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THE CONTROL OF POLLUTION FROM

CONSTRUCTION ACTIVITIES

CAUSING CHANGES IN THE CIRCULATION OF WATER

Office of Water Program Operations
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This report will discuss processes, procedures and methods to control pollution resulting from changes in the movement, flow or circulation of any navigable waters or ground waters caused by construction activities in or in conjunction with a stream channel which includes construction of dams, levees, channels or flow diversion facilities. This report is mandated in Section 304(e)(1)&(2) part (F) of PL 92-500.

The initial step in such a study is to endeavor to determine exactly what the congress intended to accomplished by this Section of the Federal Water Pollution Control Act Amendments of 1972. Examination of the Senate Committee on Public Works Report which accompanied S. 2770 and the Report of Committee on Public Works of the U.S. House of Representatives which accompanied H.R. 11896 was made to make this determination in conjunction with the specific language contained in the law as finally passed (P.L. 92-500).

The information, guideance, and procedures are described by the Senate Committee as "...the impact on water quality

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of hydrographic modification work,..." (p.49). The term 33
water quality is defined by the Committee as "...to refer to 34
the biological, chemical and physical parameters of aquatic 35
ecosystems, and is intended to include reference to key
species, natural temperature and current flow patterns,..." 36
(p.51). Thus, changes in flow patterns through channel 38
modification which must be identified and if possible, 39
methods to reverse or alleviate damages described. Another 41
problem cited by the Committee is the effects of "...the
temporary or permanent obstruction or diversion of fresh 42
water flows in the construction of a dam or other facility, 43
which may also cause salt water intrusion from estuaries" 44
(p.54).

The descriptions in the House of Representatives 46
Committee were not as expansive as the Senate Committee's 47
discussion for this section. The report directs the 49
Administrator to be "...diligent in gathering and
distribution of the guidelines for the identification and 50
the information or processes, procedures, and methods for 51
control of pollution from such non-point sources 52
as...natural and manmade changes in the normal flow of 53
surface and ground waters."

With these comments in mind, the specific language of the bill is clarified. 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) calls for guidelines for identification and evaluation; this does not require EPA to identify and evaluate rather only to provide yardsticks 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 bed modification. It does not require evaluation of these methods, only identification.

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Basically the assigned task is to develop informational 79
guidelines for evaluating the pollution caused by flow and 80
circulation changes through stream bed modifications; and to 81
describe known processes to control pollution resulting from 82
such changes. Although not mandated in the legislation, the 84
pollution problems themselves must also be identified and 86
highlighted in order for the mandated requirements to be
meaningful. This is not to say evaluated, but only 88
identified.

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Guidance for the Identification 93
and Evaluation of Channelization 94

Introduction 99

This discussion will be limited to aspects of 102
channelization where actual in-channel modifications occur. 103
Consideration of other aspects of channelization will be 105
covered under separate headings such as reservoirs. 106

The type of channel envisaged in this discussion is the 108
relatively small stream which frequently floods either urban 110
or rural areas causing significant damage. Also included 111
are those drainage projects used to render low-lying
wetlands usable for agriculture or construction of suburban 112
developments.

Current Governmental Involvement 116

The initial step in identifying and subsequently 119
evaluating channelization projects is to determine those 120
governmental agencies, private groups and individuals 122

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involved in designing and constructing projects. For Federal Agencies the list is quite short, perhaps even shorter for State Agencies but conceivably quite extensive for local agroups and individuals constructing such 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 may be indirectly involved in smaller projects because drainage or flood protection may be included as part of a project. These Agencies would include the Federal Housing Administration in the Department of Housing and Urban Development, Veterans Administration and Federal Highway Administration of the Department of Transportation. These smaller incidental projects will not be discussed in this section.

Contacts with the major Federal Construction Agencies should yield listings of projects completed, under planning

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and/or design and those being requested by various local governments or private interest groups. Such contacts would provide 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 of such organizations used 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 Districts, 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 totally for Federally ineligible projects.

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Privately constructed projects are even more difficult to identify. Usually, these projects are small and limited to an 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 developments. However, the effects of such projects may cause significant water quantity and quality changes in a given area. These projects may be identified by examination of Department of Agriculture aerial photographs, examination of construction permits issued, examination of recently constructed housing subdivisions or 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 controlled 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 highest benefit-cost ratio unless some compelling reason overrides the economic justification.

CLEARING AND SNAGGING 200

Clearing and snagging operations may be used as an 202
independent technique for increasing channel hydraulic 203
capacity or it may in essence be a maintenance technique for 205
maintaining a previously improved channel. The basic 207
operation is the removal of obstructions from the channel
which may impede flow directly, increase hydraulic friction, 208
or present obstructions which accumulate debris carried by 209
the stream during high water conditions and reduce the 210
available area of flow.

Clearing and snagging operations are frequently used 212
following high water to remove accumulated debris, logs, 213
rocks, etc. and restore the hydraulic capacity of the 214
channel. Equipment used consists of bulldozers and front 215
loaders to physically remove the obstructions. 216

Although the least expensive means for increasing the 218
hydraulic capacity, clearing and snagging is also the least 219
effective. Only modest improvements can be anticipated and 221
these frequently short lived. In certain types of basins 222

channel obstructions re-occur within relatively short spans 223
of time.

CHANNEL EXCAVATIONS 226

Channel excavating is principally of two types. In 229
many cases the existing channel is enlarged and reshaped to 230
increase hydraulic capacity. In other cases the existing 232
channel is abandoned with a new channel being excavated. 233
New channel construction has also frequently been used for 234
irrigation canals where no previous channel existed. In 236
these irrigation channels, design is more precise because 237
flow rates are predetermined and not subject to the whims of 238
nature.

The design configuration and construction of the 240
channel excavations depends on the purpose and setting of 241
the new channel. In urban areas where land values are high 242
and flood damage losses high, channels are frequently 243
designed with a rectangular configuration and are concrete 244
lined to achieve maximum hydraulic efficiency and require a 245
minimum of right-of-way. In rural settings channels may be 246
designed wider with a trapezodal shape. Side slopes are 247

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determined by soil stability or by the final covering used 247
such as grass or rip-rap. In situations where channel 249
straightening has resulted in excessively steep hydraulic 250
slopes with resulting excessively high water velocities
which erode the channel bottom or side slopes, drop 251
structures are used to dissipate energy at frequent points 252
along the channel.

The method selected for excavation varies with the 254
project size, whether "wet" or "dry" techniques are possible 255
and the method of disposing of the spoil. In dry situations 257
conventional drag lines, power shovels or front end loaders 258
are used; in wet situations generally some method of
dredging is employed. The dredging method used also depends 260
on the material to be dredged.

CHANNEL REALIGNMENT 263

The purpose of channel realignment is principally to 265
eliminate the meandering of the stream over the flood plain. 266
Such meanders frequently result in instabilities which cause 268
shifting of the channel and poor hydraulic efficiency. By 270
realigning the channel into a straighter and therefore

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shorter length, costs of a channel improvement may be reduced.

Restraints on realignment are existing roads and bridges and the existence of available land for right of way. Channel realignment is complicated by the problem of excavated material disposal and the abandonment of the fish and wildlife habitat available in the old channel. Frequently, these "oxbows" are maintained with sufficient flow or backwater to maintain the habitat.

FLOODWAYS

Floodways are channels which are constructed to convey floodwaters around a protected area. These channels may be constructed in lieu of modification of the existing channel or in conjunction with channel hydraulic improvements.

Such channels are constructed to be dry until the water stage in the stream reaches a predetermined 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 are generally shorter than the natural 297
channel and have greater hydraulic efficiency. Flood stages 299
up-and-downstream may be affected by such a project.

Since floodways are normally dry, they may be used for 301
other purposes such as pasture or as parkland. Maintence is 303
required to remove new growths of trees and brush and to
maintain grass cover to minimize erosion during flood 304
periods.

This type of flood control project requires more land 306
then a channel modification project and is therefore more 307
expensive. Maintenance costs are also high especially if 308
non-permanent overflow devices are used such as a narrow 309
earthen levee which must be replaced following each period 310
of high water.

The principal benefits as related to water quality are 312
the non-destruction of the natural fish and wildlife habitat 314
and aesthetically by maintaining the natural appearance of 315
the stream.

RESERVOIRS 318

The type of reservoir considered in this discussion of 320
channelization is basically a retarding basin. These basins 322
contain a dam with an ungated outlet which discharges water
proportional to the height of water stored in the reservoir. 324

The purpose of these structures to hold large volumes 326
of storm water initially with a subsequent gradual release 327
when the channel capacity exists to pass the flow. The 329
hydrograph thus reflects a reduced stage and is lengthened 330
time-wise consequently reducing flooding downstream.

Consideration of such structures as part of a project 332
is influenced by actual construction costs, land acquisition 333
costs and the existence of acceptable terrain. 334

DRAINAGE DITCHES 337

Drainage ditches, although included in a channelization 339
scheme as part of the justification, seldom dictate channel 341
capacity. Channel capacity normally is dictated by flood 342
flow conditions. Drainage ditches usually involve deepening 343
natural channels or in constructing new ditches where none 344
previously existed.

The major effect on the hydrology is to lower the water 346
table and perhaps reduce dry weather stream flows in the 347
main channel if ditching is sufficiently extensive. Some 349
increase in main channel peak flows may occur as a result of 350
better interception of surface run-off and more efficient
hydraulic conveyance than previously existed. 351

Depletion of ground waters and subsequent reduction of 353
stream flows can adversely affect water quality in both the 355
surface and subsurface. In addition to adverse effects on 356
fish and wildlife habitat, there is decreases dilution water 357
and higher water temperatures.

Sources of Pollution 361

Following stabilization after the various 364
channelization schemes, both direct and indirect sources of 365
pollution are identifiable. Realizing that the main purpose 367
of channelization projects is either to increase hydraulic 368
capacity to convey flood waters thus protecting adjacent 369
property; or to provide drainage of land to increase its 370
economic usefulness, the attributes in terms of 371
environmental pollution are readily apparent.

SCOUR FROM BOTTOM AND BANKS 374

In order to enhance the hydraulic efficiency of 376
channels by excavation, realignment or even clearing and 377
snagging, the channel roughness is reduced. Such a 380
reduction in roughness decreases friction losses and thereby 381
increases the velocity of flow. Increased flow velocities 382
may exceed the stability velocities of the bottom or bank 383
materials and cause erosion or scour. This in turn degrades 384
the channel and furnishes sediment for stream transport, 385

destroys natural habitats and detracts from the aesthetics 386
of the stream.

Perhaps the worst offender in this regard is channel 388
straightening and realignment. This process reduces channel 390
lengths but not the decrease in elevation over which the 391
water is lowered in traversing a stream section. The net 393
result is a substantial increase in the stream gradient with 394
resulting substantial increases in stream velocities. 395
Without extensive control measures for stabilization or the 397
use in-channel drop structures, channel degradation can be 398
extensive.

INCREASE USE OF FLOOD PROTECTED AND DRAINED LAND 401

Following the implementation of both flood control and 403
drainage projects, extensive amounts of land become 404
available for higher economic production. Land formerly 407
used for pasture or low return agricultural crops can be
converted to high yield agricultural crops. Within 409
municipal areas, property values are increased and uses with
more economic return can be developed. With such economic 411
gains generally there follows environmental degradation.

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Enhanced agricultural uses is accompained by increased fertilizer, herbicide and pesticide use and by increased land tillage which increases erosional soil losses. The by-products of this agricultural use drains to the stream and causes various amounts and kinds of water quality impairment.

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 is both the destruction of fish and wildlife habitat and to destroy aesthetic qualities.

GROUND WATER DEPLETION

Provision of protection against overbank flooding by various channel modification schemes and the provisions of drainage channels through wetland areas both contribute to the deterioration of ground water quality and the reduction in ground water quantity.

Many flood plain aquifers receive recharge during 436
overbank flooding periods. Such recharge provides in 438
addition to the quantity of available ground water, low 439
mineral content water which serves to dilute mineral
concentrations in existing ground waters. Removal of this 441
recharge will thus result in both reduced quantity and
quality of these ground waters. 442

Additionally, since ground waters frequently furnish 445
the dry weather base flow of many streams, the effects of 446
the removal of recharge and resulting lowered water table is 447
to reduce this base flow. The annual hydrograph of a stream 448
may become more extreme between wet and dry weather periods 449
of the year if the channelization project is sufficiently
extensive.

