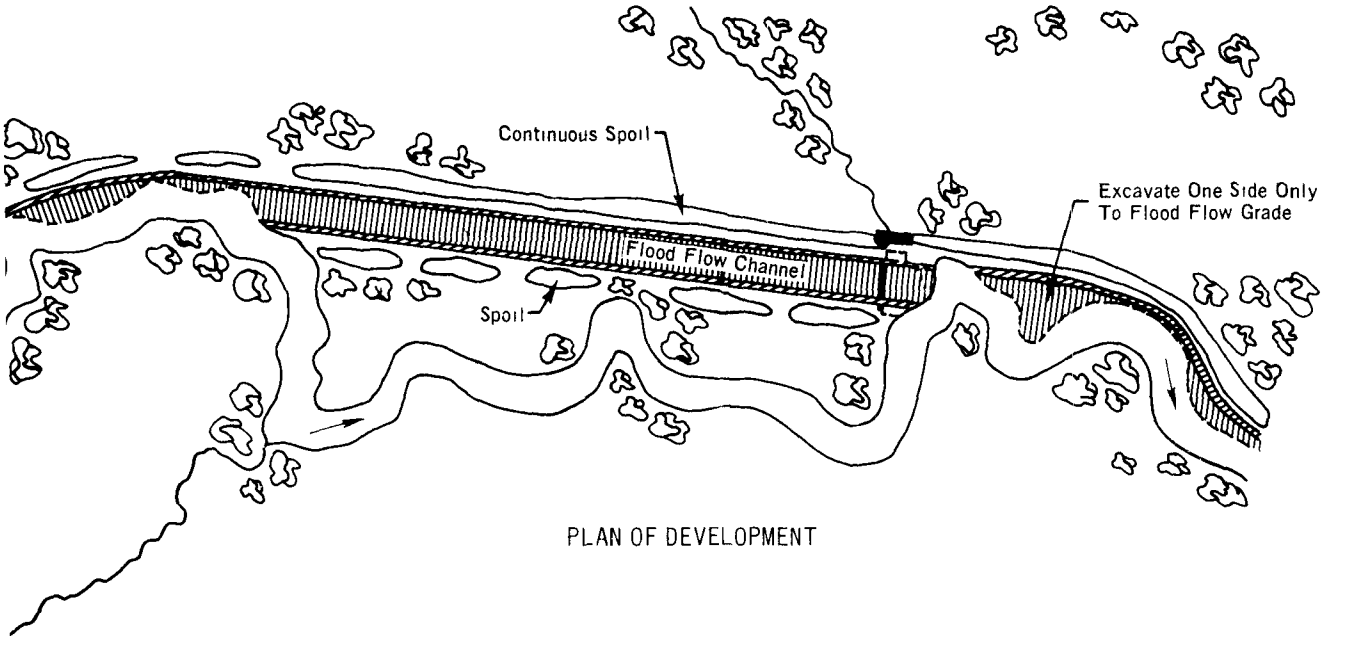
FLOODWAY CHANNELS

Floodways are usually wide artificial channels constructed to carry floodwaters that exceed the capacity of natural river channels. As such, these are invariably unlined, and the bottom elevation is at or close to the natural ground surface level.

The effect of most such channels on ground water quality is minimal, particularly as they typically carry water for only a small fraction of each year. If anything, floodwater flowing in a bypass channel and infiltrating into the ground would tend to improve the local ground water quality.

Because of the negligible effect in degrading ground water quality, no specific control measures are suggested to prevent pollution of this resource.

The effect on surface water quality depends on channel stability measures incorporated into the design of the floodway and the maintenance provided. Incorporation of proper replanting and rip-rapping of channel bends prevents the scour of sediment during high flow periods (Figure 3). Insufficient maintenance can lead to the production of



(Adapted from Tech. Release No. 25,
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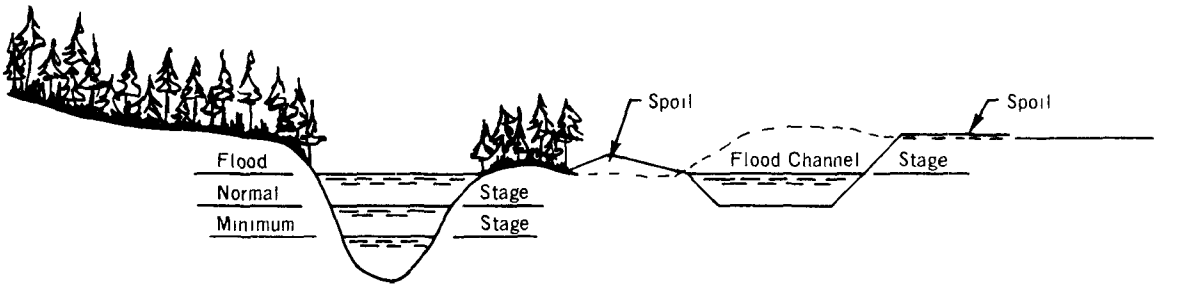

UNDISTURBED STREAM CHANNEL & SEPARATE FLOOD FLOW CHANNEL

Figure 3 Undisturbed Stream Channel and Separate Flood Flow Channel

substantial quantitities of sediment and debris which decreases water quality downstream.

RETARDING BASINS

These basins are constructed on tributary streams and in the main stream. By regulating the hydrograph downstream, flood stages are reduced and damages due to flooding consequently reduced.

Water quality is generally unchanged by these basins during low flow conditions as the water passes through essentially without alteration or retention. During the high runoff periods, the basins help reduce sediment concentrations and trap debris. If accumulated sediment and debris are not removed during maintenance operations, sediment storage will be filled and any additional quantities will be transported downstream.

Proper stabilization, planting programs and the use of sediment trap ponds help alleviate erosion and subsequent input of sediment directly into the basin and prevent caving and slumping of the inundated areas during high water.

LAND TREATMENT MEASURES TO CONTROL POLLUTANT CONTRIBUTION

Land treatment measures include proper land use management techniques and the use of erosion-controlling vegetation in the drainage basin. These measures are effective in reducing sediment-bearing runoff and extending the time for runoff itself during light and moderate rainfall periods but are not particularly effective during heavy rains that lead to flooding. Where bottomlands are cultivated and raw crops are placed adjacent to a channelized stream, it is frequently advisable to leave a filter strip of grass or shrubs along the stream to remove silt and to prevent erosion of the channel banks by field runoff. Basically these measures are beneficial and do not require abatement measures.

FLOOD PROOFING

Flood damage can be avoided by structural modification of buildings in the flood plain. The modifications used include reinforcing of foundations to resist the forces of flood water and the temporary weakening of supporting soil, sealing of windows located at lower elevations than the expected flood water level, and providing for water-tight closure of doors. Other measures recommended entail the moving of appliances, inventories and other valuable materials to the upper stories of buildings so as to be above expected flood water levels. Flood proofing is most effective for new construction as the required modifications can be expensive for older structures.

Non-Structural Alternatives to Channelization

The principal purpose of channelization projects is to reduce the damage caused by periodic flooding. Thus far in this report, the physical methods to mitigate the water quality degradation that occurs because of such channel modification have been discussed. One alternative to a physical solution to prevent damage from flooding is to delineate areas subject to flooding and prohibit uses of

these areas that are damaged by floods. Such non-structural alternatives can eliminate the pollution effects directly attributable to channel modification and if properly planned and enforced can eliminate pollution effects that would otherwise occur when the project design flood is exceeded and flooding occurs.

The CEQ Report (Ref. 1) summarizes these approaches as follows:

"Non-structural adjustments take many forms. The three major measures are regulatory, technical/administrative/policy, and economic/financial measures. Powers, programs and incentives are available for each. Regulatory measures combine State encroachment statutes, local rural and urban zoning ordinances, subdivision regulations, building and housing codes, and open space regulations. Technical/administrative/policy measures combine flood proofing, temporary (preplanned) and permanent evacuation, flood forecasting and warning systems, alternative uses of protective works, lending policies, local facilities development policies, urban renewal, and relief and rehabilitation policies and programs. Economic/financial measures combine flood-risk insurance, tax adjustments,

tax adjustments, rights, easements, dedications, reservations and public or private acquisitions."

In practice, a combination of the structural and non-structural approach is taken to reduce flood damage. For any given situation, the effects of the alternatives on water quality should be calculated and considered in the overall project evaluation.

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III. Guidance for the Identification and Evaluation of Impoundments

Introduction

This discussion of impoundments will describe the effects on water quality of both storage impoundments and run-of-the-river or main stream impoundments. In addition to distinguishing between these two classes of reservoirs, the principal difference between lakes and impoundments is discussed.

For many purposes a reservoir may be considered as the upstream half of a natural lake with the dam replacing the downstream half. Since both lakes and reservoirs are physically similar many of the characteristics of lakes are reproduced in reservoirs. There are two significant differences however which produce differences in water quality in downstream discharges.

The first difference involves facilities for controlling the rate of discharge. Downstream flows may be reduced to less than natural by controlled releases from reservoirs and in fact, in certain type operations may be

reduced to zero for significant periods during the daily operating cycle.

The second difference is the depth from which reservoir discharges are withdrawn when compared with the surface discharges from lakes. Natural lake discharges are generally surface waters which are aerobic and therefore have been subjected to the normal aerobic processes of natural purification. Water temperatures of these flows reflect the prevailing average ambient air temperatures. Reservoir discharges are frequently withdrawn from deep within the reservoir. If the reservoir is stratified, this water may be anaerobic and contain undesirable minerals resulting in decreased water quality. Water temperatures may be substantially less than ambient air temperature reflecting the temperature of the winter and spring runoff that was stored.

Run-of-the-river impoundments are located on main stream rivers and are characterized by relatively low head dams with impounded waters not extending far from the natural channel and water detention times of a few days. Water velocities are appreciable and in a positive downstream direction. Passage of water through the reservoir is by displacement usually without significant

vertical stratification other than that caused by daily surface warming by the sun. These impoundments are constructed principally to deepen rivers for navigation in canalization projects or to provide regulation downstream from storage reservoirs operated for power generation.

Storage reservoirs are generally located on tributary streams and are characterized as being relatively deep with the water surface extending far beyond the natural river channel. These reservoirs have large storage capacity in relation to the drainage area and generally have several months detention time. Because of the operation of these reservoirs passage of water through the reservoir may be discontinuous and subject the reservoir to large differences in water level on a seasonal basis. Because of the large lake level fluctuation, past designs have placed outlets deep in the reservoir. These reservoirs are characterized by thermal stratification generally of the classic three layer system during the summer warm weather periods. Primary uses of storage reservoirs include flood storage, hydroelectric power production and water supply storage. Recreational use is an important secondary use on many storage reservoirs.

Current Governmental Involvement

Several Federal agencies are involved in the construction of storage and main stream impoundments. As the principal agency responsible for navigation and flood control on the nation's inland waters, the Corps of Engineers constructs both storage and mainstream reservoirs. The Tennessee Valley Authority is also authorized by the Tennessee Valley Authority Act to construct dams and reservoirs on the Tennessee River and its tributaries for navigation, flood control and power production. The Bureau of Reclamation has constructed storage impoundments to provide water for the irrigation projects in the western States. The Soil Conservation Service constructs impoundments in cooperation with State and local agencies for flood prevention, conservation, development, utilization and disposal of water purposes. The Federal Power Commission is responsible for approving non-Federal development of hydropower and is involved in the approval of impoundment construction for this purpose. Information on reservoir projects for hydropower production of a regional nature is also available from other U. S. Department of Interior agencies including the Bonneville Power Administration, Alaska Power Administration, Southeastern Power Administration and the Southwestern Power

Administration. The Department of Housing and Urban Development has information on reservoirs constructed in housing projects in which they have an interest. State and local governmental agencies are also involved in reservoir construction. Such developments may include recreation reservoirs and public water supply reservoirs. The name of the appropriate State and local agency varies from State to State and therefore must be determined for each particular situation.

Private development of small impoundments has become commonplace. Private developers construct suburban housing developments and recreational weekend communities surrounding man-constructed impoundments. Private development of small lakes has also occurred in conjunction with campgrounds, recreational parks and even pay fishing lakes.

A survey of the governmental sources will delineate the large projects and most of the significant smaller projects. Other projects may require an examination of local construction permit files or consultation with local planning commissions.

Current Practices

Current planning and justification for large reservoirs involving the Federal Government are generally based on multipurpose use. The principal multipurpose uses included are flood control, hydroelectric power production, navigation, recreation, irrigation water supply, public water supply, low flow augmentation for water quality or other special purposes, and fish and wildlife propagation. State and local projects are also generally multipurpose with the exception that some water supply impoundments are reserved solely for that purpose.

FLOOD CONTROL

An extensive network of reservoirs has been constructed for flood control by the Corps of Engineers and the Tennessee Valley Authority. The basic theory of operation of these reservoirs is to reduce storage quantities to a minimum level prior to the normally wet seasons of the year. During the wet season, outlet flows are kept to a minimum while excess tributary flow is stored. Following the wet periods the reservoirs are usually filled to near maximum storage levels. The available storage is then used to maintain normal or increased stream flows, produce

hydroelectric power when passing through the dam, and provide recreational opportunities on the reservoir itself. During the drier periods of the year the level is gradually lowered to reach the minimum as the next wet period approaches.

POWER PRODUCTION

Water storage for power production is one of the oldest uses of reservoirs. Many small reservoirs have been constructed to furnish energy to individual mills or small communities. Presently designed developments are rarely for single purpose hydroelectric power production but the incorporation of this feature is primary at many reservoir sites.

Hydroelectric power production is generally used to meet peak daily loads in conjunction with a steam-electric facility which supplies the base electric power requirements. The steam-electric facilities operate continuously while the hydroelectric power is produced for 4-8 hours to meet peak demands for air conditioning in the summer and heating in the winter, and other home and industrial electric consumption demands. Such peaking power

operations are the standard operating scheme for many areas including that served by the Tennessee Valley Authority.

Some storage reservoirs were constructed sufficiently large in comparison with the power demands of the times to allow continuous power production operations by adjusting water turbine operations to conform to the applied load. This type operation is generally inefficient with greater economies achieved by using steam generated power for the base load and meeting peaks with hydroelectric power.

Many of the main stream impoundments also have power generating facilities. Since the operation of these reservoirs is frequently for maintenance of a specific pool elevation, peaking power with its inherent rapid pool stage fluctuations is not possible. Power production is therefore limited by the incoming river flow and must be marketed on that basis.

NAVIGATION

Development of navigation on the nation's inland waterways is a major use of main stream impoundments. Such dams are serially located along a stream with the pool of the downstream reservoir terminating at the toe of the next

upstream dam. Navigation locks are provided at each dam to raise and lower river traffic. The use of such canalization techniques have been applied on the Ohio River and the Upper Mississippi River to name two examples.

The dams are operated to maintain controlled pool elevations for the convenience of commercial barge traffic. Flow at each dam is adjusted by use of weirs, by flow through the electric generating turbines, and by the number of lockages to maintain the specified pool elevation.