Drainage ditches also lower water tables substantially 451
and reduce the base flow of streams which is provided by 452
ground water infiltration. Since swampy or wet areas which 454
are in hydraulic contact with the ground water are 455
frequently drained and converted to other uses, this
reservioir of water is also made unavailable for providing 456
infiltration to streams.

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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 that 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 depends 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 somewhat acquired in conjunction with strictly innate appreciation. Perhaps aesthetics is the most difficult environmental factor to quantify and may require the opinion of a representative cross section of the population before classification of a project is acceptable.

Types of Pollutants 486

Depending on the location of a project, perhaps almost 489
any conceivable pollutant could be introduced by a 490
channelization project. This discussion will be limited to 493
the common pollutants both contributed directly and 494
indirectly. Such pollutants are the common denominators to 495
be anticipated from the majority of projects. 496

DIRECT EFFECTS 499

Sediment 501

Sediment is perhaps the most ubiquitous of all 503
pollutants associated with channelization. The most 505
pronounced effect on sediment occurrence and concentration
is during the construction phase of the project. With bare 508
soil banks and a non-stabilized channel, the natural stream 509
flow itself and any rain that occurs flushes sediment into 510
the stream discoloring the water and making it turbid and 511
non-transparent. Following stabilization however, the 512
stream frequently remains more turbid than before the 513
project was constructed

Every stream has an ability to naturally transmit 515
certain amounts of sediment. The amount transmitted is 517
termed bedload and is a definable stream characteristic. 518
When channel hydraulic characteristics are changed by 519
constraining the channel to a fixed location, by
realignment, or by other means, the velocity of water flow 520
in increased and consequently the ability to transmit 521
sediment is likewise increased.

The effects of increased sediment or water quality are 523
to reduce light penetration, to blanket fish spawning areas, 524
to blanket and suffocate aquatic insect larvae used by fish 525
as food, to create shoaling and instabilities in the channel 526
itself, and to cause problems with sedimentation in 527
unimproved channel sections downstream from the project 528
section. In addition to these problems which directly 529
affect water quality instream, increased costs are realized 530
by water users including water suppliers and irrigators. 531
Additionally, aesthetic quality is reduced to a substantial 532
degree.

Thermal

The design of channelization projects in terms of flood prevention requires increased channel dimensions. Because of enlarged channels, the dry weather flow is directed near the center of the channel and is thus exposed to solar radiation which heats the water. Previously in the natural channel, the presence of trees along the banks provided shade and helped moderate stream temperatures. The purpose of channelization being to increase the hydraulic efficiency of the channel, those trees are removed as they impede flows during high water.

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 diel variation in temperature can result from a channelization project.

The effects on fish and 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 aquatic life during various stages of their life cycle. Specie selection, availability of food, attendant life cycle chemistry and water quality changes are all phenomene that are temperature affected.

Water quality is affected by the increased respiration rates caused by increased temperatures so that dissolved oxygen is removed more rapidly by bacterial oxidation of soluble and suspended organic materials. This problem is compounded by reduced oxygen solubility at higher temperatures so that a resulting decline in stream dissolved oxygen concentrations results. Decreased dissolved oxygen concentrations decreases water quality and stresses aquatic life dependent on this constituent.

Movement of Pollution Effects Downstream

Because one result of channel improvement projects is to improve hydraulic conveyance of channels, frequently velocities of flow are increased. In channel relocation or realignment projects where channel lengths are substantially reduced, the effect of increased velocity can be pronounced. The effects of increased velocities on surface water quality is to move the effects of pollutants which are time dependant downstream. Discharges of organic wastes or drainage of natural organics from swampy areas along the stream, both of which are bacterially degraded and oxidized in the course of moving downstream, move much farther in distance for the equivalent period of time required for completion of the reaction. Thus the effects of reduced dissolved oxygen levels extends farther downstream than previously.

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

In addition to simply transporting more sediment, increased velocities make streams more aggressive in eroding channels and stream banks which destroys much of they usefulness of the stream for other purposes.

Fish and Wildlife Habitat Alteration

Almost any modification of a channel alters the 609
existing habitat for fish and wildlife. Not all such 612
changes are detrimental however, provision of water storage 613
for example may provide increased habitat areas but perhaps 614
for a different than pre-project biological assemblage.

Most in-channel modifications do remove obstructions 616
that are used by fish for protection from predators, for 618
fish food habitats and for backwater breeding areas.
Removal of trees and brush along stream banks removes 619
protective cover and food sources for various water related 620
wildlife.

Many of these effects can be mitigated by incorporating 622
proper factors into project design. For example, 624
maintenance of water in cut-off oxbows helps retain 625
available fish and wildlife habitats.

INDIRECT EFFECTS 628

Destruction of Aesthetics 630

Channelization projects have frequently been criticized 633
for the destruction of aesthetic values of natural streams. 634
The creation of geometrical shaped channels with highway- 636
type alignment is not conducive to aesthetic appreciation by 637
naturalists or the general public. It is possible to 639
mitigate much of the aesthetic destruction by use of proper 640
design techniques. For example, those techniques which only 641
alter one stream bank or which provide a replanting program 642
similar to that existing prior to construction can be used. 643
Other similar measures can be included to minimize the 645
reduction of aesthetic values.

It should be mentioned also that aesthetic values can 647
be enhanced for many people by various channelization- 648
related projects. In many instances public accessibility to 649
water courses is improved and parks or other recrection 650
facilities can be incorporated into the right of way 651
acquired for the project.

In-stream techniques can also be applied to maintain 653
fish and wildlife habitat. Construction of pool and riffle 655
areas is one technique available. Use of more natural 656

alignment and other design features are available to project planners.

Hydrology

Considering the major function of channelization projects as either flood control or drainage or a combination of both, many of the effects on basin hydrology can be anticipated. The major effect of these changes is to increase the hydraulic capacity of the principal channel and the smaller channels which drain into the principal channel. The 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.

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 and increase peak flow rates and subsequent flooding.

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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. Lowering of the water table is not always detrimental for all purposes as this technique has been used to control phreatophyles (those plants whose roots extend into the saturated zone) by drawing the water table below the root zone. This technique has reduced transpiration losses from these plants providing more irrigation water flow existing projects. Wildlife habitat near these stream beds has suffered however.

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.

BEDLOAD

As indicated previously, bedload is the amount of sediment characteristically carried by a particular water course. It 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 on bedload of a channelization project is generally to cause an increased amount. Improved hydraulic conveyance produces increased water velocities and enhanced sediment transport capability. If the streambed is improperly stabilized following construction, this increase can be dramatic. Even though proper stabilization techniques are used, concentration 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 materials destroying hydraulic efficiency and biological life.

Indirect effects of channelization are to enhance land for higher economic uses such as increased agricultural production or urban and commercial development of some type. Many of the pollutants generated by these increased uses become adsorbed with soil grains. Such organics as herbicides and 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 and through biological concentration mechanisms cause significant ecological desturbances.

Increased bedload can be visible as increased turbidity or opaqueness of the stream water. Such turbidity can be dangerous by obstructing swimmers view of hazardous obstructions. The principal effect is to decrease the

aesthetic value of a stream. On larger streams used for 745
water supply purposes, increased turbidity causes increased 746
treatment costs for potable or industrial water users. 747

Bedload increased can therefore cause problems with 749
excess channel scour and downstream deposition; adsorbed 751
pollutant transport; and direct detrimental effects to water 752
suppliers and stream aesthetic values.

DIRECT DRAINAGE 755

The increased uses of land adjacent to streams 757
following the provision of flood protection and drained 759
arable land provide sources of pollution which directly
drain into the water course. Many of the pollutants arise 762
as the normal product of urbanization or farming practices. 763
Others arise because of the removal of natural mechanisms 764
which trap contaminants directly or provide detention time 765
for the adverse effects to decay to acceptable levels. 766

The effects of urbanization include many direct 768
discharges to the surface waters and to ground waters which 769
discharges contain pollutants that upset stream ecology. 770

Urbanized areas contain extensive paved areas which are serviced by storm sewers which discharge pollutant laden run-off directly into near-by water courses. Pollutants including inorganic fertilizer nutrients, petroleum products, rubber, animal feces and sediment are discharged without treatment. If the area is serviced by sanitary sewers, this effluent is discahrged with substantial pollutants even though treatment is provided. If not sewered, septic tanks are used which can pollute ground waters with pollutants including nitrates and sulfates in properly operating systems; organics, and unoxidized nitrogen and sulfur compounds in improperly operating systems; and synthetic organics such as pesticides in either system. These compounds pollute the ground water and if not intercepted by a well or diverted to a deeper aquifer may infiltrate along with the ground water into surface waters. Since dry weather stream flows essentially reflect the quality of infiltrating ground waters, the stream water quality may be substantially impaired.

With time, many pollutants are degraded into innocuous substances. Nature provides detention time in natural blackwaters and in sluggish meandering streams. Pollutants

in solid form or which naturally flocculate and settle are 798
assimilated and destroyed in bottom sediments by biological 799
life forms. Nutrients are chemically removed either as 800
insoluble salts or by conversion to gaseous forms which 801
evolve to the atmosphere. Following channelization and 802
drainage projects these natural places of detention are by- 803
passed or removed which has the effect of increasing 804
pollutant concentrations in the flowing waters. The effects 806
of these pollutants are then transferred downstream
decreasing water quality while in passage. 807

SOLAR INSOLATION 810

The light provided by the sun provides the energy for 812
the biology of natural waters. The so called "food web" 814
begins with primary production by algae which are capable of 816
photosynthetic production, up through the consumer species 817
including aquatic insects and fish. Too little solar 819
insolation produces too few algae, little primary
production, and a sparse fishery. Too much sunlight heats 820
the water, provides a competitive advantage for undesirable 821
biological species and an unsatifactory fishery. The 823

effects of solar insolation are both on water quality and on the biological response and effects on that water quality.

In many streams light penetration extends essentially to the stream bottom and is necessary for the maintenance of a healthy biological condition. The existence of such light provides for attached algae which provide both food and oxygen for animal life. In streams characterized by pools and riffle areas, these productive areas are interspersed along the stream. In deeper streams productive areas are near the edge of the stream extending outward until the incident light is extinguished to less than usable levels. Following channelization, the stream channels are frequently deeper reducing light penetration from former levels and higher velocities occur which scour attached algae or inundate such areas with sediment. Thus the former habitat is altered and a different biological assemblage develops. Frequently, the new assemblage is composed of less desirable species than previously.

Thermal effects become evident because shading trees and brush are removed allowing both more time of exposure and increased surface area of exposure to sunlight.

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Coldwater species of fish can not tolerate the elevated 847
water temperatures and are replaced by warm water species. 848
Thus, the direct effect of increased solar radiation 849
indirectly changes the stream fishery. 850

Magnitude and Variation 854

Available statistics for defining the national 857
magnitude and variation of channelization projects indicates 858
that perhaps 200,000 miles of waterways have been altered in 860
the last 150 years in the United States. Since the 862
initiation of Federal projects in the early 1940's planning
for and development of about 34,240 miles of waterways in 863
1,630 projects have been initiated under the federally- 864
assisted local protection and small project programs of the 865
U.S. Army Corps of Engineers and watershed programs of the 866
Soil Conservation Service. Additional projects have been 868
initiated by the Bureau of Reclamation, the Tennessee Valley 869
Authority and other Federal, State and local agencies. 870

The Corps of Engineers have assisted in 889 projects of 872
which 47 percent involve channelization and 53 percent 873
involve levees. Of these projects 6,180 miles (56%) are 874

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.

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* "Report on Channel Modifications" by A.D. Little, Inc. submitted to the council on Environmental Quality, U.S. Gov. Printing Office, Washington, D. C. (March, 1973)

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The Soil Conservation Service assisted in 558 projects 887
of which virtually all involved channelization. Of these 889
projects 4,209 miles (25%) were completed by 1971 and 12,426 890
miles (75%) still remaining to be completed. The median 892
size of the projects is about 18 miles with 38.7 percent
less than 10 miles and 24 percent less than 5 miles. 893

PROJECT DESCRIPTIONS IN COUNCIL ON ENVIRONMENTAL QUALITY 896
REPORT

The Council on Environmental Quality's sponsored report 898
previously referenced discusses 42 different projects of 4 899
different Federal Agencies. To quote that reports' 902
description of the environmental settings of the projects, 903

> "The range was from virtually untouched, natural 905
> conditions to totally altered surroundings. The 42 907
> projects encompassed dense swamp forests and mixed hill 908
> country and flood plains of the Southeast, intensively
> used citrus, sugarcane and cattle-raising leands of the 909
> flat Florida interior, the totally urbanized bedrock 910
> slopes of the Northeast, the deep-soiled featureless 911
> Mississippi details agricultural empire, the rolling 912

prairie farm and woodlot country of the Midwest, 913
totally industrialized Detroit, the semi-arid and 914
treeless northern Great Plains, and an arid Valley in
the Southwest. 915

The soils ranged from light organic mucklands to heavy 917
clay "spung", with pure sand, gravel, boulders and 918
clayes-silt in other places. The vegetation was 920
luxuriant to poor grass. Precipitation was a well- 921
distributed 70 inches annually to an intermittent 16 922
inches annually. The stream flow was swift and 923
sluggish, pure and unbelievably contaminated. 924
Streambeds and channels were bankfull with flood flows 926
and bone dry with blowing sand. Fish and wildlife 927
resources were plentiful, diverse and non-existent.
Adjacent lands were canopied forest, high-valued 928
specialty truck gardens, grain farms, fish farms, 929
vineyards, fruit and nut groves, pasture, idle 930
brushland, marshes, factories, shopping centers and
railroads. There were surrounding areas of arresting 932
scenic beauty and depressing ugliness." 933

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 report presents an excellent format for those evaluating additional projects.

ENVIRONMENTAL ASSESSMENT REPORTS

Since the enactment of the National Environmental Policy Act of 1969 (P.L. 91-190) each Federal Agency participating in a proposed channelization project that significantly affects the quality of the human environment must prepart an environmental impact statement. These statements must assess 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 which initially are made available for review and comment. 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 channelzation projects will not be directly presented in this report as a tremendous volume of literature exists discussing such effects. 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 previously mentioned CEQ Report on channel Modifications presents the results of extensive biological investigations conducted by the Philadelphia Academy of Natural Scieces. 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 1022
number of species, the populations of each, or the 1023
productivity of the stream.

Methods to predict the effects of channelization 1025
projects are in included in a volume produced by the Soil 1026
Conservation Service entitled, "Planning and Design of Open 1028
Channels." *This document comprehensively presents available 1029
information on channel design including anticipated flows; 1030
location, alignment and hydraulic design; and stability 1031
design. A recently added chapter 7(1971) includes 1033
environmental considerations. The technical methodology 1034
presented in this document is sufficient to predict the 1035
effects of the hydraulic changes caused by a channelization 1036
project including any increases in sediment transport. * 1038
U.S. Dept. of Agriculture, Soil Conservation Service,
"Planning and Design of Open Channels", Technical Release 1040
No. 25. December 15, 1964 (Rev. March, 1973).

Increases in the Stream temperature and the diel 1042
variation are not so readily predicted. The calculations 1044
can only be made by estimating the amount of protective 1045
shade removed, changes in depth and changes in channel

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length in conjunction with tables of solar insolation values. Such calculations will probably only yield approximate semi-quantitutive amounts of change.

The best technique is the field survey of a nearby stream which has undergone the changes projected for the stream of interest. Comparisons of this type of information establish 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 compenion report on Methods, Processes and Procedures to Control pollution resulting from channelization projects must be utlized.

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5. Anon., Water Quality Criteria, Report of the National Technical Advisory Committee to the Secretary of the Interior, Section 1, Recreation and Aesthetics, Federal Water Pollution Control Administration (April, 1968).

6. DeWiest, R.J.M., "Replenishment of Aquifers Intersected by Streams, Jour. of the Hydraulics Division, A.S.C.E., No. HY6, (November, 1963).

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

Discussion under channelization will be limited to those design changes in the actual channel modification project that can be incorporated to enhance and mitigate undesirable by-products. Additionally, attention 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. 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 also may be desirable to avoid passage through valuable lowland areas which serve as fish and wildlife habitats.

In constructed channels the alignment generally should follow a natural pattern which should consider the type of existing stream, the required hydraulic capacity and comparison with up-and downstream sections of the particular water course or nearby water courses. Use of such design techniques avoids the unnatural appearance of a modified channel thus improving aesthethic appeal and in many cases may aid 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 either the channel itself or the associated fish and wildlife resources. 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 up 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 of the bend to simulate natural water ways. Use of naturally occurring rocks and boulders can be placed at selected points for aesthatic 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. Inclusion of these devices however requires carefull attention of the designer, on site inspection personnel and especially the contractor.

CHANNEL GRADE 1143

Within the topographic constraints of a given project, 1145
the channel gradient can be varied between stream reaches to 1146
achieve naturally appearing pool and riffle areas, cascades 1148
or other such features. To accomodate the existence of 1150
highly erosive soils in certain reaches, gradients can be 1151
flattened and conversely, in erosion resistant soils
gradients can be steepened, all within the natural 1152
topographic constraints of channel elevations at the 1153
beginning and end of channel sections. Use of such grade 1154
variations not only enhances aesthetic appeal but increases
protection against meander development, increases channel 1155
stability and thereby minimizes sediment from channel and 1156
bank erosion.

Adjustment of the channel gradient to develop pool and 1158
riffle areas can also provide increased atmospheric 1159
recreation capacity in the stream. Reaeration increases 1160
with increased velocity and decreasing stream depth. Riffle 1162
areas additionally provide increased turbulence which also
tends to increase reaeration. The increased dissolved 1164
oxygen supplied by the increased reaeration improves the 1165

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 amy 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. Other spoil reducing measures can be included 1192
by the use of non-structural alternatives totally or 1193
partically in lieu of actual channel modification.

STRUCTURAL MEASURES 1196

Structural measures can be included in a channel 1198
modification project to alleviate problems of excessive 1199
grade to maintain stability. Structural measures can also 1202
be applied to side stream entry points to control the 1203
introduction of sediment, debris or other pollutants or 1204
effects.

For channels with excessive slopes which would 1207
otherwise erode producing sediment, typical structures
include drop structures, chutes, steepened rock armored 1208
sections and cascade structures. Each of these structural 1209
modifications provides resistance to high velocity flows and 1210
allows the use of stable, moderate gradients upstream and 1211
downstream.

For channels with sufficiently flat gradients so that 1213
channel and bank stability are not problems, designs can be 1214

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.

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 which produce sediment into the main channel and reduce channel stability.

VEGETATION

The early re-establishment of vegetative covers 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 or simulate the natural cover.

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

Use of aquired right of way for parks, hiking paths or the provision of access for fishing is also enhanced aethetically for public use by the use of suitable revegetation practices.

EFFECTS ON GROUND WATER 1252

Any channel modification will tend to alter the natural 1255
circulation of the ground water. Natural recharge to the 1256
ground water may be increased or decreased depending upon 1258
location, depth, and other characteristics of the new
channel. Thorough investigation of possible effects upon 1259
both quantity and quality of ground water should be made 1260
before undertaking a channelization project.

An important distinction in terms of their effect on 1262
ground water quality is whether channels are lined or 1263
unlined. A lined channel, constructed of an impermeable 1264
material such as concrete, prevents in many reaches the 1265
natural recharge of streamflow to ground water. The water 1266
table may be lowered, and ground water circulation and
dilution reduced, so that quality is impared. 1267

To control this situation water needs to be 1269
artificially recharged to the ground water. This can be 1270
done by installation of ditches or basins for artificial 1271
recharge in the vicinity of the lined channel. High-quality
water diverted from the stream or derived from some other 1272

source and released into these structures would infiltrate 1273
to the groundwater and thus compensate for the loss of 1274
natural streambed recharge. This is extensively practiced 1275
in California.

In unlined channels, a primary effect is that produced 1277
by changing the water table elevation. If a channel is 1278
dredged in an area where the water table is close to the 1279
ground surface, the new channel acts as a drain and lowers 1280
the water table. If the groundwater body is underlain by
saline water, the reduction in freshwater head would cause 1281
the saline water to rise and pollute the fresh groundwater. 1282

Methods to control this effect include: 1285

Install pumping wells in the underlying saline 1287
water. Removal of a portion of the saline water by 1288
pumping will counteract its upward movement and protect 1290
the overlying freshwater. Means for the disposal of 1291
the saline water must be provided, as by evaporation
from lined basins, disposal to the ocean, or desalting 1292
and use.

Line 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 groundwater quality. Some drainage to prevent uplift of the channel lining would be necessary.

There may be some loss in streambed recharge even with unlined channels of the hydraulic characteristics are improved and the gradient steepened, resulting in higher velocities. The effects on groundwater 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 groundwater if the groundwater is below the bottom of the channel and if there is no impermeable layer above the groundwater body.

In some coastal areas (e.g., Florida and California) 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 1314
saline water into the underlying freshwater aquifers.
Serious groundwater pollution has resulted, as from the Los 1315
Gerritos Creek Flood channel near Seal Beach, California. 1316
Such channels should be located, designed, and constructed 1317
with care so that the natural barriers to saline water 1318
intrusion will not be impaired. If this is not possible, 1319
the channels should be lined withal. In some flood control 1320
channels it may be possible to install inflatable rubber 1321
dams to prevent the movement of saline water from the sea or
bay into the channel. 1322

Structural Alternatives to In-Channel Modifications 1327

In many cases in-channel modifications can be reduced 1330
substantially or avoided altogether by the use of various 1331
alternative schemes involving construction of off-stream 1333
facilities. Such facilities as levees, floodways, retarding 1334
basins and land treatment can be incorporated into projects 1335
to avoid actual channel modification. The construction of 1336
these alternatives themselves potentially contribute to 1337
water quality degradation.

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 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 have a subsurface vertical extent sufficient to form a barrier to groundwater flow.

In coastal areas levees prevent the flooding of land by seawater. As a result, the quality of groundwater in the aquifers behind these levees is protected. The principal harmful effect of levees on groundwater quality occurs in floodplains of rivers. The mineral quality of most floodwaters, neglecting their suspended sediment, is higher than that of groundwater. During periodic inundations of floodplains, some of the water infiltrates to the groundwater and acts to improve its quality by dilution. Where levees prevent this action and thus reduce the natural recharge, the mineral quality of the groundwater will tend to deteriorate with time.

To counteract this effect which tends to degrade ground water, two possibilities deserve consideration. One would be to pump groundwater from the aquifer behind the levee so as to increase the circulation of groundwater and to remove accumulations of salinity. The other approach would be to divert fresh water to the land behind the levee. By overirrigation or other means of artificial recharge with water of a quality equal to or better than that of the existing recharge, a dilution of the groundwater similar to that produced by natural floodwaters could be maintained.

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 to occur. The increased scour can subject underlying less resistant geological formation to attack and perhaps even breech 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.

Floodways

These 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 groundwater 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 groundwater quality.

Because of the negligible effect in degrading groundwater quality, no specific control measures are sugged 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, rip-rapping of channel bends prevent the scour of sediment during high flow periods. Insufficient maintenace can lead to substantial quantities 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 unaffected by these basins during low flow conditions as the water passes through essentially unaffected. 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 subsequently, sediment storage will be filled and any additional quantities will be transported downstream.

Proper stabilization and planting programs will avoid 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

Land treatment measures include proper farm cultivation techniques and use of 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.

Basically these measures are beneficial and do not require abatement measures.

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 previously referenced 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, rights, easements, dedications, reservations and public or private acquisitions."

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

1. A.D. Little, Inc., "Report on Channel Modifications," submitted to the Council on Environmental Quality, U.S. Government Printing Office, Washington, D.C. (March, 1973).

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Guidance for the Identification and Evaluation of Reservoirs

Introduction

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

Essentially a reservoir may be considered as the upstream half of a natural lake with the dam providing the artificial separation. 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 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. 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.

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 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 re-regulation downstream from peaking power operated storage reservoirs.

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 stratification generally of the classic three layer system. Primary uses of storage reservoirs include flood storage, hydro power production and water supply storage. Recreational use is an important secondary use on many storage reservoirs.