WATER SUPPLY STORAGE

Water supply storage reservoirs include those reservoirs constructed to supply storage for public water supply, industrial water supply and irrigation water supply. Single purpose domestic and industrial water supply reservoirs are frequently small when compared with other types of storage reservoirs. These impoundments are constructed to provide sufficient quantities of water to augment the incoming stream flows during low flow periods. Sufficient detention time is generally provided to allow natural purification processes such as biochemical oxidation of organics and sedimentation of particulate material to enhance the water quality and reduce water treatment costs.

Storage of water for subsequent irrigation use is responsible for most of the agriculture in the western States. Large impoundments, exemplified by the reservoirs on the Colorado River, store water from snow melt and winter rains and provide irrigation water during the growing season. Huge complexes of irrigated farms have been developed to make use of the water which is diverted from these reservoirs.

MULTI-PURPOSE RESERVOIRS

Only infrequently are truly single purpose reservoirs constructed under presently existing conditions. Most reservoirs include many uses although one use may predominate.

Modern planning incorporates multiple uses to calculate the benefits accruing from a proposed project. Costs are likewise allocated to various projected uses. The final benefit-cost ratio reflects the total value of the project as against the cost of construction.

Sources of Pollution

The construction of reservoirs of all types produces direct and indirect changes on water quality of the inflowing water. Direct changes include the physical, biological and chemical alterations that occur during storage and because of the changed environment from that of a moving stream to a quiescent lake. Many of the direct changes to water that occur during storage improve the quality especially in the aerobic surface layers. Through the processes of natural purification objectionable constituents may be removed.

Indirect effects include watershed development which contribute pollutants and nutrients which may ultimately degrade water quality in the impoundment. Frequently the direct changes that occur are also either magnified or mitigated by the changed environment from stream to reservoir.

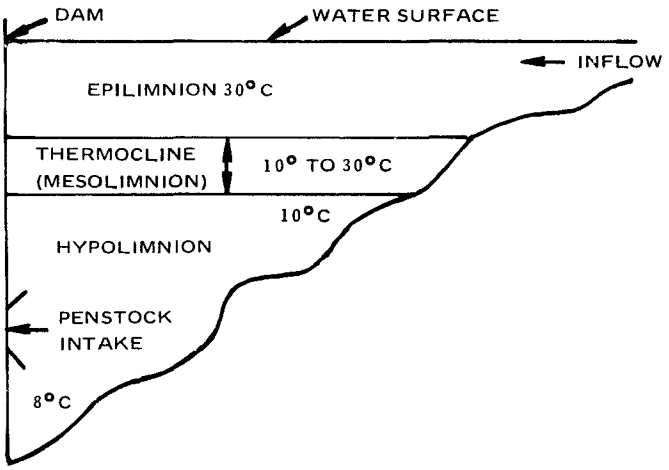
BASIC RESERVOIR HYDRAULICS

The deleterious effects on water quality caused by the construction of a reservoir or by a series of reservoirs in a canalization project can best be understood after an

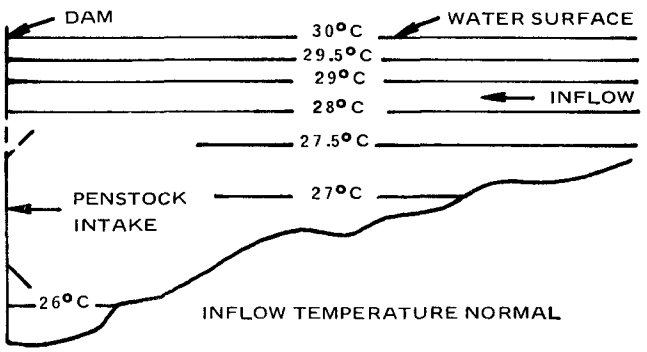
elementary understanding is acquired of basic reservoir hydraulics.

Storage reservoirs in temperate climates frequently become stratified during the summer and winter with periods of non-stratification occurring during the spring and fall. The formation of stable stratification depends on the density of water. The density of water changes with varied temperatures reaching a maximum at 4 degrees Celsius and decreasing with either an increase or decrease in temperature from that point.

The classic stratification pattern for summer has a surface layer, the epilimnion, which is well mixed by wind and wave action. Beneath the epilimnion is a narrow zone of rapid temperature decline called the thermocline or mesolimnion, which is characterized by a temperature change of more than 1 degree Celsius per meter. The lowest zone, the hypolimnion, is effectively shut-off from atmospheric reaeration, and has only a small temperature gradient. The summer stratification is graphically illustrated in Figure 4(a).



a) Storage Impoundment



b) Run-of-the-river Impoundment

Figure 4 Thermal Stratification in Reservoirs During Summer Period

The winter stratification of storage reservoirs is characterized by either ice or water of temperature less than 4 degrees Celsius floating on water of 4 degrees Celsius which then extends to the bottom of the reservoir. The hypolimnion is again stable and is effectively removed from atmospheric reaeration. Because of low temperatures however biological activity is low and water quality may not be substantially impaired during the winter stratification. The winter stratification is graphically illustrated in Figure 5.

The point of discharge in most storage reservoirs is near the bottom so that releases can continue to occur when the water level is low in the reservoir. Thus, hypolimnetic water is generally released. If anaerobic, this water may be initially of poor quality because of no dissolved oxygen, concentrations of odorous constituents and concentrations of soluble metals. The quality of the discharged water is therefore greatly affected by the dissolved oxygen concentration in the hypolimnion if withdrawal is effected from this water mass.

If the dam is constructed so that water can be withdrawn from different depths, stratification allows the selective withdrawal of water of better quality. Selective withdrawal is accomplished through the phenomenon of stratified flow.

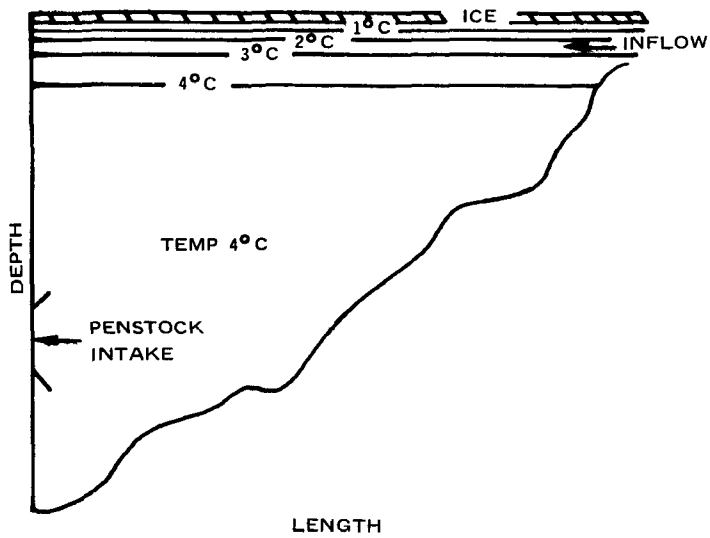


Figure 5 Thermal Stratification in Storage Reservoir During Winter Period

The thermal stratification of storage reservoirs is governed by a heat balance taking into account solar radiation, surface losses by evaporation and conduction, and the input and outputs of heat by inflows and outflows. The thermal stratification effects discussed has a dominant influence on internal flow patterns in the reservoir and greatly affects outflow water quality.

Main stream reservoirs may exhibit a gradual temperature gradient with temperatures decreasing from top to bottom. This gradient is caused by the absorption of the sun's energy in the upper water layers and the existence of insufficient downstream velocity or wind induced mixing to insure complete vertical uniformity. Such a thermal condition is graphically illustrated in Figure 4(b). If the stratification is stable enough to continue overnight or exist for several consecutive days, water quality in the lower layers may be adversely affected by declining dissolved oxygen levels. Downstream quality may be affected depending on the methods of releasing water and location of outlet works at the dam.

To summarize, thermal stratification of reservoirs occurs in both those designed for long term storage and in main stream reservoirs. The effect is to reduce vertical

circulation and the transport of dissolved oxygen to lower layers in the impoundment. Without some means to discharge waters from other than the hypolimnion, downstream water quality may be impaired.

WATER QUALITY CHANGES WITHIN RESERVOIRS

Chemical - Physical Changes

The annual cycle of storage impoundments in temperate climates consists of the winter and summer periods of stratification which are separated by periods of essentially uniform temperature distributions from top to bottom of the reservoir during which the waters freely mix. The periods of mixing are called the spring and fall turnovers. During the turnover periods soluble material entrapped in the hypolimnion is returned to the biologically active near-surface region. The source of this material is water inflows, production in the epilimnion, or leaching from the bottom muds. Such materials consist of the inorganic nutrients nitrogen and phosphorus, chemically-reduced heavy metals such as iron and manganese, and unoxidized organic material. The nutrients become available to support renewed primary production. The turnover period frequently

coincides with the typical fall and spring plankton blooms observed in many reservoirs.

During the turnover periods dissolved oxygen concentrations are uniform throughout the depth of the reservoir. As the reservoir warms following the spring overturn and stratification occurs, the supply of oxygen to the hypolimnion from atmospheric reaeration is terminated. As the summer progresses dissolved organic material in the hypolimnion which includes that present initially plus material settling into and diffusing from the upper layers, exert oxygen demands as bacteria oxidize these materials. If the organic content is sufficient to cause total depletion of dissolved oxygen concentrations then anaerobic conditions become established and water quality is seriously degraded.

Compounds such as metallic phosphates and carbonates which are chemically stable and insoluble under aerobic conditions become soluble and enter solution under anaerobic conditions. This condition leads to the leaching of materials from the bottom muds. The bottom muds have an oxidized surface layer during aerobic conditions which prevents leaching of underlying anaerobic products. Under anaerobic conditions this oxidized zone is eliminated and

compounds are readily leached. Increases in iron, ammonia, manganese, silica, phosphate and sulfide ions have been observed in oxygen depleted waters in contact with bottom muds. Increases in soluble organic compounds also occur.

Since many storage reservoirs withdraw water for release from near the reservoir bottom, the quality of this water may be much poorer than that which occurred in the pre-impoundment stream. Low dissolved oxygen concentrations, the presence of reduced metallic compounds and the presence of odorous organic compounds are evidence of such deterioration.

Main stream reservoirs as a general rule do not become stratified for extended periods of time. Depending on the dissolved oxygen concentration gradient (if one exists) similar leaching from the bottom muds as that in storage reservoirs may occur. Without stratification and assuming mixing from top to bottom, the water discharged does not represent a particular zone and thus the depth of withdrawal is not critical to water quality.

Biological Changes

In the process of converting a stream into a reservoir the biological community must adapt from a moving water stream system to a still water or lake environment. The entire biological system may change significantly in storage reservoirs whereas only minor changes may occur in main stream reservoirs. Anticipated changes include population shifts in plankton, rooted aquatic plants, aquatic invertebrates, and fish.

SITE PREPARATION EFFECTS ON WATER QUALITY

Water quality may be affected by many characteristics of the reservoir location site. Factors which affect future water quality include maximum and operating depth range, reservoir configuration, relation of principal axis to prevailing wind direction, geology of area, characteristics of the underlying soil, and the type of native vegetation.

The characteristics of the underlying soil and the vegetation that remain before inundation are important to future reservoir water quality. Both the soils and vegetation require investigation to determine the amount of organics present in the soil and its state of decay so that

the amount of leachable color, nutrient release, organic acid production and decrease in pH can be predicted. Additional soil analyses can determine the amount of leachable inorganic salts present which tend to increase the total dissolved solids in the overlying water. Based on such determinations, decisions can be made regarding the necessity of removing organic soils prior to inundation or using a mineral soil covering of the organic soils to prevent their undesirable effects.

The chemical, physical and biological reactions that occur at the soil-water interface are complex and not particularly well understood. It has been shown however that these reactions are more of a biochemical nature than purely chemical or physical. The organic content of the soil and pre-inundation vegetative cover are responsible more than other characteristics for the undesirable effects on the overlying water. The adverse effects caused originally by freshly inundated soils are reduced with time. This aging process is a combination of leaching, of organic destruction and of being covered by sediment transported into the reservoir. Estimates of the time required for reservoir bottoms to stabilize so that tastes, odors and color are not imparted to the water indicate that 10-15 years may elapse. The equilibrium condition is defined as

the point where reservoir water quality is determined by the quality of the inflowing water. The effects on dissolved oxygen concentrations usually are significant for only the 1-2 years with normal reservoir site preparation although minor effects may occur for substantially longer periods.

RELEASED WATER QUALITY

The water quality downstream from a reservoir is obviously affected by the design and operations of that reservoir. If lower quality water is discharged than previously existed before the reservoir then the effect is the same as that caused by a pollution source.

Additionally, the discharge may be of a temperature unnatural for native biological systems. This occurs frequently during the summer because the hypolimnetic water released reflects the cooler water stored during the high flow winter-early spring seasons. Such low temperature discharges interfere with natural fish spawning cycles as well as the existence and reproduction of invertebrates and other lower life forms.

The effects on downstream water users from the effects of impoundments include increased treatment costs at points

of withdrawal for water supply use. Taste and odor, color, iron and manganese concentrations all may be increased above previous stream concentrations and require treatment for removal. Inorganic nutrients, principally phosphorus and ammonia-nitrogen may be present in increased amounts if the reservoir hypolimnion was anaerobic. These nutrients can stimulate rooted aquatic plant growth as well as plankton growth in downstream reaches. Plankton in nuisance amounts can produce water treatment problems by contributing taste and odor to water and by interfering with filtration processes. Both plankton and rooted aquatics reduce the aesthetic quality of water, reduce recreational appeal and pose subsequent oxygen demands on the stream's dissolved oxygen resources.

EFFECTS ON GROUND WATER

The most important effect of a dam on ground water quality occurs where the foundation of the structure provides a substantial or complete cutoff of ground water flow in an aquifer. Such a stoppage reduces the hydraulic gradient of the ground water upstream of the dam. This causes an increased accumulation of pollutants in the ground water because of slower movement or complete stoppage.

Another effect is caused by the higher water table created back of a dam which extends around the periphery of the reservoir. The high water table brings the ground water closer to the ground's surface where the opportunity for pollution from surface pollution sources may be increased. Marshy areas, swamps, and pools also may be created.

Even in situations where the dam and its foundations do not substantially alter the total ground water flow through the underlying aquifers, the localized effects on ground water levels and on the original pattern of ground water flow may have significant adverse impacts on ground water quality. Seepage losses from the reservoir also contribute to the ground water. If the quality of the water in the reservoir is better than that of the ground water, improvement in ground water quality results. Conversely, seepage losses from a reservoir storing poorer quality water (e.g., reclaimed water) degrade the ground water.

WATERSHED DEVELOPMENT

In certain areas development of land areas tributary to reservoirs may constitute major sources of pollution and nutrient fertilization. On small reservoirs constructed in conjunction with suburban housing developments direct

drainage from streets and lawns constitutes the primary cause of water quality degradation. On large reservoirs increases in upstream tributary population and development on the periphery of the lake shore must be considered in projecting water quality although these sources may not be of immediate concern.

Suburban development surrounding a small reservoir can deteriorate water quality by direct waste disposal through the use of sewage treatment plants not providing nutrient removal, discharges from watercraft, run-off from yards and streets and by infiltration from polluted ground water where septic tanks are used. Contamination in the feeding stream upstream from the reservoir intensifies the pollution problem.