Current Governmental Involvement 1569

Several Federal Agencies are involved in the 1572
construction of storage and main stream impoundments. As 1573
the Agency responsible for navigation on the nation's inland 1575
waters, the Corps of Engineers is responsible for 1576
constructing both types of reservoirs. The Tennessee Valley 1577
Authority which was initially authorized to construct
storage reservoirs to control flooding, has additionally 1578
constructed low head impoundments to facilitate navigation. 1579
The Bureau of Reclamation has constructed storage 1580
impoundments to provide water for the irrigation projects in 1581
the western States. The Federal Power Commission is 1582
responsible for approving private development of hydropower
and is involved in the approval of reservoir construction 1583
for this purpose. Information on reservoir projects for 1584
hydropower production of a regional nature is also available 1585
from other U. S. Department of Interior Agencies including 1586
the Bonneville Power Administration, Alaska Power Admini-
stration, Southeastern Power Administration and the 1587
Southwestern Power Administration. The Department of 1588
Housing and Urban Development has information on reservoirs 1589
constructed in housing projects in which they have an 1590

interest. State and local governmental agencies are also 1590
involved in reservoir construction. Such developments may 1591
include recreation reservoirs and public water supply 1592
reservoirs. The name of the appropriate State and local 1593
agency varies from State to State and therefore must be 1594
determined for each particular situation.

Private development of small impoundments has become 1596
commonplace. Private developers construct suburban housing 1597
developments and recreational weekend communities 1598
surrounding man-constructed impoundments. Private
development of small lakes has also occurred in conjunction 1599
with campgrounds, recreational parks and even pay fishing 1600
lakes. A survey of the governmental sources will delineate 1601
the large projects and most of the significant smaller 1602
projects. Other projects may require an examination of 1603
local construction permit files or consultation with local
planning commissions. 1604

Current Practices 1609

Current planning and justification for large reservoirs 1612
involving the Federal Government are generally based on 1613
multipurpose use. The principal multipurpose uses included 1615
are flood control, hydropower production, navigation, 1616
recreation, irrigation water supply, public water supply, 1617
low flow augmentation for water quality or other special 1618
purposes, and fish and wildlife propagation. State and
local projects are generally multipurpose also with the 1619
exception that some water supply impoundments are reserved 1620
solely for that purpose.

FLOOD CONTROL 1623

Extensive use of reservoirs whose initial justification 1625
was for flood control have been constructed by the Corps of 1626
Engineers and the Tennessee Valley Authority. The basic 1629
theory of operation is to reduce storage quantities to a 1630
minimum level prior to the normally wet seasons of the year. 1631
During the wet season, outlet flows are kept to a minimum
while excess tributary drainage is stored. Following the 1632
wet periods the reservoirs are filled to near maximum 1633

storage levels. The available storage is then used to maintain normal or increased stream flows, produce hydropower 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 arrives.

POWER PRODUCTION

Water storage for hydropower production is one of the oldest uses of reservoirs. Many small reservoirs have been constructed to furnish energy to individual mills or small communities. Current developments are rarely designed for singe purpose hydroelectric power production but the 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 supplying 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, home and industrial electric consumption demands. Such peaking power operations are the standard operating scheme for many areas including the Tennessee Valley Authority.

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

Many of the main stream run-of-the-river 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 run-of-the-river 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 electric generating turbines, and by the number of lockages to maintain the specified pool elevation.

WATER SUPPLY STORAGE

Water supply storage includes small reservoirs for public water supply and industrial water supply and large reservoirs for irrigation water. 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 matters to enhance the water quality and reduce water treatment costs.

Storage of water for 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 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 conditions presently existing. Most reservoirs include many uses although one use may predominate.

Flood control reservoirs can combine power production, water supply storage and recreational benefits although the operating rules would be mandated by the flood control purpose. The Tennessee Valley Authority storage reservoirs generally operate on this scheme. Reservoirs designed with peaking power as a principal output may be hazardous for recreational use because of rapidly fluctuating water levels. However, these reservoirs may provide flood protection and water supply benefits in addition to hydro-power generation.

Other combinations of multi-purpose uses are discernable. Modern planning incorporates all such 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 to total value of the project as against the cost of construction.

Sources of Pollution 1741

The construction of reservoirs of all types produces 1744
direct and indirect changes on water quality of the 1745
inflowing water. Direct changes include the physical, 1747
biological and chemical changes that occur during storage 1748
and because of the changed environment from a moving stream 1749
to a quiescent lake. Indirect effects include waterhsed 1750
development which contribute pollutants and nutrients which
ultimately degrade water quality in the impoundment. Many 1751
of the direct changes that occur are also either magnified 1752
or mitigated by the changed encironment from stream to 1753
reservoirs.

BASIC RESERVOIR MECHANICS 1756

The deleterious effects on water quality caused by the 1758
construction of a reservoir or by a series of reservoirs in 1760
a canalization project can best be understood after an 1761
elementary understanding is acquired of basic reservoir 1762
hydraulics.

Storage reservoirs in temperate climates frequently become stratified during the summer and winter with periods of non-stratification 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 of 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, has only a small temperature gradient and is generally stable.

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 stabile 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 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 sulfur compounds 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 the different depths, stratification allows the selective withdrawal of water of better quality. This is accomplished through the phenomena of stratified flow to accomplish selective withdrawal.

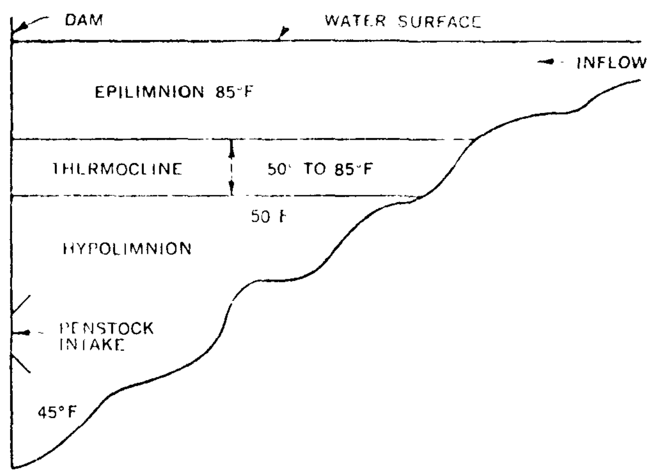

Figure 1 — Representative profile showing summer stratification in a typical storage reservoir (Ref. 3)

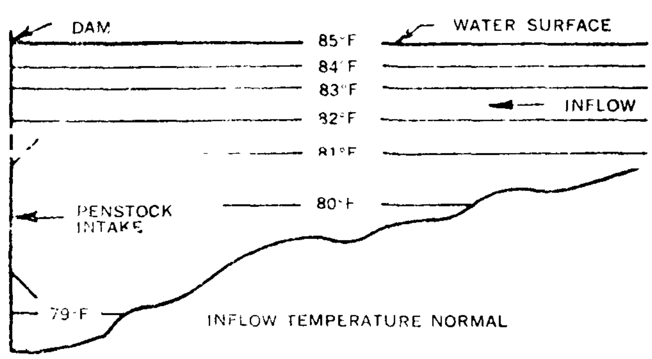

Figure 2 — Summer stratification in main stream reservoirs (Ref. 3).

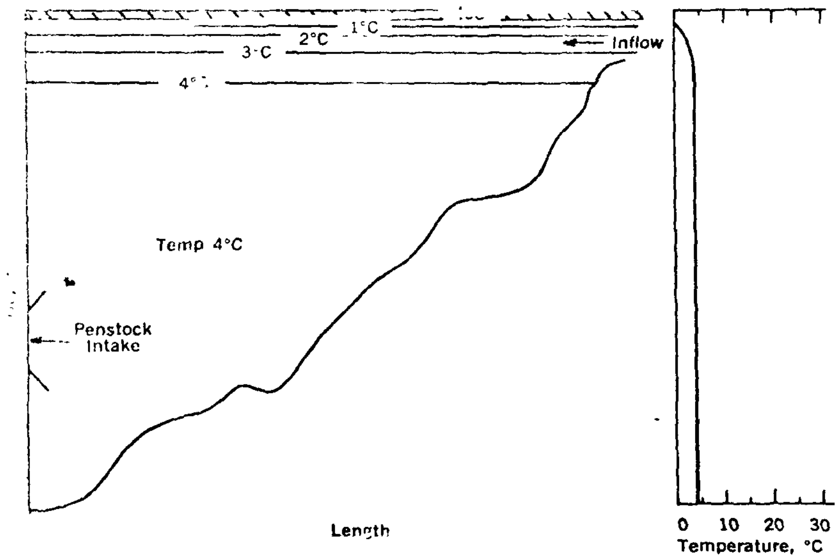

Figure 7 — Storage reservoir — winter stratification.

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. 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 method and location of outlet works.

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

circulation and the transport of dissolved oxygen to lower 1830
layers in the impoundment. Without some means to discharge 1831
waters from other than the hypolimnion, downstream water 1832
quality may be impaired.

WATER QUALITY CHANGES WITHIN RESERVOIRS 1835

CHEMICAL - PHYSICAL 1837

The annual cycle of storage impoundments in temperate 1839
climates consists of the winter and summer periods of 1840
stratification which are separated by periods of essentially 1842
uniform temperature distributions from top to bottom of the 1843
reservoir during which the waters freely mix. The periods 1844
of mixing are called the spring and fall turnovers. During 1845
the turnover periods soluble material entrapped in the hy-
polimnion which was derived from material either settled 1846
from the epilimnion or was leached from the bottom muds is 1847
returned to the biologically active near surface region. 1848
Such materials consist of the inorganic nutrients nitrogen 1849
and phosphorus, reduced heavy metals such as iron and 1850
manganese, and unoxidized organic material. The nutrients 1851
become available to support renewed primary production. 1852

This 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 is created, the supply of oxygen to the hypolimnion from atmospheric reaeration is terminated. As the summer progresses dissolved organic material in the hypolimnion including that present initially and which is supplemented by material settling from the epilimnion, exert oxygen demands as bacteria oxidize these materials. If the organic content is insufficient to exhaust available dissolved oxygen concentrations then waters withdrawn from the hypolimnion have improved quality based on organic concentration. However, if the organic content is sufficient to exhaust dissolved oxygen concentrations then anaerobic conditions become established and water quality is sericusly degraded.

Compounds 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 ferrous, ammonious, manganeous, silica, phosphate and sulfide ions have been observed in oxygen depleted waters in contact with bottom muds. Increases in soluble organic compounds have also been reported.

Since many storage reservoirs withdraw water for release from near the reservoir bottom, the quality of this water may be much poorer than occurred in the preimpoundment 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 dc not become stratified for extended periods of time. Depending on the dissolved oxygen concentration gradient (if one exists) however similar leaching from the bottom muds may occur as that in storage reservoirs. Without stratification and assuming mixing from top to bottom, the water discharged

does not represent a particular zone and thus the depth of 1893
withdrawal is not critical to water quality.

BIOLOGICAL 1896

In addition to various other classification schemes 1898
used for aquatic biological systems are the differentiation 1899
between lentic and lotic communities. Those biological 1901
communities adapted to the moving water stream system are 1902
termed lotic; those adapted to still water or lake 1903
environments are termed lentic.

In the process of converting a stream into a reservoir 1905
the biological community must adapt from lotic to lentic. 1906
The entire system may change significantly in storage 1907
reservoirs whereas only minor changes may occur in main 1908
stream reservoirs depending on prior conditions. 1909
Anticipated changes include plankton, rooted aquatic plants, 1910
aquatic invertebrates, and fishery speciation.

SITE PREPARATION 1914

A critical process to the future water quality of an 1916
impoundment is the preparation of the area to be flooded. 1917
Older impoundments for power production frequently performed 1919
little if any site preparation but simply flooded an area. 1920
Such reservoirs are typified by highly colored waters and 1921
low dissolved oxygen concentrations. Current practice 1922
usually provides clearing at least from the minimum pool 1923
elevation to several feet above the maximum flood pool 1924
elevation. Organic deposits such as peat boggs are
generally either removed or covered with sufficient material 1925
to effect a seal. The remaining brush and shrubbery below 1926
the minimum pool level if left to decay will produce 1927
undesirable color, provide organic material which 1928
subsequently depletes dissolved oxygen, and provides
nutrient and growth factors which supports plankton growth. 1929

RELEASED WATER

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 caused by a pollution source.

Additionally, the discharge may be of a temperature unnatural for natural 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 low 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 manaqanese concentrations all may be increased above previous stream concentrations and require treatment for removal. Increased 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 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 groundwater quality occurs where the foundation of the structure provides a substantial or complete cutoff of groundwater flow in an aquifer. For example, Prado Dam on the Santa Ana River in southern California, is located at the upper end of a narrow, V-shaped canyon which forms the natural outlet for both surface and groundwaters from the Upper Santa Ana Valley, an extensively developed region. The cutoff wall extends to bedrock and blocks subsurface flow out of the upstream groundwater basins. Such a stoppage reduces the hydraulic gradient of the groundwater upstream of the dam. This causes an increased accumulation of pollutants in the groundwater, because of slower movement or complete stoppage; the natural disposal of salinity from the basin or aquifer is reduced or eliminated. Under these circumstances the resulting accumulation of salts from natural or man-made sources, such as irrigation return flows, could markedly increase the groundwater salinity.

A second and related effect is due to the higher water table created back of a dam. This brings the groundwater closer to the ground surface where the opportunity for pollution from agricultural and septic system sources, for example, may be increased. Marshy areas, swamps, and pools may be created; evapotranspiration losses then concentrate salinity in the groundwater. There may also be adverse effects on surface-water quality.

Even in situations where the dam and its foundations do not substantially alter the total groundwater flow through the underlying aquifers, the localized effects on groundwater levels and on the original pattern of groundwater flow may have significant adverse impacts on groundwater quality.

The reservoir created by the dam may have somewhat similar effects on the groundwater of the area. If water is stored in the reservoir for significant periods of time, the effects may be more pronounced than those resulting from the dam itself. Seepage losses from the reservoir also contribute to the groundwater. If the quality of the water in the reservoir is better than that of the groundwater, improvement in groundwater quality results. Conversely, seepage losses from a reservoir storing poorer quality water (e.g., reclaimed water) degrade the groundwater.

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 wastes disposal through the use of package sewage treatment plants not providing nutrient removal, discharges from watercraft, run-off from yards and streets and by polluted groundwater 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 the direct sources described above but because of the volume of dilution available, these effects may not be 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 non-point sources may accelerate eutrophication processes causing algal blooms and subsequent dissolved oxygen problems.

In order to estimate future water quality rationally, mass balances of waste and nutrient sources are required to determine accumulations and future increased constituent concentrations and the corresponding development of water quality deteriorating conditions.

CHANNEL MAINTENANCE

Frequently, since one of the principal reasons for the main stream reservoir is to maintain minimum depths for navigational use, channel maintenance is a key feature to maintaining the system. 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, the total extent is determined by the spoil disposal method employed.

The dredging itself 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 coumpounds and nutrients, which travel with these siltaceous materials, may be released to the aquatic phase either stimulating or inhibiting biological 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 facilities. These potential pollution sources are unpredictable as to time of occurence 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. Reaeration is increased by an increase in water velocity and decreased by an increase in water depth. A reservoir both decreases velocity and increases depth and therefore reduces reaeration by both factors.

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 as 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 below acceptable levels but to greatly intensify the amount of depletion that occurs with that reach. For dischargers, this means increased waste treatment.

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 predicted with great difficulty and little precision.

Types of Pollutants

Water quality changes which are related to reservoirs are of concern within the reservoir itself and in the downstream reaches receiving discharges from the reservoir. The water quality at the surface is of importance for recreational, biological and aesthetic purposes; that in the hypolimnion affects water quality of released water for 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.

Reference is here made to a report entitled "Measures For the Restoration and Enhancement of Quality of Freshwater Lakes" which was prepared to comply with section 304(i) of P.L.92-500. The Appendix to this report covers the source of pollutants more thoroughly than here. For more detail the report should be obtained.

BIOLOGICAL FACTORS

The biological life in the epilimnion indicates many water quality changes in both this zone and 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 in developing and sustaining their populations. Increases in nutrients 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.

The population of plankton in relation to other factors is used as indicators in the estimation of the eutrophic condition of a body of water. Dense populations are indicative of eutrophic waters while sparse populations are indicative of oligotrophic waters. The concept of eutrophy however is not strictly applicable to reservoirs as to age but is more indicative of aesthetics and water quality as affected by plankton populations.

Dense plankton populations directly effect the chemical quality of water. During daylight hours these algae remove carbon dioxide from solution which causes increases in pH; and by photosynthetically producing dissolved oxygen in quantities that frequently exceed the water solubility of this element. At night carbon dioxide is released by respiration which reduces pH and depletes dissolved oxygen concentrations below values that would otherwise occur. These diel fluctuations in pH and dissolved oxygen can have detrimental effects on other biological life. For example, in extreme situations dissolved oxygen levels may approach zero at night because of plankton respiration.

Upon the death of these algae so-called "algae rains" occur as the remains settle into the hypolimnion. Bacterial decay exerts a demand on the hypolymnion oxygen resources which may ultimately cause total dissolves 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.

The higher organisms in the biological chain feed directly on plankton, 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, which include fish, are caused by dissolved oxygen depletion, pH changes, or plankton-produced toxins. These effects occur through the plankton activity.

Microbiological factors must also be considered. Tributary drainage, waste treatment plant discharges and direct water craft discharges potentially contribute disease causing organisms. For recreational use bacteriological quality must be maintained so that disease transmission from fecal discharges is minimized. Monitoring by using 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 development and 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, inputs of point and non-point waste materials and any toxic materials. Common measures of chemical water quality

include dissolved oxygen, color, pH, various inorganic 2228
salts, metals, nutrients and organic compounds including 2229
pesticides and herbicides. Specific levels for these 2230
materials are contained in the various State Water Quality
Standards. Discussion of these materials with recommended 2231
levels are also available in a book entitled "Water Quality 2232
Criteria" published by the Environmental Protection Agency. 2233

Chemical factors are important for maintaining the 2235
usefulness of the reservoir for recreational use, water 2236
supply use, maintenance of fish and aquatic life and for 2237
preserving downstream water uses.

PHYSICAL FACTORS 2240

The physical factors of water quality include 2242
determinations such as temperature and turbidity which 2243
affect the usefulness of water and mediate other chemical 2245
and biological reactions.

Temperature affects the rate of physical, chemical and 2247
biological reactions. In terms of reservoir hydraulics, 2248
temperature related density changes in water causes the 2249
development of the stable summer stratification with its 2250

pronounced affect on water quality. Chemically, the solubility of gases with dissolved oxygen principally being of interest; the solubility of chemical compounds is affected; and the reactiveness of certain constituents all are affected by water temperature. Biologically, reaction rates roughly double for every 10 degree Celsius increase in temperature as well as regulating reproductive mechanisms and life itself. Temperature is obviously 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 it includes measurements such as suspended solids and secchi disc in addition to a turbidimetric measurement. The suspended matter in epilemnetic waters may be plankton while in hypolimnectic waters it may be sediment clays or silts. 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 inter

flow which would insert a layer between existing water 2271
layers and subsequently affect discharged water quality. 2272
Turbidity is both an economic and quality parameter to be 2273
excluded in Reservoir water quality.

Methods of Pollutant Transport 2277

The basic hydraulics of both storage reservoirs and 2280
main stream reservoirs has been previously discussed. The 2281
movement of soluble pollutants through a reservoir simulates 2283
the hydraulic movement. Particulate pollutants, if organic, 2284
may be biologically solublized; inorganic materials may be 2285
indefinitely held up by being incorporated into the 2286
reservoir sediments. Other factors such as solar insolation 2287
and the reservoir operating schedule influence water quality
in the reservoir itself and the stream downstream from the 2288
reservoir.

Pollutant transport in a stream is generally quite 2290
simple as the pollutant travels at the same rate as the 2291
water itself. This generalization has exceptions as for 2292
example sediment bed load which varies with respect to the 2293
water velocity and temperature. This same essential

transport process occurs in main stream impoundments where 2294
velocities are typically discernable and sufficient to 2295
maintain particulate matter in suspension. Stratified 2296
storage reservoirs in contrast have extemely ecomplex 2297
hydraualics. Density effects, surface mixing caused by 2298
winds and the level of water release all bear on pollutant
residence time. 2299

TRANSPORT INTO THE STORAGE RESERVOIR 2302

Discharges directly into reservoirs which includes 2304
direct runoff, tributary streams or waste streams are 2305
segregated in the reservoir by their density. Beginning in 2306
the spring as discharges typically become progressively 2308
warmer and less dense, the flows form layers above the
existing cooler waters. Toward fall when inputs become 2309
cooler and therefore more dense than stored water the inputs 2310
may form interflows between existing layers. Waste 2311
discharges would also tend to be density segregated which in 2312
that case may include ionic density effects in addition to
thermally caused density effects. Thus the location of an 2313
incoming pollutant depends on the existing density regime in 2314
the reservoir and the density of the water tranporting the 2315
pollutant.

TRANSPORT WITHIN THE STORAGE RESERVOIR 2318

The principapl controlling factor on water release is 2320
the location of the outlet. Normally, the water discharged 2321
is the densest existing layer above the outlet structure. 2323
In storage reservoirs with fixed deep outlets progressively 2324
less dense water is released during the summer stratified 2325
period which approximates the time of entry into the
reservoir. This progressive release may be interrupted by 2326
the occasional passage into and through of more dense 2327
sediment-laden storm water or some other density anomaly. 2328
As the fall season approaches, but before the fall overturn, 2329
cooler tributary inflows may also flow beneath existing
storage and pass through the reservoir ahead of existing 2330
storage. Soluble pollutants which are stable (eg salts) 2331
would be transported in a similar fashion. 2332

Particulate pollutants if off sufficient size, tend to 2334
settle toward the reservoir bottom. These materials settle 2335
at different rates depending on a myriad of factors but may 2336
finally reach the bottom or be retained by buoyant forces 2337
occurring in more dense water layers. Thus a density
segregation of particulate matter also occurs. Particulate 2338
pollutants that reach the bottom may be essentially 2339

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. Because of density effects, the water withdrawn will principally be from the densest layer above the outlet level. 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 hypolinion releases contain the worst water quality of the year in terms of dissolved oxygen, nutrients, metals and odorous compounds. Release of aerated epilimnion waters avoids this problem to the maximum available extent.

hypolimnetic releases during late summer may release materials that settled to the bottom and became biologically solubilized or those chemically precipitated with subsequent settling to the bottom which become resolubilized under the 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 initially removed but resolubilized.

Epilimnetic releases contain the active biological life in this zone plus the existing surface water quality as affected by those biological processes and other physical processes. These waters are generally characterized by high quality water including substantial concentrations of dissolved oxygen.

Magnitude and Variation of Pollutant Effects

Water quality transformation for reservoirs as compared with the preimpoundment streams have been prepared on several basins under the auspices of the constructing agency. For main stream reservoirs one series is available for the Ohio River which includes changes observed following the initial installation of low head impoundments. subsequently many of the low head impoundments have been replaced by higher head impoundments for which pre-and post-water quality investigations have been conducted. (See bibliography for references)

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.

State and local controlled reservoirs whether for recreation or water supply purposes, monitor the water quality to meet public health requirements. 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 2429
establish baseline conditions. 2430

EMPIRICAL TECHNIQUES 2433

Empirical methods are generally developed specifically 2435
for one reservoir and include analyses of data recorded for 2436
a number of seasons or years. Although simpler analyses are 2438
used, statistical correlations are developed between input 2439
water quality variables, reservoir water quality and output 2440
water quality. Operating rules for the reservoir can be 2441
modified based on such analyses to maximize one set of 2442
parameters as opposed to another.

Simpler techniques than statistical methods would be 2444
simple graphs with trend line development. Obvious problems 2445
with such methods includes: the applicability to only one 2447
site, predictive ability only in range used for development, 2448
no mechanism to correct for changes in physical conditions, 2449
lack of fundamental understanding in reservoir mechanics,
and extended record required for development. 2450

The principle advantages are the relatively inexpensive 2452
development cost and simplicity in use. Depending on 2453

precision required such techniques may be adequate for many 2452
purposes.

HYDRAULIC MODELS 2455

Hydraulic models range in scope from simple laboratory 2457
scale aquariums to multidam basin models covering several 2458
acres. These models are used to verify dam designs for 2460
hydraulic properties, effects on reservoir stratification of 2461
these designs, or entire river conditions for various flow 2462
regimes.

Data from the models are collected by using various 2464
tracer and stage-velocity measurement techniques. The data 2465
is then fitted to a mathematical formulation for 2466
incorporation into a particular design. These data are also 2467
valuable for evaluating mathematical models as some water 2468
quality parameters can be empirically or theoretically 2469
scaled from model to prototype.