Larger reservoirs are also adversely affected by direct sources but because of the volume of dilution available, these effects may not be immediately noticeable. Large direct discharges from industries or municipalities however can seriously degrade water quality unless adequate treatment is provided these sources. Nutrient concentrations from upstream point and nonpoint sources may accelerate eutrophication processes causing algal blooms and subsequent dissolved oxygen problems.

CHANNEL MAINTENANCE

Since one of the principal reasons for the construction of the main stream reservoir is to maintain minimum depths for navigational use, channel maintenance becomes a key feature to maintaining the system. The removal of settled materials provides an additional benefit by providing renewed space for the settling of additional sediment transported by the tributary streams. Such maintenance generally consists of some method of dredging but may include channel bank maintenance where affected by wave action or propeller wash. Water quality is affected by the dredging operation itself, and by the spoil disposal method employed.

The dredging operation resuspends silt and other fine grained material which increases turbidity. These materials later settle blanketing downstream sections of the impoundment. Adsorbed materials, such as organic compounds and nutrients which travel with these silty materials, may be released to the aquatic phase either stimulating or inhibiting stream life.

NAVIGATION RELATED SPILLS

Any stream which is maintained for navigation is subject to accidental spills of cargo and fuel while in transit plus the possibility of catastrophic accidental spills from shore storage and support facilities. These potential pollution sources are unpredictable as to time of occurrence but can be expected from time to time. The effects of these spills can be disruptive to other water uses and disastrous to aquatic life.

REDUCTION IN WASTE ASSIMILATIVE CAPACITY

Waste assimilative capacity has traditionally been based on the dissolved oxygen requirements necessary to maintain fish and aquatic life. The calculation of the dissolved oxygen concentration profile downstream from a waste source essentially is a balance between the amount of oxygen required to oxidize organic material and the amount of oxygen supplied by atmospheric reaeration. Currently available formulations for estimating reaeration indicate that rates are increased by an increase in water velocity and decreased by an increase in water depths. A reservoir both decreases velocity and increases depth and therefore reduces reaeration by both factors. The increased surface

area of an impoundment increases the available surface area as compared to the original stream. The increased surface area increases the opportunity for direct reaeration, for photosynthetic oxygen production and for wind-induced wave action. These effects are generally insufficient to counter the decrease in turbulence caused by the decreased velocity and the net effect is reduced reaeration (Ref. 1).

The decreased water velocity also provides for sedimentation of particulate material in waste discharges usually near the outfall. This material intensifies oxygen demands near the outfall and reduces oxygen levels even more rapidly.

The biochemical oxidation of organic material is generally assumed to be a function of time. By reducing the water velocity the distance over which this demand is exerted is reduced.

The net effect of the reservoir is to reduce the distance over which dissolved oxygen concentrations are reduced by the biochemical oxidation of organic material and to greatly intensify the amount of depletion that occurs within that reach because of reduced reaeration. To maintain water quality, less organic material can be placed

into the reservoir, than was previously placed in the flowing stream.

For main stream reservoirs the effects on dissolved oxygen resources are readily calculable using standard techniques; for storage reservoirs the hydraulics are complicated and variable and such changes are not as easily predicted (Ref. 2 and 3).

Types of Pollutants

Water quality changes related to reservoirs are of concern within the reservoir itself and in the downstream reaches of the stream which receives releases from the reservoir. The water quality at the surface is of importance for recreational, biological and aesthetic purposes; that in the hypolimnion because of the effects that quality of released water has on downstream uses. At times of non-stratification the existing quality affects all uses and establishes the mixing of materials which will determine water quality in both zones following re-establishment of stratification.

BIOLOGICAL FACTORS

The biological forms in the epilimnion mediate many physical and chemical water quality changes in this zone. Because of this activity water quality is affected subsequently in the hypolimnion. Bacteria, plankton, rooted aquatic plants, invertebrates and fish all contribute and react to these water quality changes.

The plankton as primary producers in the system use available inorganic nutrients to develop and sustain their populations. Increases in nutrient concentrations provide material for increased plankton numbers. The major nutrients required include inorganic nitrogen, carbon and phosphorus. So-called minor nutrients and growth factors may also be required. Plankton populations generally are related to nutrient concentrations assuming adequate light and the absence of toxic materials.

Dense plankton populations directly affect the chemical quality of water. The process of photosynthesis occurs during daylight hours. Algae remove carbon dioxide from solution which causes an increase in pH. The carbon dioxide is photosynthetically reacted upon to produce dissolved oxygen and new algal cells. The dissolved oxygen is

produced in quantities that frequently exceed the water solubility of this element. At night carbon dioxide is produced by algal respiration which reduces pH and depletes dissolved oxygen concentrations below values that would otherwise occur. These diurnal fluctuations in pH and dissolved oxygen can have detrimental effects on other biological life. For example, in extreme situations dissolved oxygen levels may approach total depletion at night because of plankton respiration.

The particulate waste products of the aquatic community in the near surface waters eventually becomes trapped in the hypolimnion. Materials such as dead algae, zooplankton and fish plus the feces of all living forms constitute the materials upon which bacterial decay occurs. Bacterial decay exerts a demand on the hypolimnion oxygen resources which may ultimately cause total dissolved oxygen depletion.

Rooted aquatic plants along the shoreline of the impoundment detract from aesthetic qualities, reduce recreational opportunity for swimming or other water contact sports, provide protection for insect development which may pose a health hazard, and become a liability on the reservoirs oxygen resources when death occurs. These plants

require stable water levels and clear water allowing light penetration in order to become established.

Organisms in higher trophic levels such as fish, feed directly on plankton, on their detrital remains in the bottom muds, or on those organisms that do. The population of these higher organisms depends on the productivity of the plankton. Detrimental effects on these organisms are caused by dissolved oxygen depletion, pH changes, or plankton-produced toxins. Such effects occur because of plankton activity.

Microbiological factors must also be considered. Tributary drainage, waste treatment plant discharges and human wastes discharged from water-craft potentially contribute disease-causing organisms. For recreational use the bacteriological quality must be maintained so that disease transmission from fecal discharges is minimized. The fecal coliform test is the standard technique for determining the sanitary microbiological quality of reservoir waters.

AESTHETIC FACTORS

Aesthetic appeal of an area can be enhanced or degraded by reservoir design and operation. Ignoring shoreline development and concentrating on water quality aspects the most important factors are the control of aquatic plants; maintenance of dissolved oxygen, color, turbidity and other chemical constituent concentrations in the range conducive to desirable fish and aquatic life maintenance; and maintaining lake levels sufficiently high during the recreation season to safely allow reservoir recreational use. A balance of these factors aid in the enjoyment of the water resource.

CHEMICAL FACTORS

Maintenance of the water quality in a reservoir for multiple uses requires control of the water chemistry, of inputs of waste materials and of any toxic materials. Common measures of chemical water quality include dissolved oxygen, color, pH, various inorganic salts, metals, nutrients and organic compounds including pesticides and herbicides. Specific levels for these materials are contained in the various State Water Quality Standards. Discussion of these materials with recommended levels are

also available in a book entitled "Water Quality Criteria" published by the Environmental Protection Agency (Ref. 4).

PHYSICAL FACTORS

The physical factors of water quality include determinations such as temperature and turbidity which affect the usefulness of water and mediate other chemical and biological reactions.

Temperature affects the rate of physical, chemical and biological reactions. In terms of reservoir hydraulics, temperature related density changes in water cause the development of the stable summer stratification with its pronounced affect on water quality. Chemically, water temperature effects the solubility of gases with dissolved oxygen principally being of interest; the solubility of chemical compounds; and the reactiveness of certain constituents. Biologically, reaction rates for aquatic organisms roughly double for every 10 degree Celsius increase in temperature. Temperature also regulates reproductive mechanisms and the life process itself. Temperature is obviously a most important consideration in reservoir water quality evaluations.

Turbidity is a measure of the reduction in incident light penetration caused by suspended particulate matter. As a generic term its magnitude is measured by determinations such as suspended solids and secchi disc in addition to a direct turbidimetric measurement. The suspended matter in epilimnetic waters may be plankton while in hypolimnetic waters it may be sediment. In surface waters turbidity is used as a factor in determining the depth of light penetration in determining the so-called euphotic zone or zone of photosynthetic activity. In water supply uses of various types it is a factor in treatment costs. In reservoir hydraulics a turbid inflow may be more dense than certain existing layers and produce a phenomenon known as an interflow which would insert a layer between existing water layers and subsequently affect discharged water quality. Turbidity is both an economic and quality parameter to be included in reservoir water quality.

Methods of Pollutant Transport

The basic hydraulics of both storage reservoirs and main stream reservoirs has been previously discussed. The movement of soluble pollutants through a reservoir coincides with the hydraulic movement. Particulate pollutants, if organic, may be biologically solubilized; inorganic

materials may be indefinitely held up by being incorporated into the reservoir sediments. Other factors such as solar radiation and the reservoir operating schedule influence water quality in the reservoir itself and the stream downstream from the reservoir.

Pollutant transport in a stream is generally quite simple as the pollutant travels at the same rate as the water itself. This generalization has exceptions as for example sediment load which varies with respect to the water velocity. This same essential transport process occurs in main stream impoundments where velocities are typically discernable and sufficient to maintain particulate matter in suspension. Stratified storage reservoirs in contrast have extremely complex hydraulics. Density effects, surface mixing caused by winds and the level of water release all bear on pollutant residence time.

TRANSPORT INTO THE STORAGE RESERVOIR

Discharges directly into reservoirs which include direct runoff, tributary streams or waste streams are segregated in the reservoir by their density. Beginning in the spring as discharges typically become progressively warmer and less dense, the flows form layers above the

existing cooler waters. Toward fall when inputs become cooler and therefore more dense than stored water, the inputs may form interflows between existing layers. Waste discharges would also tend to be density segregated which in that case may include salinity-induced density effects in addition to thermally caused density effects. Thus the location of an incoming pollutant depends on the existing density regime in the reservoir and the density of the water transporting the pollutant.

TRANSPORT WITHIN THE STORAGE RESERVOIR

The water discharged from a reservoir is the densest existing water layer above the outlet structure. In storage reservoirs with fixed deep outlets progressively less dense water is released during the summer stratified period. The sequence of release approximates the time of entry into the reservoir. This progressive release may be interrupted or modified by the processes of diffusion or by the occasional passage into and through the reservoir of more dense sediment-laden storm water or some other flow containing a density anomaly. As the fall season approaches, but before the fall overturn, cooler tributary inflows may also flow beneath existing storage and pass through the reservoir ahead of existing storage. Soluble pollutants which are

stable (e.g. salts) would be transported in a similar fashion.

Particulate pollutants if of sufficient size, tend to settle toward the reservoir bottom. These materials settle at different rates depending on a myriad of factors but may finally reach the bottom or be retained by buoyant forces occurring in more dense water layers. Thus a density segregation of particulate matter also occurs. Particulate pollutants that reach the bottom may be permanently removed while those trapped in lower lying denser flows may pass through the reservoir more rapidly than the initial transporting water.

Many organic pollutants are biologically degradable and during the storage provided in the reservoir are destroyed. These may be either soluble or particulate in form but are amenable to biological attack. These materials are therefore not transported out of the reservoir but are decayed.

TRANSPORT OUT OF THE STORAGE RESERVOIR

Older dams frequently were designed and constructed with low level outlets only. Newer designs incorporate

multiple outlets so that water from various levels within the reservoir can be released. With a multiple outlet system, water of the best available quality can be withdrawn to protect downstream uses. This is especially important during the late summer period when normal hypolimnion releases contain the worst water quality of the year in terms of dissolved oxygen, nutrients, metals and odorous compounds. Release of aerated epilimnetic waters avoids this problem as much as possible.

Hypolimnetic water releases during late summer may release materials accumulated since the spring overturn. Such materials may have settled to the bottom and become biologically solubilized; or become chemically precipitated, settled to the bottom, and become redissolved under low oxygen conditions near the reservoir bottom. Examples include detritus of planktonic origin which decay and metallic phosphates which become soluble under anaerobic conditions. Thus hypolimnetic releases contain the non-reactive dissolved materials contained when the water entered the reservoir plus those products initally removed but redissolved.

Epilimnetic releases contain the active biological life contained in this zone and are generally characterized by

high quality water including substantial concentrations of dissolved oxygen.

Magnitude and Variation of Pollutant Effects

Documentation of the water quality transformation caused by reservoir construction has been presented for several basins. For main stream reservoirs one series of reports is available for the Ohio River which includes changes observed following the inital installation of low head impoundments and subsequent replacement by higher head impoundments. (Ref. 5 and 6).

Similar studies are available from the Tennessee Valley Authority for both main stream and storage impoundments. Monitoring information for each operating year for various water quality parameters are also available in addition to special studies performed during the year.

The Bureau of Reclamation reservoirs also have water quality studies available for their reservoirs. Such studies are required for determining the quality of irrigation water in addition to monitoring for recreational and other uses.

Reservoirs operated by State and local governments are frequently monitored for water quality. These measurements are available in annual State monitoring system reports or local water supply annual reports.

In addition to these governmental sources of quality information, engineering and biological literature is replete with special water quality studies of reservoirs. Examples are included in the bibliography to this section.

Water Quality Prediction Methods

The prediction of water quality in reservoirs has been performed by several methods. Included among the various techniques are empirical techniques, hydraulic model studies, and mathematical model studies. All of these techniques require field data for verification or calibration. Such surveys include chemical, biological and physical studies to ascertain existing water quality and establish baseline conditions.

EMPIRICAL TECHNIQUES

Empirical methods are generally developed specifically for one reservoir and include analyses of data recorded for

a number of seasons or years. Although simpler analyses are used, statistical correlations are frequently developed between input water quality variables, reservoir water quality and output water quality. Operating rules for the reservoir can be modified based on such analyses to maximize one set of parameters as opposed to another. Simpler techniques than statistical methods would include the use of simple graphs with trend line development. Obvious problems with such methods include: the applicability to only one site, predictive ability only in the range used for development, no mechanism to correct for changes in physical conditions, lack of fundamental understanding in reservoir mechanics, and the extended record required for development.

The principle advantages are the relatively inexpensive development cost and simplicity in use. Depending on the precision required such techniques may be adequate for many purposes.

HYDRAULIC MODELS

Hydraulic models range in scope from simple laboratory scale aquariums to multi-dam basin models covering several acres. These models are used to verify dam designs for hydraulic properties, effects on reservoir stratification of

such designs, or entire river basin conditions for various flow regimes.

Data from the models are collected by using various tracer and stage-velocity measurement techniques. The data are then fitted to a mathematical formulation for incorporation into a particular design. These data are also valuable for evaluating mathematical models as some water quality parameters can be empirically or theoretically scaled from model to prototype.