MATHEMATICAL MODELS 2472

Mathematical models are used for many purposes in 2474
reservoir design and operation. The hydrology of an entire 2476
basin may be modeled to aid in sizing and locating the 2477

optimum number of reservoirs or the amount of water storage 2478
required to meet certain objectives. Internal reservoir 2479
hydraulics and mixing have also been simulated by
mathematical models frequently as a first step in predicting 2480
the distribution of pollutants in the reservoir or to 2481
predict the discharge sequence of stored water with a given 2482
water quality for each stratified layer. Recent attempts 2483
have been made at ecological modeling. These models begin 2484
with material inputs from which plankton and fish
populations are ultimately predicted. Hydraulic 2485
simulations, water quality constituent distributions, 2486
phytoplankton production, zooplankton controls on 2487
phytoplankton populations, and fish populations are all 2488
incorporated in such models.

The basis for the water quality and ecological models 2490
is a basic understanding and prediction of the thermal 2491
stratification process in reservoirs. Recent research 2492
efforts have extended knowledge of the stratification 2493
process to the extent that reasonable predictions of the 2494
internal temperature distributions can be made. Using the
system hydraulics as the basic transport process, the 2495
chemical, physical and biological reactions are imposed 2496

using the laws of conservation of mass and from general kinetic principles. Equations are constructed for each constituent with the entire set of equations subsequently being solved using numerical techniques with the aid of the digital computer. The model outputs include the important water quality characteristics for water quality models and additionally 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. For most management decisions concerning reservoirs the results offer adequate accuracy and a valuable tool for evaluating alternative waste treatment schemes including input locations, operating rules for the reservoir to maximize water quality, and the projected water quality for various uses.

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 2520
verified by field observations. The basis for the validity 2521
of predictive techniques requires the performance of 2522
intensive water quality surveys augmented by routine
monitoring. Key parameters of water quality require 2523
delineation both temporally and spatially within a reservoir 2524
as well as in the inflows and the outflow. These data 2525
provide information for compliance with water quality 2526
standards in addition ro providing data for future 2527
improvements in analytical and modeling technology.

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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 the obvious ones 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.

Thermal stratification, especially the classical three layer system typical of summer conditions, creates an effective trap in the hypolimnion (lower layer) for material initially there at the time of stratification or accumulated there by sedimentation or other processes. If sufficient organic material accumulates in the hypolimnion, dissolved oxygen may be totally depleted creating anaerobic conditions. Such conditions eliminate desirable biological life, produce reduced compounds which contribute taste and odor to water and presents conditions conducive to re-solubilization of many chemical compounds. These effects decrease the quality of water released downstream which may violate water quality standards.

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.

Reference is here made to a report prepared in compliance with Section 304(i) of P.L. 92-500 entitled, "Measures for the Restoration and Enhancement of Quality of Freshwater Lakes." That report covers in more detail many of the same techniques which are applicable to both lakes and reservoirs.

SITE PREPARATION

Water quality may be affected by many characteristics of the location site. Factors which affect future water quality include maximum and operating depth range, 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 remains 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 and production and decrease in pH can be predicted. Additional soil analysis 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 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 overlying water. The adverse effects caused originally by freshly inundated soils are reduced with time. This aging process is a combination of leaching, or 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.

It is generally agreed in the literature 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.

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. Several reports listed in the bibliography discuss the prediction of thermal stratification and others discuss the hydraulics of selective withdrawal.

DESTRATIFICATION AND HYPOLIMNETIC AERATION

In reservoirs with deep withdrawal points that do not contain multilevel 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 have been developed, reservoir destratification and hypolimnetic aeration without destratification.

Destratification is most commonly accomplished by compressed air diffuser aerators or mechanical pumping. 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 anaerobic processes and thereby maintains the quality of water released downstream. Aerobic conditions inhibit leaching of color, solubilization of metals and nutrients from the bottom sediments, and provide for biological distribution 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 of 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 lift to move the water from the surface up to the pump (plus minor intake pipe friction losses) which may be only a few feet.

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. 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 aeration.

Hypolimnetic aeration is a procedure to provide aeration 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 but the water quality is protected or enhanced.

Several techniques for accomplishing hypolimnetic aeration have been developed. U-tube designs, that is where water is withdrawn from the hypolimnion, pumped to the surface and returned to the hypolimnion are a common method.

Compressed air may be injected into the water at the intake of the U-tube, which provides contact time while traveling to the surface, and be subsequently vented at the surface; or low pressure air or pure oxygen may be injected at the surface of the U-tube before returning to the hypolimnion utilizing the increased pressure during the descent to effect oxygen absorption. Care must be exercised in operation to avoid creating sufficient turbulence to destroy the thermal stratification.

AERATION OF RESERVOIR RELEASES

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

The Venturi tube aeration device has not been tested on full scale reservoir releases and therefore must be considered experimental. In the device, air was injected into the throat of a Venturi section. The air was admitted used 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 subsequent friction losses. The device may only be efficient on small flows and not full size reservoir discharges.

Turbine aeration uses the water flowing through the power turbines which are vented with air to produce increased dissolved oxygen levels. In the older horizontal type turbines existing draft tube vents have been used which are frequently available to control cavitation. Oxygen transfer efficiencies of 37% have been reported with turbine power losses of about 5%. Modern turbine units may have the turbine water wheel at elevations less than tail water elevation which produces only small negative pressures and 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 initially 80%

saturated with oxygen varied from 25% - 50%. Turbine efficiency was decreased by 0.83%.

The Howell-Bunger valve is a fixed dispersion cone valve which can be used for reservoir releases to provide aeration. The Tennesse Valley Authority has performed extensive evaluation of this device for aeration purposes. 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 6 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, the 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 which are frequently used in waste treatment processes.

Factors to be considered before installing aeration include feasibility and costs. Many methods are theoretically available but selection requires evaluation of local factors in addition to theoretical considerations.

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 existence 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 harvest is inversely proportional to the population density because of the volumes of fluids to be processed to recover a given amount of algae. Without a market for the removed algae to recover substantially the cost of removal, in-situ chemical treatment methods for algal control are less costly to apply. There appears to be little hope of developing an economically feasible harvesting technique for the naturally occurring relatively dilute algal population densities.

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 before final disposal.

Mechanical removal in natural waters is also a nutrient removal process. The typical standing crop of algae of 2 tons per acre (wet weight) would contain about 15 pounds of nitrogen and 1 1/2 pounds of phosphorus. Typical yields for submerged aquatic plants are 7 tons per acre (wet weight) which contain 32 pounds of nitrogen and 3.2 pounds of phosphorus. Under nuisance conditions yields may be substantially higher. Comparison of mechanical removal costs of nutrients with other control techniques generally are unfavorable at least where controllable point discharges are the principal nutrient source.

The usual application of mechanical methods is for control where chemical methods would possibly cause a severe oxygen demand because of the dead plant residues and subsequent development of anaerobic conditions. The odorous conditions and fish kills caused may be more aesthetically undesirable than the nuisance organisms in the water.

Chemical control methods use alqicides on herbicides to control plant populations. Attributes of a satisfactory alqicide or herbicide include: reasonably safe to handle and apply; kill specific nuisance plants; be relatively non-toxic to fish, other aquatic animals and terrestrial animals at plant-killinq concentrations; be safe for water contact by humans or animals or for withdrawn water uses; and be of reasonable cost. Table 1 presents those herbicides presently registered in accordance with the Federal Insecticide, Fungicide, and Rodenticide Act for use in or on water. Table 2 lists those registered for use at or above the water line. These tables indicate dosages and typical application locations and limitations.

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 2876
species.

HERBICIDES
REGISTERED FOR USE
IN OR ON WATER

Chemical Summary Page	Dosage As Active Ingredient	Sites, Types of Weeds, Limitations
Acrolein I-A-1	1.2 - 7.2 ppm	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.
	1.2 - 46.0 ppm	Irrigation canals and drainage ditches. Do not use treated water for irrigation until concentration falls to 13.8 ppm.
Amitrole	8 - 20 lbs./A.	Site unspecified - cattails. Do not contaminate water used for domestic or irrigation purposes.
Amitrole - T	6 - 10 lbs./A.	Drainage ditches, marshes; cattails. Do not apply where water may be used for domestic or irrigation purposes.
	8 - 20 lbs/A.	Drainage ditches, marshes; phragmites. Do not apply where water may be used for domestic or irrigation purposes.
	1 - 1.5 lbs./A.	Drainage ditches, marshes; water hyacinth. Do not apply where water may be used for domestic or irrigation purposes.
Copper sulfate $5H_2O$ I-C-14	0.05 - 2.3 ppm (pentahydrate) (exempt)	Lakes, ponds, potable water reservoirs; algae

Chemical Summary Page	Dosage As Active Ingredient	Sites, Types of Weeds, Limitations
Copper sulfate chelated	1.0 - 4.0 ppm (pentahydrate)(exempt)	Lakes, ponds, potable water reservoirs; algae.
I-C-14	1.6 - 12.0 ppm (pentahydrate) (exempt)	Industrial ponds.
Dalapon	11 - 22 lbs acid/A (10 - 15 lbs) (100 gal. H_2O)	Drainage ditches, spot treatment; cattails. Do not contaminate water used for irrigation or domestic purposes.
Dehydroabietyl-amine acetate	0.4 - 0.68 ppm	Lakes and ponds; algae. Do not apply to water used for domestic purposes.
	1.0 - 12 ppm	Irrigation canals, ditches; algae. Do not use treated water on crops.
Dichlobenil I-D-4.3	10 - 15 lbs/A	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 I-D-5	0.025 - 0.055	Lakes, ponds, canals; certain bloom producing blue green algae. Do not use in potable water.
Diquat I-D-25.2	2 - 4 lbs cation/A	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.

Chemical Summary Page	Dosage As Active Ingredient	Sites, Types of Weeds, Limitations
Diquat (continued) I-D-25.2	1 - 1.5 lbs cation/A	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.
	2 lbs cation/A	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.
	0.5 - 1.5 ppm cation	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)	0.05 - 0.83 ppm	Lakes and ponds; algae. Do not use treated water within 7 days at 0.3 ppm, 14 days at 3.0 ppm.
I-E-1.2	0.5 - 2.5 ppm	Lakes and ponds; submersed weeds. Do not use treated water within 7 days at 0.3 ppm, 14 days at 3.0 ppm.
	1 - 5 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)	0.36 - 3.5 ppm	Lakes and ponds; weeds. Do not use treated water for irrigation or domestic purposes within 7 days.

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Chemical Summary Page	Dosage As Active Ingredient	Sites, Types of Weeds, Limitations
Petroleum Solvents I-P-3.5	1000 ppm	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 I-S-1.2	8 lbs/A Liquid 40 lbs/A Granular	Lakes, ponds; emerged floating weeds. Do not contaminate water intended for domestic, irrigation, or crop spraying purposes.
	2.2 ppm Liquid 40 lbs/A Granular	Lakes, ponds; submersed weeds. Do not contaminate water intended for domestic, irrigation, or crop spraying purposes.
Simazine	0.78 ppm	Ornamental ponds. Do not use in water intended for domestic or irrigation purposes.
Sodium penta-chlorophenate	4.5 - 18 ppm	Paper mill supply impoundments, algae.
2,4-D I-D-7.7	2.4 lbs acid/A	Lakes, ponds; floating weeds. Do not use treated water for domestic or irrigation purposes.
	43.5 lbs acid/A	Lakes, ponds; submersed weeds (granular). Do not use treated water for domestic or irrigation purposes.
	6.0 lbs acid/A	Lakes, ponds; emerged marginal weeds. Do not use treated water for domestic or irrigation purposes.
Xylene I-X-1	740 ppm (exempt) DRAFT	Irrigation ditches, inject into water. Treated water may be used for furrow or flood irrigation.