MATHEMATICAL MODELS

Mathematical models are used for many purposes in reservoir design and operation. The hydrology of an entire basin may be modeled to aid in sizing and locating the optimum number of reservoirs or the amount of water storage required to meet certain objectives. Internal reservoir hydraulics and mixing have also been simulated by mathematical models. Frequently these simulations are a first step in predicting the distribution of pollutants in the reservoir or to predict the discharge sequence and quality of stored water. Recently attempts have been made at ecological modeling. These models begin with assumed material inputs and ultimately predict plankton and fish

populations. Hydraulic simulations, water quality constituent distributions, phytoplankton production, zooplankton controls on phytoplankton populations, and fish populations are all incorporated in such models.

The scientific basis for water quality and ecological models is a basic understanding of the thermal stratification process in reservoirs. Recent research efforts have extended knowledge of the stratification process to the extent that reasonable predictions of the internal temperature distributions can be made. Using the system hydraulics as the basic transport process, the chemical, physical and biological reactions are imposed using the laws of conservation of mass and from general kinetic principles. Equations are constructed for each water quality constituent with the entire set of equations subsequently being solved using numerical techniques frequently with the aid of the digital computer. The model outputs include the time and space variations of the important water quality constituents for water quality models and additionally, the populations of principal biotic species in ecologic models.

The predicted concentrations and biological populations from the models generally follow the observed trends of the

data used for verification with numerical values being representative of actual values. For most management decisions concerning reservoirs the results offer adequate accuracy and offer a valuable tool for evaluating alternative water quality protection schemes. Assessments such as waste input locations, operating rules for the reservoir to maximize water quality, and the projected water quality for various alternative uses can be made using such models.

WATER QUALITY SURVEYS

The use of any statistical or modeling technique requires adequate information for verification and development. The usefulness of the various models depends on the accuracy of the predictions made which can only be verified by field observations. The basis for the validity of predictive techniques requires the performance of intensive water quality surveys augmented by routine monitoring. Key parameters of water quality require delineation both temporally and spatially within a reservoir as well as in the inflows and the outflow. These data provide information for compliance with water quality standards in addition to providing data for future improvements in analytical and modeling technology.

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IV. Methods, Processes and Procedures to Control Pollution Resulting From the Impoundment of Water

The principal water quality changes that occur by transforming a flowing stream into a reservoir are those related to the reduced water velocity and extended detention time, and those changes affected by thermal stratification of the stored waters.

Reduced water velocity enhances sedimentation of inorganic suspended material and tends to increase water clarity. Such quiescent conditions in conjunction with increased light penetration and sufficient nutrient materials are ideal for the production of aquatic plants. Under certain conditions this may lead to phytoplankton production while in others rooted aquatic or floating aquatic plants may develop. Such production ultimately may produce organic materials for decomposition in the hypolimnetic waters or bottom muds following the death of such organisms.

This brief discussion of changes in water quality caused by water impoundments demonstrates the typical problems faced. Available methods, processes and procedures to ameliorate or mitigate these problems will be presented

and discussed. A bibliography will be presented to enable a more detailed presentation of a particular subject for those contemplating use of a particular method.

Site Preparation

It is generally agreed in the literature (Ref. 1 and 2) that to minimize changes in water quality caused by natural materials it is necessary to remove all standing timber, brush, stumps, logs, structures and man-made debris. Grass and other forms of herbage should be mowed with trimmings removed just prior to inundation. Additionally organic mucks from swamps should be substantially removed with the residual covered with 2 or more inches of clean sand. It is also desirable to cut channels to pockets within the reservoir bottom to provide drainage when water levels are lowered. To protect the sanitary quality of the reservoir cleaning of barnyards, privies and cesspools should be performed prior to inundation.

Occasionally, soil stripping is employed to remove soils with heavy organic content (1% to 2%). This operation is expensive and of only temporary benefit when compared with non-stripped reservoir bottoms. Without the effects of significant sediment inflows, the effects on overlying water

quality are equivalent in 10-15 years as between stripped and non-stripped reservoir sites. Sediment in reservoir inflows may reduce this time for equilibrium to occur.

Multilevel Outlets

Multilevel outlets are increasingly incorporated in storage reservoirs to provide flexibility in the withdrawal level for released water. Two principal water quality criteria are used to gage the need for such variable releases: temperature and dissolved oxygen.

Multilevel outlets provide the ability to withdraw aerated epilimnetic (near surface) water during periods when hypolimnetic (near bottom) water may be low or devoid of dissolved oxygen. This release procedure provides water of suitable quality to support fish and aquatic life downstream.

When dissolved oxygen levels are sufficient throughout the reservoir, the temperature of the released water may be critical to support anadromous fish runs, induce spawning or to maintain cold water species of fish. Multi-level outlets provide the opportunity to furnish water of the desired quality if available at any level in the reservoir.

The hydraulics of selective withdrawal have been extensively researched in recent years. It is on the basis of this theory that multi-level outlets can be rationally designed.

Destratification and Hypolimnetic Aeration

In reservoirs with deep withdrawal points that do not contain multi-level outlets or any method to release aerated epilimnetic waters, methods to provide aerated water at the withdrawal point provide alternatives to construction of such facilities. Two principal methods are possibilities: reservoir destratification and hypolimnetic aeration without destratification.

Destratification is most commonly accomplished by compressed air diffuser aerators or mechanical pumping (Ref. 3 and 4). By either method mixing of the hypolimnion and epilimnion is accomplished to destroy the thermally-induced density stratification. The induced mixing provides aerated water at all reservoir depths which prevents water quality deterioration within the reservoir caused by oxygen depletion and thereby maintains the quality of water released downstream. Aerobic conditions inhibit leaching of color, solubilization of metals and nutrients from the

bottom sediments, the production of noxious gases, and provide for the distribution of more desirable aquatic life throughout the affected area.

Compressed air aeration has an advantage in that oxygen is absorbed directly from the rising bubbles in addition to the aeration at the surface that occurs because of the mixing. However, in deep reservoirs operating costs may be greater than pumping because of the necessity to increase air pressure above the static level of the depth of water above the diffusers. Pumping conversely only requires sufficient energy to lift the water from the water surface up to the pump (plus minor intake pipe friction losses) which may be only a few feet of head.

Both relatively large and small reservoirs can be destratified. Under given morphologic conditions a long reservoir has been mixed for a substantial distance upstream from the dam by providing mixing from a single location. Smaller reservoirs can be entirely mixed (Ref. 3). It is not necessary to destratify an entire lake to achieve outflows of good quality water. Only the area near the outlet's structure may require oxygenation.

Hypolimnetic aeration is a procedure to provide oxygenation of the hypolimnion without destroying the existing thermal stratification. The purpose of avoiding the disturbance of the thermal stratification is to protect existing cold water in the hypolimnion. This water may be required for releases to support anadromous fish runs and fish spawning. By restricting aeration to the hypolimnion the temperature change inherent in mixing is prevented and the water quality is protected or enhanced.

Several techniques for accomplishing hypolimnetic oxygenation have been developed. U-tube designs, in which water is withdrawn from the hypolimnion, pumped to the surface and returned to the hypolimnion are a possible method. Compressed air may be injected into the water at the intake of the U-tube. Injection at this point provides contact time while the water travels to the surface. The undissolved air is subsequently vented at the water's surface. In another technique low pressure air or pure oxygen may be injected at the surface of the U-tube before returning the water to the hypolimnion. The process utilizes the increased hydrostatic pressure during the water's descent to effect oxygen absorption. Care must be exercised in operation to avoid creating sufficient turbulence to destroy the thermal stratification or to

increase total dissolved gases to toxic levels. The injection of pure oxygen is one method to avoid supersaturation of other gases (principally nitrogen) contained in air.

Aeration of Reservoir Releases

In order to discharge water with dissolved oxygen concentrations necessary to meet water quality standards it may be necessary to provide aeration of the reservoir releases. Proper design of multilevel outlets and other procedures may be insufficient to meet downstream requirements. Several methods of aerating discharges are available including turbine aeration by venting, Venturi tubes and Howell-Bunger valves.

The Venturi tube aeration device has not been tested on full scale reservoir releases and therefore must be considered experimental. In one device, air was injected into the throat of a Venturi section. The air was injected by taking advantage of the inherent vacuum created by these devices. The maximum efficiency of such a device occurs with only 0.5 mg/l increases; higher oxygen transfers required increased water velocity and consequential friction

losses. The device may only be efficient on small flows and not full size reservoir discharges (Ref. 4).

Turbine aeration makes use of the vacuum created by water flowing through the power turbines. Air is vented to the turbines to produce increased dissolved oxygen levels in the reservoir release. In the older style horizontal-type turbines existing draft tube vents have been used. These are frequently incorporated in the turbine to control cavitation. Oxygen transfer efficiencies of 37% have been reported with turbine power losses of about 5% (Ref. 5). Newer turbine units may have the turbine water wheel at elevations lower than tail water elevation which has the effect of producing only small negative pressures. The absence of substantial negative pressures is not conducive to efficient aeration. One solution to this constraint has been the installation of wedge shaped deflector plates in the draft tubes slightly below the turbine wheel. The negative pressure created in the wake of the turbulent flow past the deflectors is used to induce aeration flow. Aeration efficiency for water initally 80% saturated with oxygen varied from 25%-50%. Turbine efficiency was decreased by 0.83% (Ref. 6).

The Howell-Bunger valve is a fixed dispersion cone valve which can be used for reservoir releases to provide aeration. The Tennessee Valley Authority has performed extensive evaluation of this device for aeration purposes (Ref. 7). The valve produces a spray discharge which is similar to the common garden hose spray nozzle except that the cone is fixed rather than adjustable. Aeration efficiencies were determined during the TVA testing program and were defined as the ratio of final dissolved oxygen deficit to the initial dissolved oxygen deficit. Efficiencies of 80% were achieved when exit velocities exceeded 9 meters per second for a free discharge. Initial dissolved oxygen concentrations for these tests were less than 1 mg/l.

In addition to the possibilities for aeration while passing water through the dam, aeration may be applied in the tailrace or immediately downstream. Methods previously discussed such as U-tube aerators and diffused air aerators can be used as well as mechanical surface aerators. Methods which increase turbulence in the reservoir release increase aeration. The use of weirs or other devices can be employed in the tailrace to increase the turbulence.

Control of Biological Nuisance Organisms

Nuisance organisms in reservoirs related to water quality include excessive numbers of algae and rooted aquatic plants. The populations of these plants depend on a myriad of factors including nutrient concentrations and sufficient light. The most satisfactory and only long term control of these plants requires the institution of measures to reduce the causative factors. Nutrient reduction in inflows, shoreline alteration to reduce the existence of shallow areas, and the implementation of reservoir operation schedules are factors in controlling aquatic plant populations.

Temporary control measures are principally mechanical or chemical. Operational techniques of fluctuating reservoir water levels can also be practiced. In addition to reservoir destratification previously discussed, mechanical techniques include algae harvesting by centrifugation, coagulation and filtration, microstraining, and flotation; and the use of special cutting machines for harvesting rooted aquatics.

Harvesting algae from natural water bodies by any of the above methods has not received extensive investigation.

The efficiency of such harvesting methods is inversely proportional to the algal population density. This is because dilute solutions require additional pumping cost to recover a given amount of algae. Without a market for the removed algae to recover substantially the cost of removal the economics are not favorable to these techniques. There appears to be little hope of developing an economically feasible harvesting technique for the relatively dilute algal population densities that occur in natural waters.

The development of efficient, specialized cutting and harvesting machines allows the direct removal of rooted aquatic plants. In addition to the expense of operating the machines, disposal of the voluminous plant residue also must be taken into account. Various methods have been employed to reduce the volume of the plant material by compaction or drying before final disposal.

Chemical control methods use algicides or herbicides to control plant populations. Attributes of a satisfactory algicide or herbicide include: reasonably safe to handle and apply; kill specific nuisance plants; are relatively non-toxic to fish, other aquatic animals and terrestrial animals at plant-killing concentrations; are safe for water contact by humans or animals or for withdrawn water uses;

and are of reasonable cost. Tables 1, 2 and 3 present those herbicides presently registered in accordance with the Federal Insecticide, Fungicide, and Rodenticide Act. These tables indicate typical application locations and limitations. Application rates of these materials should reflect label instructions to avoid damage to non-target plant and animal species.

The suppression of rooted aquatics by water-level management has been utilized because of its practical advantages in economy and simplicity. Various kinds of plants can be controlled by drowning if depth and duration of submersion are sufficient. Use of lowered water levels is also efficient to control some plants although care must be exercised because other varieties of plants than the target species may become established while water levels are down. Flooding following mechanical cutting or herbicide application may assist in eliminating the return of nuisance species.

TABLE 1

HERBICIDES
REGISTERED FOR USE
IN OR ON WATER

Chemical	Sites, Types of Weeds, Limitations
Acrolein	Lakes, ponds; algae, submersed weeds. Do not apply to water used for domestic purposes. May use for irrigation and farm uses 3 days after application.
	Irrigation canals and drainage ditches. Do not use treated water for irrigation until concentration falls to 13.8 ppm.
Amitrole	Site unspecified - cattails. Do not contaminate water used for domestic or irrigation purposes.
Amitrole - T	Drainage ditches, marshes; cattails. Do not apply where water may be used for domestic or irrigation purposes.
	Drainage ditches, marshes; phragmites. Do not apply where water may be used for domestic or irrigation purposes.
	Drainage ditches, marshes; water hyacinth. Do not apply where water may be used for domestic or irrigation purposes.
Copper sulfate $5H_2O$	Lakes, ponds, potable water reservoirs; algae

Chemical	Sites, Types of Weeds, Limitations
Copper sulfate	Lakes, ponds, potable water reservoirs; algae
chelated	Industrial ponds.
Dalapon	Drainage ditches, spot treatment; cattails. Do not contaminate water used for irrigation or domestic purposes.
Dehydroabietyl-amine acetate	Lakes and ponds; algae. Do not apply to water used for domestic purposes.
	Irrigation canals, ditches; algae. Do not use treated water on crops.
Dichlobenil	Lakes, ponds; submersed weeds. Apply to water surface. Do not use treated water for irrigation or for human or livestock consumption. Do not use fish for food or feed within 90 days after treatment.
Dichlone	Lakes, ponds, canals; certain bloom producing blue green algae. Do not use in potable water.
Diquat	Lakes, ponds, ditches, laterals; submersed weeds. Do not use treated water for animal consumption, swimming, spraying, or irrigation until 10 days after treatment. Do not use treated water for drinking purposes until 14 days after treatment.
	Lakes, ponds, ditches, laterals; floating weeds. Do not use treated water for animal consumption, swimming, spraying, or irrigation until 10 days after treatment. Do not use treated water for drinking purposes until 14 days after treatment.

Chemical	Sites, Types of Weeds, Limitations
Diquat (Continued)	Lakes, ponds, ditches, laterals; emersed marginal. Do not use treated water for animal consumption, swimming, spraying, or irrigation until 10 days after treatment. Do not use treated water for drinking purposes until 14 days after treatment.
	Lakes, ponds, ditches, laterals; algae. Do not use treated water for animal consumption, swimming, spraying, or irrigation until 10 days after treatment. Do not use treated water for drinking purposes until 14 days after treatment.
Endothall (dimethyl alkylamine)	Lakes and ponds; algae. Do not use treated water within 7 days at 0.3 ppm, 14 days at 3.0 ppm.
	Lakes and ponds; submersed weeds. Do not use treated water within 7 days at 0.3 ppm, 14 days at 3.0 ppm.
	Irrigation canals, drainage ditches weeds. Do not use treated water within 7 days at 0.3 ppm, 14 days at 3.0 ppm, and 25 days at 5.0 ppm.
Endothall (dipotassium) (disodium)	Lakes and ponds; weeds. Do not use treated water for irrigation or domestic purposes within 7 days.

Chemical	Sites, Types of Weeds, Limitations
Petroleum Solvents	Irrigation and drainage ditches, inject into water. Do not contaminate water used for domestic purposes. Do not use treated water for irrigation until emulsion breaks or waste treated water.
Silvex	Lakes, ponds; emerged floating weeds. Do not contaminate water intended for domestic, irrigation, or crop spraying purposes.
	Lakes, ponds; submersed weeds. Do not contaminate water intended for domestic, irrigation, or crop spraying purposes.
Simazine	Ornamental ponds. Do not use in water intended for domestic or irrigation purposes.
Sodium pentachlorophenate	Paper mill supply impoundments, algae.
2,4-D	Lakes, ponds; floating weeds. Do not use treated water for domestic or irrigation purposes.
	Lakes, ponds; submersed weeds (granular). Do not use treated water for domestic or irrigation purposes.
	Lakes, ponds; emerged marginal weeds. Do not use treated water for domestic or irrigation purposes.
Xylene	Irrigation ditches, inject into water. Treated water may be used for furrow or flood irrigation.

TABLE 2
HERBICIDES
REGISTERED FOR USE
AT OR ABOVE WATER LINE

Chemical	Sites, Types of Weeds, Limitations
Amitrole	Drainage ditchbanks. Do not contaminate edible crops.
Amitrole-T	Ditchbanks. Keep livestock off treated areas.
Ammonium Sulfamate	Around lakes, ponds, potable water reservoirs and their supply streams; brush. Do not contaminate water.
	Around lakes, ponds, potable water reservoirs and their supply streams; weeds. Do not contaminate water.
Bromacil	Drainage ditch banks - spot treatment; brush control. Do not contaminate water or use in irrigation ditches.
	Ditchbanks; weeds. Do not contaminate domestic water.
Dimethyl arsinic acid	Drainage ditches; weeds. do not contaminate water used for domestic or irrigation purposes.
Diuron	Drainage ditchbanks.
DSMA	Ditchbanks, spot treatment. Do not contaminate water used for domestic or irrigation purposes.
Erbon	Drainage ditchbanks. Do not contaminate domestic or irrigation water.

Chemical	Sites, Types of Weeds, Limitations
Fenuron	Drainage ditchbanks; brush control.
Fenac	Ditchbanks. Do not contaminate water used for irrigation or domestic purposes.
Hexachloro-acetone	Drainage ditchbanks; weeds. Apply in oil.
MCPA	Ditchbanks; weeds.
MSMA	Drainage ditchbanks, spot treatment. Do not contaminate water used for domestic or irrigation purposes.
Petroleum solvents	Ditchbanks, irrigation and drainage. Do not contaminate irrigation water.
Picloram	Non-crop area - outer slope of ditches only, spot treatment. Do not contaminate water used for irrigation or domestic purposes.
	Drainage ditchbanks. Do not contaminate water used for domestic or irrigation purposes.
TBA	Ditchbanks.
2,4-D	Margins of lakes, ponds; emerged weeds. Do not use treated water for domestic or irrigation purposes.

TABLE 3
HERBICIDES
REGISTERED FOR USE
ON MUD BOTTOMS AFTER DRAWDOWN

Chemical	Sites, Types of Weeds, Limitations
Dichlobenil	Lakes, ponds; submersed weeds. Apply to exposed shore and bottom.
Diuron	Drainage and irrigation ditches. Drain off water, spray moist soil in ditch. Fill ditch and let stand 72 hours, then waste contained water before use of ditch. Do not contaminate domestic water.
Fenac	Lakes, drainage ditches; submersed weeds. Drain area and apply to exposed bottom. Do not use treated water for domestic purposes.
Monuron	Irrigation and drainage ditches; drain water off area, spray bottom, fill ditch and hold 72 hours, then waste contained water before use of ditch.
Xylene	Ponds, canals; drain off water and spray vegetation. Do not refill for 5 days.

Control of Adverse Effects on Ground Water

Methods to control ground water pollution caused by dams include the use of one or several alternatives. The dam and its foundation could be designed so that there is a minimum restriction to the down-valley-flow of ground water. The feasibility of this approach will depend, of course, on the size and type of dam as well as the geologic conditions of the dam-site.

In impoundments where the water-level is maintained such as for navigation the water table upstream from the dam could be lowered by appropriately placed pumping wells. Such wells would reduce the opportunity for pollution from ground water sources and would reduce the residence time of stored ground water. In general, water pumped from the wells would be of satisfactory quality for any available local beneficial uses; if none existed, the water could simply be released downstream from the dam. This procedure would increase the outflow of salts from the basin, minimizing accumulation. The drawdown of ground water occurs naturally in storage impoundments as reservoir levels decline. Pumping would not accomplish any benefit in these circumstances.

A more drastic measure would be to minimize potential sources of pollution in the area upstream of the dam. This could involve changes in land use, reduction in the application of agricultural fertilizers, or removal of agriculturally-related animals from the area. Justification for such a measure would require the absolute necessity for good quality water down gradient.

If the reservoir is to store poor-quality water, a site should be selected where seepage losses to the ground water will be minimal. If such a site does not exist, it may be necessary to wholly or partially line the reservoir bottom using, for example, compacted clay.

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V. Guidance for the Identification and Evaluation of the Effects of Urbanization

Introduction

Urbanization is the concentration of people and of domestic, commercial, and industrial structures in a given geographic area. Urban areas commonly include both suburban and central city complexes. The rapid trend toward urbanization is indicated by the fact that more than two thirds of the nation's population now reside in urban centers that occupy about 7 percent of the land area of the United States. By the year 2000 the urban population may include as much as three-fourths of the population.

This concentration of people and their activities results in a concentration both of water resource demands and of the wastes produced. Water may be diverted and conveyed to an urban area from sources hundreds of miles away. An example is the Los Angeles-San Diego metropolitan complex which receives water from the Colorado River and from Northern California. Runoff and infiltration in urban areas are markedly different than in the original undeveloped area. Thus, urban areas produce hydrologic and hydraulic problems connected with development of water supplies; increases in peak streamflows; and increased

mineralization of water resources due to changes in land-use patterns.

Extensive research has been directed toward the effects of urbanization especially directed toward surface water quality and surface water hydrology. This discussion will emphasize the effects on the ground water resource, which has not been as extensively recognized. Bibliographic material for both surface and subsurface material are included.

Sources of Pollution

Seawater intrusion in coastal aquifers is often associated with urban areas due to overpumping, reduction in natural recharge, and sometimes loss of recharge from septic systems that have been replaced by public sewers. Runoff from urban areas is heavily polluted, especially the initial flows. Urban leachate, a source of ground water pollution, owes its composition to dissolved organic and inorganic chemical constituents derived from a multiplicity of sources such as the cleansing of dirty air by precipitation, the leaching of materials from asphalt streets, inefficient methods of solid waste disposal, and poor housekeeping techniques at innumerable domestic and industrial locations. Urban leachate can be a direct contributor to stream

pollution because many urban centers are located in lowlands adjacent to large streams. In reverse, ground water withdrawals may permit flow of polluted water from streams to hydraulically interconnected aquifers. The expansion of densely populated urban and suburban developments into former rural or heavily fertilized agricultural areas has compounded the problem of ground water pollution by causing a mingling of the effluent from cesspools and septic tanks with fertilizer contaminated ground water. Moreover, in many urban and suburban areas, wastes that are accidentally or intentionally discharged on the land surface often reach shallow aquifers.

The pollutional effects of urbanization change as development proceeds. Initially, large amounts of erosional debris are produced as the original land surface is disturbed by construction. In the mature stage, domestic and industrial sewage, street runoff, garbage and refuse are the principal sources of pollution, which intensify with time.

Pollution from urban areas is not confined to the immediate area or to the immediately adjacent areas. The effects often extend for considerable distances in ground waters as well as in surface waters. A relatively recent

and unique problem that has attracted considerable attention is the pollution of ground water resulting from application of deicing salts to streets and highways in winter. The region affected is largely the Northeast and the North-Central states. The salt appears to reach the ground water both from storage stockpiles (Figure 6) and from solution of salt that has been spread on roadways.

The problem is widespread, litigation on the matter is not uncommon, and research on alternative non-polluting substances is underway.

Ground water in an urban environment may contain almost every conceivable inorganic and organic pollutant. A brief summary by source of the principal potential urban pollutants is given in Table 4.

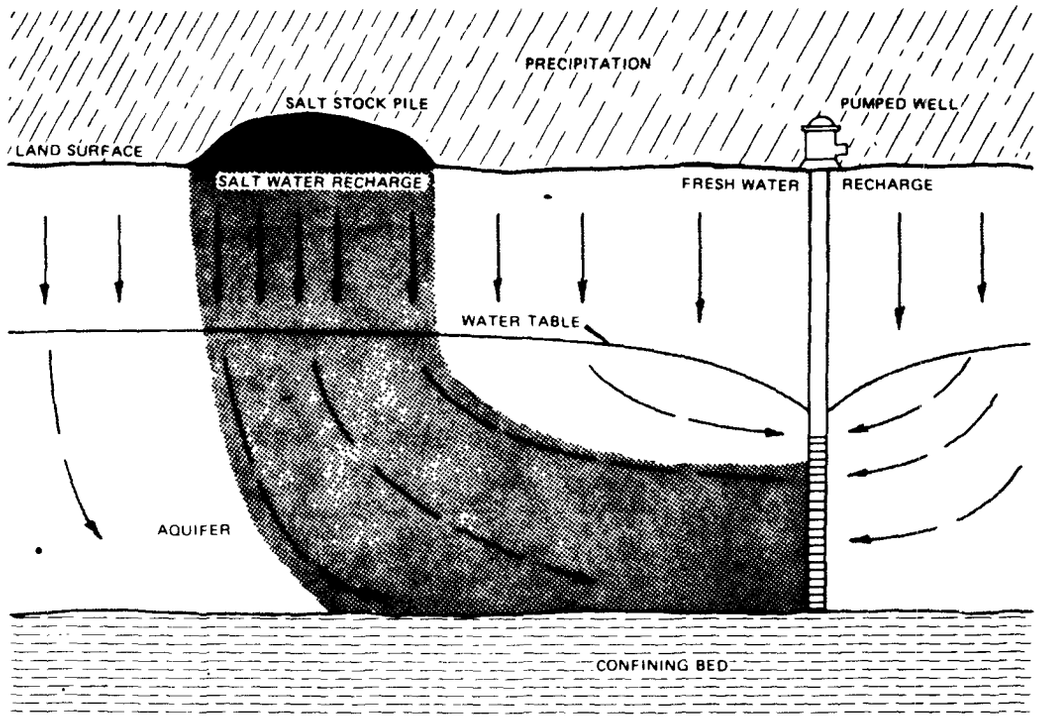

Figure 6 Conceptual Mechanism of Ground Water Pollution from Stock Pile Leaching

Table 4. Summary of Urban Ground Water Pollutants

Source	Principal Potential Pollutants
Atmosphere	Particulate matter, heavy metals, salts.
Precipitation	Particulate matter, salts, dissolved gases
Seawater encroachment	High dissolved solids, particularly sodium and chloride
Industrial lagoons	Heavy metals, acids, solvents, other inorganic and organic substances
Cesspool, septic tank, and sewage lagoon effluents	Sewage contaminants including high dissolved solids, chloride, sulfate, nitrogen, phosphate, detergents, bacteria
Leaky pipelines and storage tanks	Gasoline, fuel oil, solvents, and other chemicals
Spills of liquid chemicals	Heavy metals, salt, other inorganic and organic chemicals.
Urban runoff	Salt, fertilizer chemicals, nitrogen, and petroleum products
Landfills	Soluble organics, iron, manganese, methane, carbon dioxide, exotic industrial wastes, nitrogen, other dissolved constituents, bacteria
Leaky sewers	Sewage contaminants, industrial chemicals, and miscellaneous highway pollutants
Stockpiles of solid raw materials	Heavy metals, salt, other inorganic and organic chemicals
Surface storage of solid wastes	Heavy metals, salt, other inorganic and organic chemicals
Deicing salts for roads	Salts

Types of Pollutants

The change in land uses which occurs during the process of urbanization introduces new and varied constituents to both the surface and subsurface environments. The addition of some types of pollutants may actually decrease while others increase because of the land use transitions involved. Areas previously used for agricultural crop production may have received heavier applications of fertilizers, pesticides and herbicides prior to urbanization whereas unmanaged forest land may not have received directly applied materials from man's activities.

The basic inorganic pollutants added to the land's surface because of urbanization include the various constituents of fertilizers such as inorganic nitrogen, phosphorus and potassium; constituents associated with human wastes and associated domestic uses including chlorides, inorganic nitrogen, sodium, and phosphorus; constituents applied for street deicing such as calcium chloride and lawn soil neutralizers such as lime. Additional constituents are added by lawn sprinkling using imported water which include dissolved solids such as chlorides, sulfates, sodium, calcium and magnesium. Heavy metal concentrations also frequently increase following urbanization.

Organic pollutants include the whole gamut of commercially available products used commercially and in the home. These materials reach the surface and ground waters by direct application or through septic tank - tile field disposal systems. Examples of familiar organic compounds include detergents, insecticides, petroleum products, paints and other surface protection products, and chemicals related to various industrial or home use applications. Many of these compounds are sorbed by the soil where they are detained from passage into the surface and ground waters for indeterminate time periods. If persistence times for such materials exceed the time to saturate soil sorption sites, then ultimately these materials will be added to the local surface and ground water.

Biological contaminants are also of concern. These are principally contained in the fecal discharges of humans which are discharged to the environment through septic tank - tile field systems or leaky sewerage systems and those of domestic pets including dogs and cats. Pathogenic microbiological forms including both bacteria and viruses and parasites are potentially contained in these wastes.

Another effect of urbanization is the increased water temperature of both surface and ground waters. Surface

waters become heated because of increased temperatures of yards and paved areas which heat incident rainfall. Ground water temperatures are increased by the percolation of such waters and by the use and return of well water to cool air conditioning systems.

Methods of Pollutant Transport

Urbanization grossly alters the hydrology of an area. In general, the hydrological changes result in a decrease in the natural recharge to underlying ground water unless compensated for by artificial recharge. A reduction in recharge has an adverse effect on ground water quality if the quality of the natural recharge was high. The decrease in recharge is due to the impervious surfaces of an urban area: houses, streets, sidewalks, and commercial, industrial, and parking areas, which reduce direct infiltration and deep percolation of precipitation. Peak storm runoff and total runoff are increased by urbanization. However the occurrence of the runoff is over shorter time periods, and results in decreased streambed percolation. Natural streambed recharge is further decreased because of the lining of natural channels for flood control purposes.