HERBICIDES
REGISTERED FOR USE
AT OR ABOVE WATER LINE

Chemical Summary Page	Dosage As Active Ingredient	Sites, Types of Weeds, Limitations
Amitrole	4 - 10 lbs/A	Drainage ditchbanks. Do not contaminate edible crops.
Amitrole-T	2 - 4 lbs/A	Ditchbanks. Keep livestock off treated areas.
Ammonium Sulfamate I-A-7	57 - 171 lbs/A (57 lbs/100 gals.)	Around lakes, ponds, potable water reservoirs and their supply streams; brush. Do not contaminate water.
	95 - 190 lbs/A (95 lbs/100 gals.)	Around lakes, ponds, potable water reservoirs and their supply stream; weeds. Do not contaminate water.
Bromacil	1.8 - 4.8 grams/plant	Drainage ditchbanks - spot treatment; brush control. Do not contaminate water or use in irrigation ditches.
	3.0 - 24.0	Ditchbanks; weeds. Do not contaminate domestic water.
Dimethyl arsinic acid	(2.6 - 5.2 lbs.) / (100 gals. H_2O)	Drainage ditches; weeds. Do not contaminate water used for domestic or irrigation purposes.
Diuron	16 - 48 lbs/A	Drainage ditchbanks.
DSMA	2.3 - 4.5 lbs/A (5.33 lbs) / (100 gals H_2O)	Ditchbanks, spot treatment. Do not contaminate water used for domestic or irrigation purposes.
Erbon	120 - 174 lbs/A	Drainage ditchbanks. Do not contaminate domestic or irrigation water.
Fenuron	10 - 30 lbs/A	Drainage ditchbanks; brush control.

Chemical Summary Page	Dosage As Active Ingredient	Sites, Types of Weeds, Limitations
Fenac	4.5 - 18 lbs/A (4.5 - 36 lbs) / (100 gal. H_2O)	Ditchbanks. Do not contaminate water used for irrigation or domestic purposes.
Hexachloro-acetone	2.6 - 5.3 gals/A	Drainage ditchbanks; weeds. Apply in oil.
MCPA	3/4 - 3.0 lbs/A	Ditchbanks; weeds.
MSMA	2 - 4.5 lbs/A (4 - 8 lbs/100 gals.)	Drainage ditchbanks, spot treatment. Do not contaminate water used for domestic or irrigation purposes.
Petroleum solvents I-P-3.5	100 gals/A	Ditchbanks, irrigation and drainage. Do not contaminate irrigation water.
Picloram	2 - 3 lbs/A	Non-crop area - outer slope of ditches only, spot treatment. Do not contaminate water used for irrigation or domestic purposes.
Sodium TCA	33 - 166 lbs/A	Drainage ditchbanks. Do not contaminate water used for domestic or irrigation purposes.
TBA	20 - 40 lbs/A	Ditchbanks.
2,4-D I-D-7.7	6.0 lbs/A	Margins of lakes, ponds; emerged weeds. Do not use treated water for domestic or irrigation purposes.

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HERBICIDES REGISTERED FOR USE ON MUD BOTTOMS AFTER DRAWDOWN

Chemical Summary Page	Dosage As Active Ingredient	Sites, Types of Weeds, Limitations
Dichlobenil I-D-4.3	7 - 10 lbs/A	Lakes, ponds; submersed weeds. Apply to exposed shore and bottom.
Diuron I-D-27.8	16 - 48 lbs/A	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	15 - 20 lbs/A	Lakes, drainage ditches; submersed weeds. Drain area and apply to exposed bottom. Do not use treated water for domestic purposes.
Monuron I-M-10.2	32 - 80 lbs/A	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	100 gals/A	Ponds, canals; drain off water and spray vegetation. Do not refill for 5 days.

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CONTROL OF ADVERSE EFFECTS ON GROUNDWATER

Methods to control groundwater pollution by dams could include use of one or several of the alternatives. The dam and its foundation could be designed so that there is a minimum restriction to the down-valley flow of groundwater. 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. The design could make provision for controlled releases of groundwater past the dam.

The water table upstream from the dam could be lowered by appropriately placed pumping wells. This would reduce the opportunity for pollution from ground surface sources and would reduce the residence time of stored groundwater. 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.

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 application of agricultural fertilizers, or removal of cattle 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 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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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 resources 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. These urban-area problems are discussed briefly in the material that follows.

Extensive research has been directed toward the effects of urbanization especially directed toward surface water quality and surface water hydrology. This discussion will concentrate on the degradation of 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, the source of ground water pollution, owes its composition to dissolved organic and inorganic chemical constituents derived from a multiplicity of sources such as dirty air and precipitation, leaching of asphalt streets, inefficient methods of 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 62
are located in lowlands adjacent to large streams. In 64
reverse, ground water withdrawals may permit flow of
polluted water from streams to hydraulically interconnected 65
aquifers. The expansion of densely populated urban and 66
suburban developments into former rural or heavily 67
fertilized agricultural areas has compounded the problem of 68
ground water pollution by causing a mingling of the effluent 69
from cesspools and septic tands with fertilizer contaminated 70
ground water. Moreover, in many urban and suburban areas, 71
wastes that are accidentilly or intentionally discharged on 72
the land surface often reach shallow aquifers. 73

The pollutional effects of urbanization change as 75
development proceeds. Initially, large amounts of erosional 77
debris are produced as the original land surface is 78
disturbed by construction. In the mature stage, domestic 79
and industrial sewage, street runoff, garbage and refuse are 80
the principal sources of pollution, which intensify with 81
time.

Pollution from urban areas is not confined to the areas 83
themselves or to the immediately adjacent areas. The 85
effects often extend for considerable distances in ground 86
waters as well as in surface waters. A relatively recent 87

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) and from solution of salt that has been spread on roadways.

Long-term degradation of ground water quality has been the experience of the New Hampshire Highway Department with highway deicing salts. Year after year, chloride contents of water in certain shallow wells rose, to concentrations of 3800 mg/liter. Not only was the ground water quality degraded, but also the casings and screens of the wells were badly corroded, so that 37 wells had to be replaced. A similar situation has been reported in Michigan where water

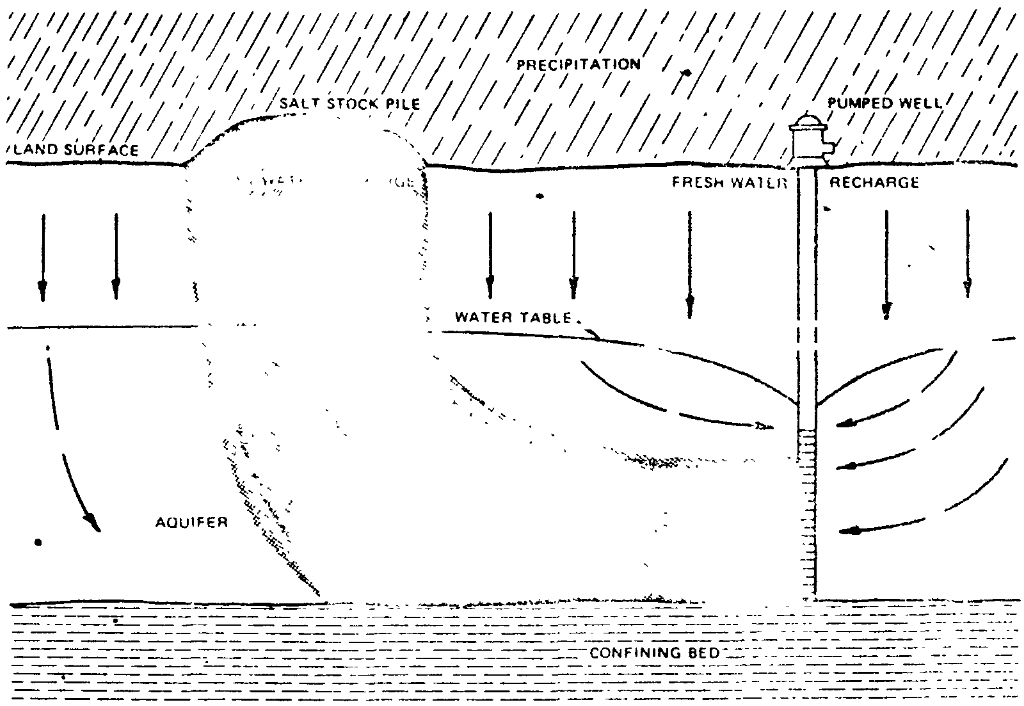

Figure 5-2. Flow pattern showing downward leaching of contaminants from a salt stockpile and movement toward a pumped well (Deutsch, 1963).

from wells was found to contain as much as 4400 mg/liter of chloride due to infiltration of highway salts.

An analysis of the steady-state concentration of road salt added to ground water has been made for east-central Massachusetts. Assuming an application rate of 20 metric tons of salt per lane mile per year, and taking into account local rainfall and infiltration values, a chloride concentration of 100 mg/liter was obtained for the gross area. Local deviations from this regional average could easily be from two to four times this figure, especially near major highways. Wells in at least 15 communities in eastern Massachusetts produce water containing more than 100 mg/liter of cloride per leter.

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 .

Table . 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 184

Degradation of water quality may occur in both shallow and 186
deep aquifers. Increased mineralization, including 188
increases in the content of nitrogen, chloride, sulfate, and 189
hardness of the water, has resulted in limitations on 190
pumping from some shallow aquifers in california and Long 191
Island.

In scattered places illnesses have resulted from 193
contamination of water by sewage and industrial wastes. The 195
occurrence of nitrate, MBAS (detergent), and phosphate in
ground water in Nassau County, Long Island, New York, has 196
been investigated in detail. Figure shows the location 197
and subsurface extent of MBAS contamination in shallow 198
ground water beneath an unsewered suburban residential area 199
in southeastern Nassau County, Long Island, New York. The 201
Nassau-Suffolk Research Task Group (1969) has made detailed
studies of pollution near individual septic systems in Long 202
Island.

Gaining streams in Long Island also show significant 204
contents of nitrate and MBAS from inflow of contaminated 205
ground water. High nitrogen content of ground water in 206
Kings County, Long Island, New York, is attributed largely 207
to long-term leakage of public sewers. Contamination of 208

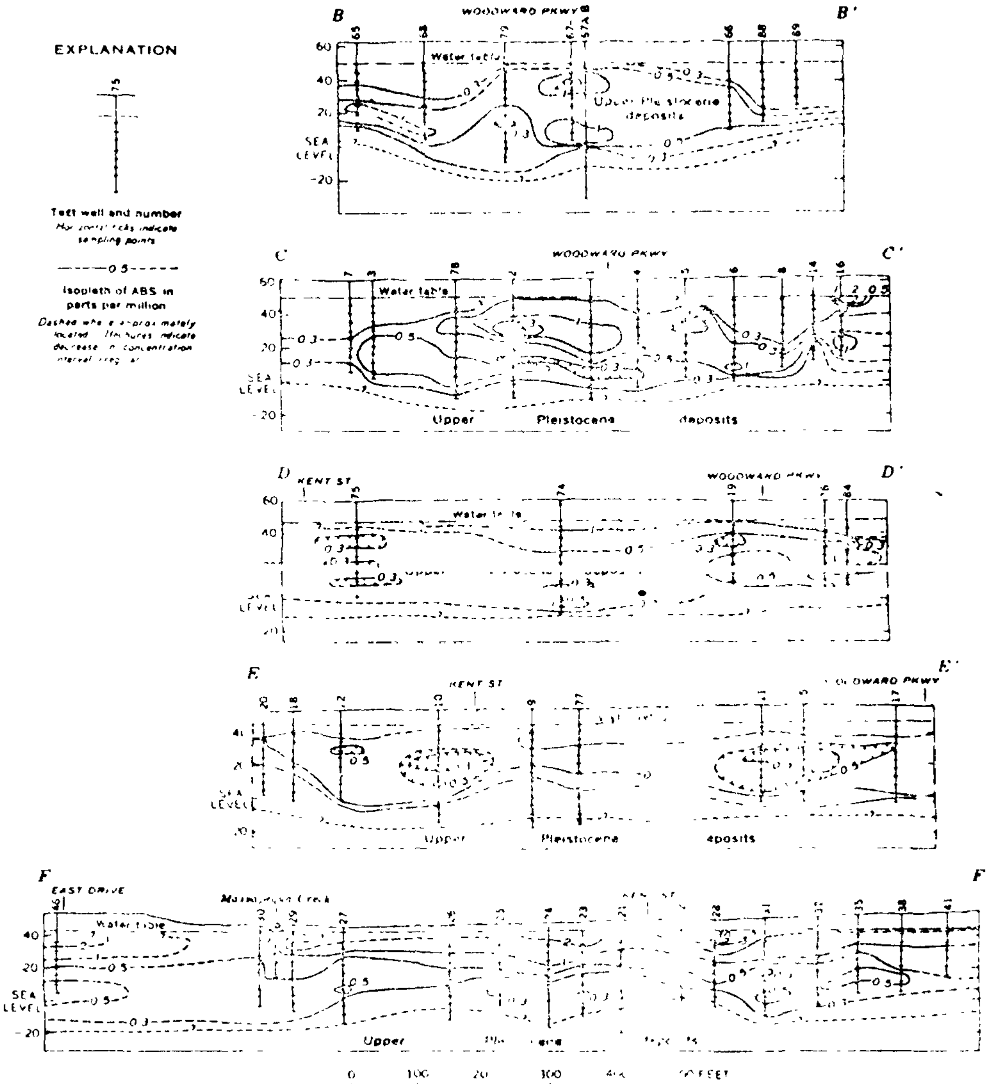

Figure 5-1. Hydrogeochemical sections oblique to the direction of groundwater flow, showing lines of equal concentration of MBAS in Nassau County, Long Island, New York. Contaminated water is shaded; lower limit shown at about 0.1 mg/liter (Perlmutter, et al, 1964).

shallow public-supply wells by detergents from cesspoll 208
effluent in Suffolk County, Long Island, New York, has 209
resulted in shutdowns of wells except during periods of peak 210
demand. Similar problems occur in California. The contents 212
and trends in salinity and nitrate in the Fresno-Clovis area 213
have been analyzed to confirm this trend.