The principal mechanism for ground water pollution transport in urban areas are infiltration of fluids placed

at or near the land's surface and leaching of soluble materials on the surface. The sources of fluids include deliberate disposal through wells, pits, and basins, and seepage from hundreds or thousands of miles of leaky storm water and sanitary sewers, water mains, gas mains, steam pipes, industrial pipelines, cesspools, septic tanks, and other subsurface facilities. Some natural treatment of the fluid occurs as it seeps downward through the soil zone; however, large quantities of pollutants, particularly the mineral constituents, may reach the water table in the uppermost aquifer. From there, the polluted water may move laterally toward natural discharge areas or toward pumping wells.

Magnitude and Variation

Major surface water sources have quality information available for urbanized areas. Smaller streams draining localized watersheds frequently do not have such information. Frequently the local drainage streams, do not have flow other than during the annual wet season or following rainstorms. The effects of urbanization on these waters is most noticeable when street, drainage and storm water from sewers constitutes the flow.

Ground water quality information in general is not nearly as available as surface water quality information. Wells are frequently sampled upon completion for chemical and bacteriological analyses. In urban areas where few wells exist and these principally for lawn sprinkling, quality analyses are relatively rare.

Information in areas with particularly severe ground water problems associated with urbanization is available. For example, extensive efforts have been made to determine the ground water quality on Long Island, New York. Much of this information is available in a professional paper series (No. 627) of the U.S. Geological Survey. Additional information is available from state geological surveys.

Surface water quality is available for some local streams from counties and cities in addition to the state water quality monitoring agency. Many of these agencies produce annual monitoring reports describing water quality in local streams.

Where urban areas use ground water from local wells, the wells should be monitored for pollutants that are associated with urban activities but may not be included in standard water analyses; for example, heavy metals. When

specific threats to ground water quality from past or present practices of waste disposal (accidental or deliberate) can be identified, special monitor wells may be warranted to provide advance warning of pollutants approaching water-supply wells.

Even though local ground water may not be a presently important source of supply in many communities, monitoring of its ambient quality is highly desirable in order to detect degradation and take action to reduce or prevent further pollution.

Prediction Methods

Prediction methods for the effect of urbanization for surface waters traditionally utilize basic hydrological methods to predict the quantity of run-off produced for various intensity storms coupled with field surveys of the pollution sources tributary to the stream. The most common hydrological model is the so called "rational method" which takes into acount the imperviousness of the area and the time of concentration for rainfall to flow to the collection point. Experience factors for determining pollutional loads from storm sewers and direct runoff can be applied to determine resulting water quality.

More sophisticated techniques have been devised using the concept of synthetic hydrology and stochastic processes to predict expected runoff and resulting water quality from various intensity storms. Such models are useful for planning channel capacity requirements as well as justifying treatment of incoming wastes. By projecting changes in runoff characteristics, the projection of future conditions is also possible.

Ground water quality prediction models are generally much more crudely developed than surface water models. Highly sophisticated mathematical hydraulic models are available but these lack the ability to predict mass transport of adsorbed or partially soluble compounds because of the difficult chemistry involved. Additionally, surveys of ground water conditions are expensive because of the great number of observation wells required to establish flow directions and existing water quality. Thus models must use scanty field data for verification or development.

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VI. Processes, Procedures and Methods to Control Pollution Resulting from Urbanization

The control of the effects of urbanization on surface water runoff has received considerable research attention especially in the area of storm water overflow. Potential control methods have been suggested and in some cases demonstration projects have been performed to evaluate such techniques (Ref. 1, 2, 3).

The effects on ground water caused by urbanization have not received an equivalent amount of research effort. Suggested control techniques in this report must in some cases rely on judgment rather than proven techniques.

The protection of urban water resources, both surface and subsurface, can be divided into 3 major categories: regulation of land use by zoning or other legal means; the maintenance of adequate waste collection, waste management and general environmental sanitation; and public education to minimize inadvertent pollution by maintaining public awareness of the environmental effects of various actions.

Regulation of Land Use

One method of controlling the evolution of pollutants from urbanization is to control the type of land development that occurs. Such control can be exerted through zoning, building codes or other regulatory measures. Such measures control the resulting population density, industrial activity, waste disposal technology used and the amount of impervious areas created by new roads, parking lots and roof areas.

Applicable legal control methods must be tailored to the requirements of the particular geographic area. Land use control measures for an area which furnishes the recharge to a principal aquifer or which forms the immediate drainage area for a water supply reservoir require different control measures than for other areas.

In the area of local codes and permits, ground water protection can be instituted by the use of controls requiring the proper plugging of abandoned wells. Although the pollution caused by abandoned wells within urban areas has never been assessed, the use of such wells as drains or for the disposal of other liquid materials can pollute local ground waters.

Regulations can also be designed to control the stockpiling of chemicals in such a manner as to prevent the leaching of these materials into local streams or ground waters. Storage on impermeable platforms, leachate control and treatment, and the provision of adequate covers are methods to control possible pollution from these sources.

Another code provision to protect ground water quality and to avoid surface nuisance in many other situations is the abandonment or prohibition of new installations of cesspool and septic tank systems in densely populated areas. Such systems can be replaced by sanitary sewer systems.

Waste Management and Environmental Sanitation

Once urbanization has occurred, the prevention of waste materials generated within the community from polluting local streams and ground waters requires attention to waste management and general environmental sanitation.

In addition to the proper operation of point sources such as waste treatment plants, provision for the collection, by means of drains and wells, and subsequent treatment of leachate from landfills or other storage, or treatment ponds or basins can minimize ground water

pollution. The necessity for such treatment operations can be combined with inspections to maintain adequate "housekeeping" practices at locations employing land storage or disposal of wastes.

The provision of frequent solid waste collection and care to keep the collected material contained within the collection vehicle helps to keep material from being flushed into local streams following rains. This practice in conjunction with thorough and frequent street cleaning reduces the pollutant strength in drainage from urban areas.

In areas where salt is applied to streets to control snow and ice, such use should be minimized to the amounts required for safety. Reductions may be accomplished in some cases by the use of clean sand in conjunction with the salt.

Public Education

Assistance from the public in controlling potential sources of surface and ground water pollution can be a major factor in reducing the pollution effects of urbanization. This assistance can be fostered by education programs administered through schools, community organizations, public seminars and public service announcements in the

local media. Such programs can emphasize good "housekeeping" practices to reduce litter, publicize procedures for optimal application of lawn fertilizers and chemicals to minimize runoff or leaching, and emphasize the following of label instructions for use and disposal of commonly used household chemicals.

In the process of alerting the public to specific things they can do to reduce pollution, an overall awareness of environmental protection is fostered which may carryover to prevent pollution in other areas of activity.

Reduction of Downstream or Down-Gradient Effects

In areas where ground water furnishes substantial quantities of the water used, aquifer depletion because of the loss of recharge area through urbanization is a serious problem. Ground water basins can be recharged using high quality surface waters which may be imported from other basins or by using highly treated waste effluents. The source and quality of the recharge water depends on the subsequent aquifer use that is being protected.

The recharge of ground water with high quality water has an added benefit in situations where ground water

sustains the base flow in local streams. When this water infiltrates it provides dilution water in lower stream reaches for both organic and inorganic materials and helps to maintain water quality for later uses.

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VII. Guidance for the Identification and Evaluation of the Nature and Extent of Dredging and Dredged Material Disposal

The purpose of this section is to indicate potential pollution problems associated with the general aspects of dredging and dredged material disposal. This section provides information that, when considered in the light of local conditions, will provide an indication of the kinds of measures that may be useful in a program to control pollution resulting from dredging and disposal activities. Problems associated with dredging or dredged material disposal may be minimal and may not adversely affect water quality under conditions at a given location.

It is not the intent of this section to provide sufficient detail for selecting practices for specific geographic areas, water courses, or individual dredging operations. Expertise, well-founded in the application of dredging and disposal techniques, must be brought to bear in design of the final control plan.

Current Involvement

The Corps of Engineers has been concerned with the development and maintenance of navigable waterways in the United States ever since Congressional Authorization was received in 1824 to remove sand bars and snags from major navigable rivers. The Code of Federal Regulations, Title 33, Chapter II, Part 209 assigns to the Corps of Engineers responsibility for enforcement of the principal laws for protection and preservation of navigation and navigable waters with respect to work or structures in or over such waters. Not only is the Corps of Engineers responsible for its own operations in navigable waters, it is also responsible for issuing permits for such activities by other Federal agencies, State or municipal governments, and private citizens or corporations, all of which are subject to the provisions of the laws for protection and preservation of navigable waters.

Recently enacted laws indicate the public's increasing awareness and concern over the possible adverse environmental effects associated with dredging and dredged material disposal. The National Environmental Policy Act of 1969 requires a detailed statement of environmental impact of proposed new navigation projects and projects requiring

maintenance dredging. The Rivers and Harbors Act of 1970 (Public Law 91-611) authorizes the Secretary of the Army, acting through the Chief of Engineers, to construct, operate, and maintain contained disposal facilities to handle polluted dredge material from the Great Lakes. The 1970 Rivers and Harbors Act, Sec. 123(i), also authorizes the Corps of Engineers to initiate a comprehensive nationwide program of research, study, and experimentation to provide more definitive information on the environmental impact of dredging and dredged material disposal and to develop new or improved alternative disposal practices. In a report entitled "Ocean Dumping A National Policy" submitted to the President in 1970 by the Council on Environmental Quality it was recommended that ocean dumping of harmful forms of dredged material be phased out as soon as alternatives are available that do not excessively increase costs. The report also recommended that dumping of unpolluted material be regulated to prevent damage to estuarine and coastal areas. The development of guidelines for selection of dredged material disposal sites in the navigable waters by the Administrator of the Environmental Protection Agency is authorized by the Federal Water Pollution Control Act Amendments of 1972 under Section 404. This Act gives the Administrator authority to restrict the use of any defined area for dredged material disposal.

To date over 35,000 kilometers (22,000 miles) of waterways have been modified for commercial navigation and over 30,000 kilometers (19,000 miles) of waterways and some 1,000 harbor projects are currently being maintained by the Corps of Engineers. The total annual quantity of material removed averages about 229 million cubic meters (300 million cubic yards) in maintenance dredging and about 61 million cubic meters (80 million cubic yards) in new work dredging. Total annual costs currently exceed $150,000,000 (ref. 1). Volumes of material produced by private dredging have been estimated to approximate the total annual volume of Corps dredging. The volume of material removed at a single project may vary from a few thousand cubic meters in a harbor maintenance project to many millions of cubic meters in channel development projects. Variation in the nature of the dredged material ranges from clean sand and gravel; to organic muck and sludge of natural origin; or to municipal and industrial waste sludges or any combination thereof.

The distribution and characterization of the material dredged is illustrated in figures 7, 8 and 9. The approximate average annual quantity of material dredged separated into types (i.e. mud, clay, silt vs. organic muck, sludge, etc.) is presented in Figure 7 broken down by each Corps of Engineers District. Figures 8 and 9 present for

each District an estimate of the amount of polluted and non-polluted material removed in maintenance dredging operations and the type of area used for final disposal. Similar information is unavailable for private dredging operations.

(Adapted from Tech. Report H-72-8, U. S. Army Engineers, 1972)

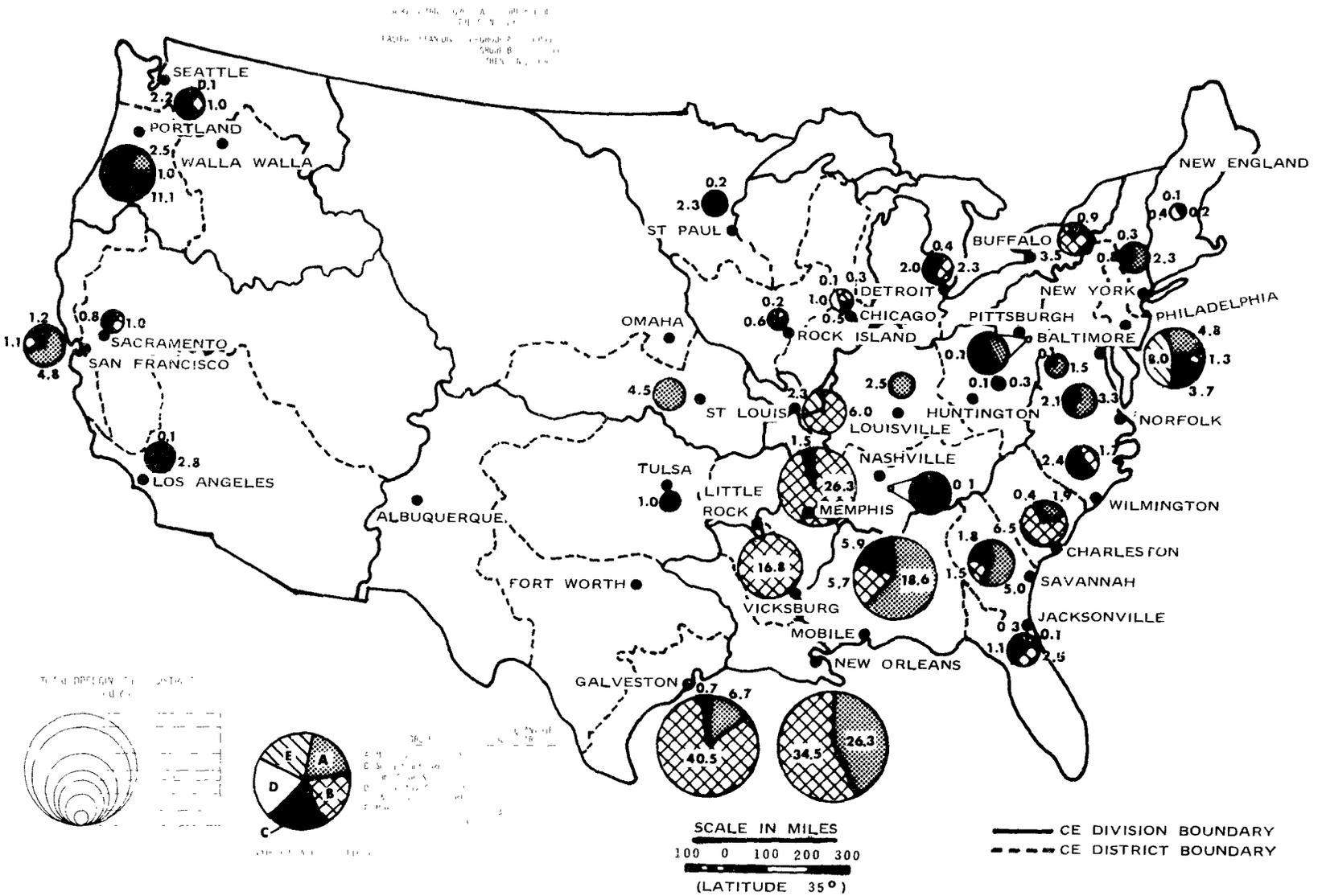

Figure 7 Corps of Engineers Dredging by District Including Total Amount and Spoil Classification

(Adapted from Tech. Report H-72-8, U. S. Army Engineers, 1972)

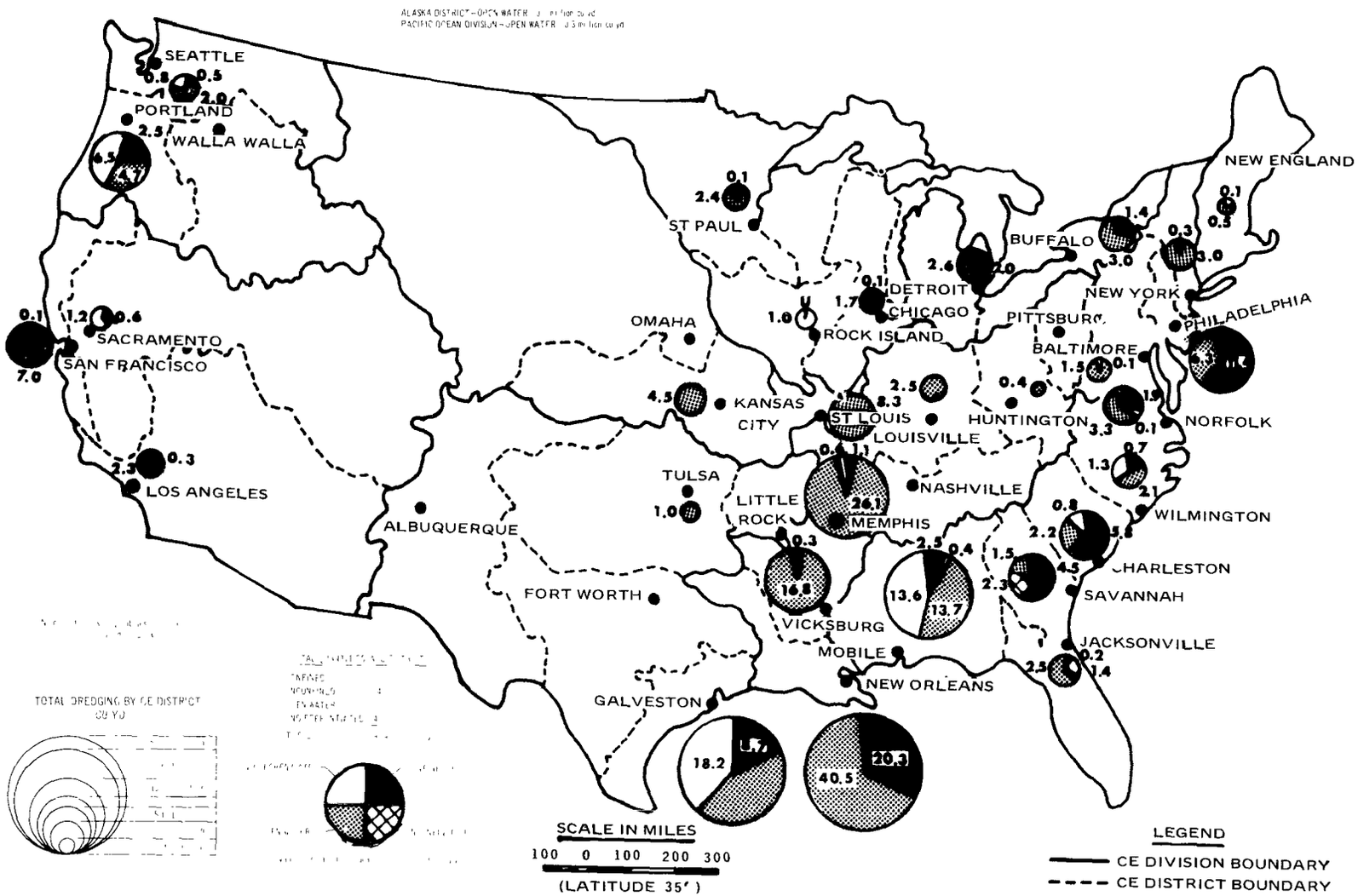

Figure 8 Corps of Engineers Dredging by District Including Total Amount and Method of Disposal

(Adapted from Tech. Report H-72-B, U. S. Army Engineers, 1972)

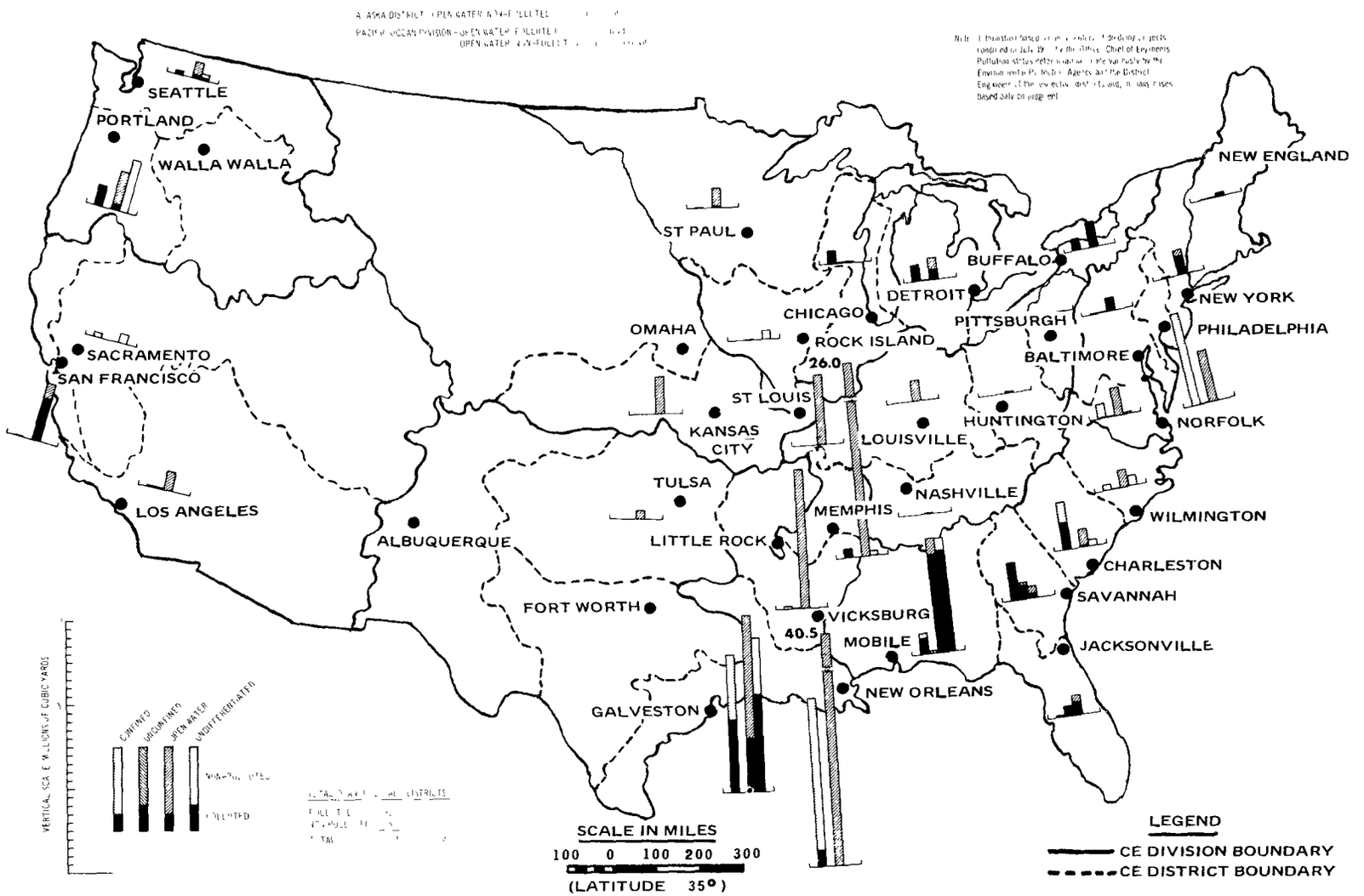

Figure 9 Corps of Engineers Dredging by District Differentiating Between Polluted and Non-Polluted Spoil

Current Practices

Dredging is a process in which sediments are removed from the bottom of streams, lakes, and coastal waters, transported via ship, barge, or pipeline, and discharged to land or water (Ref. 1). The usual purposes of dredging are to maintain, improve, or extend navigable waterways and to provide construction materials such as sand, gravel, or sea shell.

Methods available for dredging can be classified as either mechanical or hydraulic. Mechanical dredges are analogous in operating principal to land-based excavation equipment such as the dragline, shovel, or trenching machine, and can be operated from either dry land or from above the water's surface. Hydraulic dredges employ a pump to lift the material from the bottom and transport it by boat or through a pipeline, to the point of disposal. Hydraulic dredges of various configurations can be employed depending on the location of the operation and the nature of the particular materials to be removed. The principal concern in the design of dredging operations is generally with the volume of material to be removed and the location of the disposal site. Consideration of the potential

environmental consequences has increased markedly in recent years.

Sources and Types of Potential Pollutants

In order to assess the pollution potential of dredging and disposal of bottom material, a basic understanding of the types and sources of sediment and sediment contaminants is required. Basically, the types of contaminants found associated with the bottom sediment are no different than the constituents found in various industrial and domestic wastes or found occurring naturally. The types of materials encountered can be categorized into inorganic nutrients and biostimulants such as phosphates, toxic materials such as metals, organic materials such as peat or sewage sludge, and bioaccumulatory agents such as pesticides. In addition to the categorization of contaminants affiliated with bottom sediment, the sediment soil particles are usually classified by grain size into silt, clay, and sand, as well as into various ill-defined groups such as mud, peat, organic muck, and municipal and industrial sludges.

Overland runoff and accompanying sheet and gully erosion are often a major source of suspended solids. Plant nutrients and pesticides applied to the topsoil in

agricultural regions, or applied to lawns and gardens in municipal areas, may become attached to soil particles and be transported to the water. Other sources of suspended solids include bank erosion, bed erosion, other natural sediment suspension processes such as wave action, and various industrial and domestic sludges. Various dissolved chemical constituents, including a large variety of pollutants, often become sorbed on suspended silt and clay particles which subsequently settle to become sediments.

Disturbance of the bottom sediment, such as by dredging operations, increases the exposed surface area of these sediments. Thus the potential for sediment-related contaminants to leach into the overlying water is increased. In this sense, then, dredging may be considered as a potential source not only of suspended sediments, but of dissolved pollutants as well.

Effects of Dredging & Disposal Operations

AQUATIC DISPOSAL

The environmental impacts associated with dredging are those resulting from the removal of bottom material and its subsequent disposal. The physical alterations resulting

from the removal of bottom material include changes in bottom geometry by the creation of deep water regions, creation of new open water areas, changes in bottom substrates and biological habitats, alterations in water velocity and current patterns, changes in future sediment distribution patterns, alteration of the sediment-water interface with the potential subsequent release of biostimulatory or toxic constituents, and the creation of increased turbidity.

Direct effects of dredging on biological communities and/or water quality are the result of the physical disturbance and associated chemical pollutional effects on the aquatic biota. The principal concern is ordinarily with the short-term direct effects on biological communities but long-term effects should not be ignored. The long-term environmental impact of dredging is the subject of several investigations including the Dredged Material Research Program being conducted by the Corps of Engineers at the Waterways Experiment Station in Vicksburg, Mississippi. The direct effects, however, are usually confined to the project area. The possibility of benthic extermination, or, at a minimum, extensive damage, is often greater in those locales where "new" work has been instituted rather than in old or maintenance areas. A primary reason for this difference is

that often the substrate in such previously dredged areas is not conducive to benthic recruitment.

The most common adverse environmental effects potentially associated with spoil disposal include: turbidity, which is aesthetically displeasing, reduces light penetration, flocculates planktonic algae and decreases availability of food for aquatic organisms; sediment build-up, which could destroy spawning areas and smother benthic organisms, reduce bottom habitat diversity, and reduce food supply and vegetative coverings; and oxygen depletion which suffocates organisms in the area and releases noxious and undesirable materials such as methane, sulfides, and metals.

Increased sediment resuspension is commonly associated with dredging and spoil disposal operations. Disturbance of the channel, harbor, estuary, lake or other water body results in the resuspension of solids in the dredged area. These vary in physical, chemical and biological character and may result in both short-term and long-term effects on the quality of water at the site, or at times, at some distance from the actual operation. If these solids are composed of a large amount of very fine clays, silts and organic materials, the resulting increase in turbidity may effectively reduce light penetration and subsequently impair

primary food production necessary to the survival of higher organisms. Turbidity created during dredging can have harmful effects on fish. These adverse effects may include reduction of gill function, impairment of swimming ability, reduction of rate of growth and increase in susceptibility to disease.

Toxic materials and biostimulants such as heavy metals, phosphates, and pesticides sorbed or otherwise incorporated with sediment particles may be solubilized during dredging and resultant sediment resuspension, and thus degrade water quality. In some instances exposure of organic materials resulting from disturbance may reduce the dissolved oxygen content of the water. Total oxygen depletion in turn can suffocate organisms and cause anaerobic decay which may release methane, hydrogen sulfide and other toxic gases, further degrading water quality.

Sorbed constituents may give rise to long-term pollution effects in water. Prior to disturbance, the sediment with its sorbed chemicals has a minimum exposure to the overlying water. Consequently the release of sorbed material is very slow inasmuch as detachment normally only occurs at the sediment-water interface. Desorption is the release of chemical constituents from the surface of

particles including colloidal silts and clays. Inasmuch as the rate and amount of constituent desorption may be dependent on bottom sediment movement, dredging operations have the potential for increasing desorption. Conversely, it is also possible that the increased exposure of sediment surfaces due to dredging and disposal operations may increase the rate and extent of sorption of some materials thus reducing dissolved concentrations of such pollutants.

The most adverse effects of sediment on the aquatic ecology may result from maintenance dredging and spoil disposal where the volume of silt, clay, mud, organic muck, sewage and industrial sludges, together with municipal and industrial debris is high. Materials from maintenance dredging may also contain considerable amounts of heavy metals, sulfides, phenolics and other toxic elements.

Sediments dredged from previously undisturbed areas are ordinarily of relatively high chemical and physical quality inasmuch as their composition is similar to that of the geologic strata which they represent. These sediments are primarily sand, gravel, rock particulates, clay and shale. Contamination by organic and toxic materials, nutrients, pesticides and municipal-industrial wastes may be slight or even absent, in "new" work areas.

LAND DISPOSAL

On-land dredged material disposal sites, unless carefully chosen, may be instrumental in polluting both adjacent water bodies and the ground water environment underlying the disposal site. In addition to objectionable odors, fine grained spoil masses may retain their high water content and remain slurry-like for considerable periods of time. This condition may result in a high degree of instability, particularly in low lying marginal areas. Following such disposal operations the foundation conditions in these areas often remain unsuitable for residential, commercial, and industrial construction.

Spoil is often placed near or adjacent to urban centers or in congested areas as a land fill material. In the past many fill areas developed in an unplanned fashion as a result of a secondary or indirect (by-product) effect of dredging. In recent years such fill operations have been intentionally performed to reclaim or improve land. This practice is proceeding at an accelerated rate. Under such conditions spoil is confined or contained by various means which tends to regionally limit destruction that previously occurred in unconfined areas of land disposal.

Suburban development involves land that is scarce and costly. Foundation conditions are generally competent, allowing spoil to be placed to considerable heights. There are, however, coastal community, coastal resort, and other areas where poor foundation conditions prevail. Disposal in these locales is often aggravated by poor drainage and a shallow water table.

In the initial stage of a new fill, seepage out of the fill area may be excessive and should be controlled if possible. Seepage through and beneath containment dikes should be analyzed to determine if a pollution potential exists and if so, to identify those pollutants and measures to control them. The extent of possible groundwater contamination should also be established and remedial measures applied. If the spoil contains a high percentage of fine-grained organic material, it usually yields a highly compressible, weak (incompetent) foundation. The unstable condition is further aggravated when the fill is placed on wet, organic and compressible subsurface soils.

Where spoil disposal occurs in a containment area, proper design consideration must be given to outlet structures such as outfalls and return ditches that discharge and convey the fluid fraction of the material.

The return flow is often contaminated and may contain a high percentage of suspended solids, dissolved chemicals, and sorbed pollutants. The removal efficiency of these solids and associated pollutants in the fill area is often very low due to limited retention time. A large percentage of the escaping solids are colloidal and essentially impossible to remove by relatively inexpensive, conventional procedures. Without proper controls being incorporated, channelization at the outlet works and further erosion of the land surface by indiscriminately discharged water may occur.

Damage to the ground water province beneath and adjacent to fill areas occurs through the leaching of soluble minerals, chemicals, nutrients and toxic substances. Such leaching is an ever-present hazard associated with any dry land spoil disposal operation. Once contaminated, the aquifer may be damaged "permanently" or, at best, long-term and may result in the ultimate abandonment of water wells in the vicinity. Potential adverse water quality effects on aquifers underlying a proposed fill area should be carefully evaluated prior to initiation of spoil disposal.

Potential sources of ground water pollution associated with dredging and dredged material disposal can include: the breaching of aquicludes which results in the direct

introduction of saline or contaminated surface waters to an underlying aquifer; changes in the surface water hydrology or circulation patterns with a subsequent seepage of contaminated surface waters to the ground water regime; and infiltration of polluted seepage and leachate from land deposited spoil.

Prediction Methods

Prediction of the potential for water pollution from dredging and disposal operations requires consideration of a number of interacting factors. These include the hydraulics of the project area and the waters adjacent to the disposed material, the chemistry of the spoil material, the chemical and physical character of the newly exposed surface, and a knowledge of the involved biological communities.

Prediction of the flow patterns and associated bank and bed scouring, silt deposition, and flooding is facilitated by hydraulic model studies such as those conducted for many years by the Corps of Engineers. Mathematical models to predict effects from hydrographic modifications have been developed by many agencies including the Environmental Protection Agency, Corps of Engineers and the Geological Survey.

Comparative field studies of the effects of dredging and dredged material disposal on aquatic biota have recently been undertaken. The number of these types of studies will no doubt be greatly increased in the future.

In those instances involving the scalping of an aquifer, or other alteration of the flow of ground water, hydrogeological investigations are also required to predict the detrimental effects which may involve surface geological mapping, stratigraphic drill core analyses, pumping tests and mathematical or analog modeling.

If the spoil disposal is into water, the fines and other solids and associated sorbed pollutants will be carried in the direction of water current movement. In a river, the downstream effects of these materials are a function of such factors as the quality, particle size, solubility and particle density of the sorbed pollutants and the current velocity, and amount and type of turbulence of the river. Additional factors affecting sediment travel are the slope of the channel, the irregularity of stream bottom, the depth, and the discharge volume. The rate of change of velocity is also an important factor regarding the range of sediment travel. Velocity decreases promote settling,

whereas velocity increases encourage scouring and resuspension of sediments.

Spoil discharged into large water bodies such as estuaries, harbors and bays may form temporary turbidity plumes whose extent and geometry are primarily a function of the water movements in which they are transported.

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VIII. Methods, Processes and Procedures to Control Pollution Resulting from Dredging and Dredge Spoil Disposal

Dredging may result in pollution at both the removal and disposal sites. The direct water quality effects of dredging, especially those confined to the project, may be short-term and may include: turbidity effects, sediment build up, oxygen depletion, removal of substrate materials, and resuspension of solids. For the most part these effects are inseparable from the dredging operation and occur to some degree in every project. It is possible, however, with good engineering practices, to minimize and localize the adverse effects both at the removal and disposal site.

The information presented in this section relies heavily on that developed by the Corps of Engineers as published in the report entitled "Disposal of Dredge Spoil-Problem Identification and Assessment and Research Program Development," Boyd, M. B. et. al. 1972 (ref 1).

Treatment Before and During Dredging

Dredged materials vary widely in both physical and chemical characteristics. While many types may be considered polluted, major problems are generally limited to highly organic, petrochemical-laden silts and clays and domestic and industrial sewage sludges found in waterways bordered by heavy population or industrial concentrations. High concentrations of heavy metals may also be associated with these materials.

AERATION

Aeration can be utilized to stabilize (oxidize) highly organic material. Successful utilization in dredging will depend on proper application of established sanitary engineering principles including sufficient oxygen/water interaction over an adequate time period. Mechanical aerators and pneumatic bubbler systems have been used experimentally in the pilot programs. In concept, satisfactory aeration by mechanical or bubbler systems using air or oxygen could possibly be performed within either a confined land disposal site or an enclosed open water area bounded by a silt curtain. Basically, the process involves spraying, by sidecasting or similar method, the material

into a sufficient volume of water surrounded by a silt barrier. The spoil would then be subjected to prolonged aeration in an effort to satisfy the associated oxygen demand. It is conceivable that aeration could be followed by coagulation. If this system proves practical, dredging could be used to both improve the area from which the material was removed by removing unwanted organic substances and improving overall water quality by satisfying the oxygen demand associated with organic material. Aeration offers the potential to deal with highly polluted spoil in a progressive, environmentally compatible manner.

Aeration of bays, harbors, and other areas has been suggested as a possible method of treatment where organic sludges are responsible for noxious anaerobic conditions. The method, if ultimately proven practicable, could result in changeover from anaerobic to aerobic decomposition and conceivably modify long-term ecologically undesirable and aesthetically displeasing conditions. Effectiveness of such techniques may be enhanced if combined with the selective removal of organic bottom sediments by dredging.

CHEMICAL TREATMENT

Chemicals such as oxidants, flocculants, and non-wetting agents may improve dredged materials during or subsequent to dredging and disposal operations. Chemical treatment methods are currently under investigation.

DISPOSAL TREATMENT

Dredged material may also be treated before being redeposited. Such treatment would not effect the dredged site, but could possibly aid in improving the deposition area.

Suggested methods all of which have had limited application in treating dredged material before redeposition include:

Flocculation

Flocculation within a diked disposal area has been successful in speeding the natural sedimentation process and thus clarifying the resultant effluent. However, this technique requires fairly quiescent water, maximum settling prior to addition of chemicals, and efficient mixing. A

suggested open water disposal practice would utilize a silt barrier to enclose a "treatment area" in which dredged material could be deposited.

After an initial settling period flocculants would be applied. This method holds promise of limiting possible undesirable effects of dredged material disposal.

Incineration

Much as in municipal and industrial waste treatment, the treatment of highly organic dredged material requires handling of a solid and liquid phase. Incineration is a proven technique that can be expected to handle organic solids and may be applicable to highly organic dredged material. Sludge with a sufficiently high volatile solids content occurs in a number of harbor areas. The sludge would require preliminary dewatering through settling, vacuum filtration, or some other technique before incineration. Other proposed stabilization techniques include wet oxidation and fluid bed incineration. Air pollution must be controlled in all cases.

Filtration

The use of filters of various types is a possibility. If the spoil contains a sufficient percentage of sand, gravel, or other large particles, a screening or centrifuge process can perform fairly efficient water-solids separation. In the case of finer materials, sand bed filters, as used in municipal water treatment plants, could possibly find application in effluent treatment. Such filters could be built as integral parts of a diked area.

Since the spoil placed in a confined disposal area may often be physically similar to domestic sewage sludge, the use of vacuum filters for initial dewatering appears possible. In this manner, the sludge could be separated out for eventual inland disposal (by other means such as rail or road haul). The disposal area could be regarded as a treatment plant, the larger solids being separated by vacuum filters and the liquid effluent being treated by other processes. Pretreatment by coagulant aids such as long-chain polymers, or alum, would probably be necessary to aid the dewatering process.

Sewage Treatment Plants

Disposal of highly organic dredged material from waterways into a waste water treatment plant may be practical in some cases, but is expensive and requires long periods of time to dispose of large quantities of solids. The nature and volume of the material would normally overwhelm the capacity of a typical treatment facility. A major limitation of this system is the requirement that dredging operations cease during periods of high sewage flow, such as those following a rainstorm. The scheme would be unworkable in large dredging projects, but may be a viable alternative in small projects, particularly if temporary storage facilities are available to hold the material for further processing.

Dredged Material Disposal Techniques

Dredged material can be disposed of on land, in estuaries or in open water. Some of the adverse effects can be mitigated or ameliorated by proper disposal site selection to minimize ecological effects. Additionally, modified dredging techniques or the use of peripheral equipment designed to reduce spoil losses can also reduce adverse effects.

OPEN WATER DISPOSAL

The Environmental Protection Agency has published guidelines for disposal in the oceans (16 May 1973 Federal Register) and will establish guidelines for the navigable waters under Section 404 of Public Law 92-500. The discussion here is of a general nature and not meant to supplant these activities. Short-term effects of open water disposal of dredged material on the benthic biological community included destruction of less mobile forms whereas some types were able to surface and survive. High turbidity associated with spoil disposal apparently had little direct effect on organism mortality.

Methods designed to minimize the effects of dredged material disposal include: investigation of current dispersal patterns before site selection, benthic community surveys and the accurate placement of dredge spoil.

If the spoil contains pollutants, estimates of the impact of oxygen demands created or the release of toxic compounds must be made before disposal. Site selection or the use of alternative disposal methods will be influenced by the nature and presence of these pollutants.

LAND DISPOSAL

Land disposal is defined as disposal neither in open water nor on marsh land. It includes disposal on upland areas or on bars or islands. Such areas may be confined by dikes or natural barriers or may be unconfined. Confined areas are usually equipped with spillways or overflow weirs and occasionally with settling basins.

Dikes may be constructed of incompetent material and in these instances careful design is required to prevent failure. Dikes have breeched on numerous occasions causing extensive losses of spoil. In some instances dikes may be pervious and permit seepage through and beneath the structure. Ground water contamination adjacent to and beneath the disposal area may occur. If such contamination is likely, the use of liners or other impervious materials may be required.

Methods of improvement and utilization have been developed to minimize the effects of dredged material disposal. The spoil often contains a significant percentage of fine grained organic constituents and high water content. Such materials are generally ill-suited for foundations. Improvement of structural properties can be accomplished by

dewatering and compacting. Dredged material drains very slowly because the dikes foster perched water tables and water retention.

Several methods have been incorporated into projects to improve the structural properties of the material:

Ditching - The water table can be lowered by ditches which also provide drainage of surface runoff. Removal of the water also promotes consolidation.

Sand Drains - The vertical sand drain is a cylindrical column of sand or granular material placed in a vertical hole and connected at the original surface with a drainage blanket. These drains provide an avenue of escape for pore water and promote consolidation.

Ground Surface Drains - This method requires that the disposal site be initially covered by a layer of sand before applying dredged material. The horizontal sand "blanket" provides a permanent drain for overlying water and promotes consolidation.

Experimental projects have suggested the possible use of vacuum wells, electroosmosis and dessication for

dewatering dredged material. Additional research and testing will be required to evaluate these techniques.

MARSHLAND DISPOSAL

Marshland disposal has been common in the past because of accessibility and the inexpensive value of the land. Because of the increasing expense of other land resulting from development of coastal areas, these marshlands were frequently the only land disposal sites available.

Disposal of dredged material on marshes and wetlands is contrary to existing Environmental Protection Agency policy. The Environmental Protection Agency's policy statement on protection of the Nation's wetlands appeared in the Federal Register, Volume 38, Number 84 Wednesday, May 2, 1973. The policy statement is aimed at preservation and protection of the wetland ecosystems from destruction by waste water or nonpoint source discharges. The policy makes specific reference to the necessity "...to protect wetlands from adverse dredging or filling practices..."

Productive Uses of Spoil

Rather than being considered detrimental, spoil can be used advantageously under certain circumstances. Potentially beneficial uses are outlined below.

ARTIFICIAL WILDLIFE HABITAT CREATION

Among the most promising artificial habitat creation schemes using dredged material is the dredged-material island and the creation of marshes. Artificially created dredged-material islands may be naturally colonized by indigenous terrestrial vegetation or specialized waterfowl feed plants can be introduced. Small lakes may be created for fish and wildlife habitats within the disposal area.

Careful spoil placement and recolonization of marsh vegetation is required. Since many of the nation's marshes have been destroyed by previous dredging operations and other of man's activities, the creation of new marshes in such areas is desirable to restore or replace the ecological nursery and habitat for fish and wildlife.

Another possible artificial habitat is the development of shellfish beds in open coastal water areas. Whole

ecosystem habitats can possibly be re-created in conjunction with dredged material islands and artificial marshlands. These methods must be evaluated as to their possible effect on existing ecosystems.

LAND DEVELOPMENT

Land environments adjacent to the oceans, estuaries and major streams offer valuable sites for commercial, industrial and recreational development. Dredged material disposal practices in these areas can be very useful if properly managed.

Dredged material landfill can be directed to the development of recreational areas to the benefit of man. The use of life-supporting "top" material on a spoil fill will encourage rapid development of terrestrial vegetation.

Land created by dredge material disposal has historically been used in harbor development and for other construction whether deliberately placed or fortuitously located. Piers, access roads and commercial and industrial structures have been constructed on dredged spoil material.

Special materials such as sand which have good drainage and competent structural properties should be used where construction is anticipated. Since these materials are generally not polluted to a significant degree, the drainage and runoff ordinarily cause minimal environmental effects. However, these projects generally do not assist in the disposal of material from maintenance dredging which may contain a high percentage of silts and clays. Treatment methods would be required to use these materials in fills where construction is anticipated.

The use of maintenance dredging materials, often organically polluted, also creates the possibility of ground water pollution. Unless the material is appropriately treated or the drainage adequately controlled, percolating waters may convey leached pollutants from the fill into the underlying ground waters.

AGRICULTURAL LAND USE

Isolated studies have been made on the application of organically rich dredged material to agricultural lands using methodology similar to that developed for applying sewage sludge to the land. Careful material selection is required so that damage may be avoided. Application of

clay-silt dredged material to sandy soils may improve moisture holding, ion exchange, and textural characteristics. Improper application could reduce drainability.

Agricultural use of marine dredged material generally is not possible inasmuch as the high salinity level of the material may be lethal to plant life. Also, leaching of marine material may seriously impair ground water quality.

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