METHODS OF POLLUTANT TRANSPORT 215

Urbanization grossly alters the hydrology of an area. In 218
general, this results in a decrease in the natural recharge
to underlying ground water unless compensated by artificial 220
recharge. This, in turn, has an adverse effect on ground 221
water quality if the quality of the natural recharge was 223
high. The decrease is due to the impervious surfaces of an 224
urban area--houses, streets, sidewalks, and commercial, 225
industrial, and parking areas, which reduce direct 226
infiltration and deep percolation of precipitation. Peak 227
storm runoff and total runoff is increased but over shorter 228
time periods, resulting in decreased streambed percolation.
Natural streambed recharge is further decreased by concrete 229
storm drains and the lining of natural channels for flood 230
control purposes.

In the Santa Ana River Basin in Southern California, pollution of ground water has resulted from the importation by municipalities of Colorado River water, which is high in salinity (750-850 mg/liter total dissolved solids). Pollution has resulted from artificial recharge and also from percolation of water used for irrigation of lawns and parks.

High local ground water temperatures attributed to recharge of warm water used for air conditioning have been investigated in Manhattan, the Bronx, and in Brooklyn, New York. A 5-to80-degree Celsius rise in the summer temperature of water in gaining streams on Long Island has been attributed to a variety of urban factors such as pond and lake development, cutting of vegetation, increased stormwater runoff into streams, and decreased ground water inflow.

Several pollution incidents related to urbanization in Minnesota have been reported. These included drainage of surface water through wells in sumps which produced discolored and turbid water as well as positive coliform determinations, pollution from leachate in poorly designed landfills, and pollution from solvents disposed of in pits and basins. Poor housekeeping practices at an 80-acre industrial site resulted in the saturation of the area with creosote and other petroleum products over a long period of time. The severity of the cresosote leaching problem was recognized when the water from a nearby municipal well developed an unpleasant taste.

The principal mechanism of ground water pollution in urban areas are infiltration of fluids placed at or near the land 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 or 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 becteriological 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 329

Prediction methods for the effect of urbanization for 332
surface waters traditionally utilize basic hydrological
methods to predict the quantity of run-off produced for 333
various intensity storms coupled with field surveys of the 334
pollution sources tributary to the stream. The most common 336
hydrological model is the so called "rational method" which 337
takes into acount the imperviousness of the area and the
time of concentration for rainfall to runoff to the 338
collection point. Experience factors for determining 339
pollutional loads from storm sewers and direct run-off can 340
be applied to determine resulting water quality 341

More sophisticated techniques have been devised using 343
the concepts of synthetic hydrology and stochestic processes 344
to develop expected runoff and resulting water quality from 345
various intensity storms. Such models are useful for 346
planning channel capacity requirements as well as justifying 347
treatment of incoming wastes. By projecting changes in 348
runoff characteristics, the projection of future conditions 349
is also possible.

Ground water prediction methods are generally much more 351
crudely designed than surface water models. Highly 353
sophisticated mathematical hydraulic models are available

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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. As ground water in urbanized areas becomes a more important source of supply and its quality continues to deteriorate adversely affecting the uses to which that water which is extracted is put, quality prediction techniques will be improved.

Processes, Procedures and Methods to Control Pollution Resulting from Urbanization

Control of the effects of urbanization for surface run-off has received extensive research attention. Control methods have been identified and in some cases demonstration projects performed for evaluation.

Ground water effects have not received this research effort so that suggested control methods are more intuitive in some cases rather than proven techniques. For this reason, these ideas are presented in a brief form.

The following list suggests procedures that can prevent, reduce, or eliminate pollution in urban and suburban areas. The applicability of any particular method depends, of course, on local circumstances.

- Pre-treatment of industrial and sewage wastes before disposal into lagoons and pits.

- Lining of disposal basins where the intent is to prevent leaching into ground water.

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- Collection, by means of drains and wells, and treatment of leachate derived from landfills, industrial basins, and sewage lagoons.

- Proper management of ground water pumping to prevent or retard seawater encroachment in coastal aquifers.

- Creation, by means of wells, of injection ridges or pumping troughs to retard seawater encroachment.

- Abandonment or prohibition of cesspool and septic tank systems in densely populated areas and replacement by sanitary sewer systems.

- Proper construction of new wells and plugging of abandoned wells.

- Implementation of better housekeeping practices for land storage of wastes, and monitoring of potential industrial polluters through permits and on-site inspection.

- Reduction in use of road deicing salts.

- Storage of stockpiles of chemicals under cover and on impermeable platforms to prevent leaching; recovery and treatment of leachate which has occurred.

- Publicizing procedures for optimal applications of lawn fertilizers and garden chemicals to minimize potential leaching.

- Frequent and adequate cleaning of streets.

- Provision for artificial recharge with high quality water to compensate for reduction in natural recharge.

- Use of high-quality water for municipal and industrial purposes where return flow from those uses will contribute to ground water; alternatively, desalination of wastewaters before discharge.

- Provision for adequate treatment of runoff from urban areas prior to discharge into streams which recharge ground water.

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GUIDANCE FOR THE IDENTIFICATION AND EVALUATION OF THE EFFECTS OF DREDGING

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 tc 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 municiapl goverments, and private citizens or corporations, all of which are subject to the provisions of the laws for protection and preservation of navigable waters.

The River and Harbor 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

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spoil from the Great Lakes. The National Environmental Policy Act of 1969 requires a detailed statement of environmental impact of proposed new navigation projects and projects requiring maintenance dredging. In a report on "Ocean Dumping A National Policy" submitted to the President in 1970 by the Council on Environmental Quality it was recommended that ocean dumping of polluted dredge spoil be phased out as soon as aternatives can be employed and that dumping of unpolluted spoil be regulated to prevent damage to estuarine and coastal areas. The Federal Water Pollution Control Act Amendments of 1972 under Section 404 requires the Administrator of the Environmental Protection Agency to develop guidelines for selection of spoil disposal sites and gives the Administrator authority to restrict the use of any defined area for spoil disposal. These recently enacted laws indicate the public's increasing awareness and concern over the adverse environmental effects associated with dredging and dredge spoil disposal. While most of the public attention has been directed at the effects on the aquatic environment (which will be extensively treated under Section 404 of the Act) this section will focus mainly on the pollution of ground water from dredging and dredge spoil disposal.

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Current Practices

Dredging is currently empolyed in channel development and maintenance, construction of canals, to provide material for landfill, in lake and pond improvements, and in mining of minerals including sand and gravel.

Methods available for dridging can be classified as either mechanical dredging or hydraulic dredging. Mechanical dredges are analogous in operating principal to land-based excavation equipment such as the dragline, shovel, or treching machine, and can be operated from either dry land or the water surface. Hydraulic dredges employ a pump to lift the material from the lake bottom and transport it by boat or pump it through a pipeline to the point of disposal. Cutter heads of various configurations are employed depending on the nature of the materials to be removed. Primary concern in dredging operations is generally with the volume of material to be removed and the location of the disposal site. Until recently little consideration was given to potential dangers to the environment, and even now little thought is given to the possible consequences to the ground water region.

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Sources of Pollution

The environmental impacts associated with dredging are those resulting from the removal of bottom material and those resulting from the redeposition of this material. The physical alterations resulting from the removal of bottom material include changes in bottom geometry and the creation of deep water regions, new open water, changes in bottom substrates and habitats, alterations in water velocity and current patterns, changes in future sediment distribution pattersn, alteration of the sediment water interface with subsequent release of biostimulatory or toxic chemicals, and the creation of turbidity clouds. The most common adverse environmental effects associated with spoil disposal include: turbidity which is aesthetically displeasing, reduces light penetration, flocculates planktonic algae, and decreases the availability of food for aquatic organisms; sediment build-up which destroys spawning areas, smothers benthic Organisms, reduces bottom habitat diversity, reduces food supply and vegetative coverings; and oxygen depletion which suffocates organisms in the area and releases noxious materials such as methane, sulfides, and metals.[1]

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Potential sources of ground water pollution associated with dredging and dredge spoil disposal include: the breaching of aquicludes and the resultant direct introduction of contaminated surfaces waters to shallow ground waters; changes in surface water flow or circulation patterns with subsequent seepage of contaminated surface waters to the ground water regime; and infiltration of seepage and leachate from land deposited spoil.

Types of pollutants

Types of Pollutants Resulting from
Dredging Operations

Sediment

The principal pollutant created by dredging operation is sediment. Disturbance of the channel, harbor, estuary, lake or other water body results in the development of suspended solids in the dredge area. These vary in physical, chemical and biological character and may result in both short-term and long-term effect on the quality of

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water at the site or even at some distance from the actual operation.

Direct effects of bottom disturbance is the generation of suspended solids. If these are composed of a large amount of very fine clays, silt and organic materials, the resulting increase in turbidity will effectively reduce light penetration and subsequently impair primary food production necessary to the survival of higher organisms. In relatively deep water, turbidity effects can alter the rate of temperature change and promote thermal stratification.

Disturbance and resuspension of sediments following dredging can blanket an undisturbed bottom, thereby burying and smothering benthic organisms, destroy fish eggs, and generally destroy spawning areas and bottom-dwelling animals and plants.

Direct effects of sediment created during dredging on fish includes such harmful effects as reduction of gill function, impairment of swimming ability reduction of rate of growth and increase in susceptability to disease.

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Sediments associated with chemically and physically sorbed toxic materials and biostimulants such as heavy metals, pesticides, phosphates, nitrates and organics, may be reintroduced to further solution, thus degrading water quality. Exposure of organic materials through disturbance often reduces the dissolved oxygen content of the water. Oxygen depletion, in turn, suffocates organisms whose decay may release methane and other toxic gasses, further degrading water quality.

Ordinarily, the most adverse effects of sediment on the aquatic ecology result from maintenance dredging where the volume of fine silt, clay, mud, organic muck, sewage and sludge, together with municipal and industrial debris is high. Maintenance spoil (sediment) may also contain considerable amounts of heavy metals, sulfides, phenols, and other toxic elements.

Sediments dredged from previously undisturbed areas are ordinarly of relatively high chemical and physical quality inasmuch as their composition is similiar to that of the geologic strata which they represent. These sediments are primarly, 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.

Adsorbed Chemicals Attached to Sediment

Among the principal pollutants sorbed on sediments are plant nutrients and pesticides. The sorption usually takes place while the sediment is a part of the land surface, i.e., topsoil, or a compound of an industrial or municipal procedure, i.e., waste water facility.

Sorbed constrtuants ordinarily give rise to long-term pollution effects on water. Prior to disturbance, the sediment with their sorbed chemicals have a minimum exposure to the water. As a result the release of sorbed material is very slow inasmuch as detachment normally only occurs at the sediment water interface. This releace on intercharge is a function of bottom sediment movement.

Desorption is the release of adsorbed molecules from the surface of particles including colloidal sizes. Desorption has been demonstrated for a number of herbicides

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including 2, 4-D, amiber, monuron, dalapon, atrazine, and simazine. These are concentrated in the bodies of aquatic animals and the stored pesticides passed on the to their consumers. The estuary is the primary breeding ground and nursery of many oceanic species. Any accumlation of pesticide in these species will be carried to the ocean and then passed on to higher trophic forms of the open ocean and then to man.

Aquatic vegetation can sorb significant quantities of pesticides which may be metabillically degraded or stored. Those stored may become a part of the flood sequence or ? retired to the bottom sediment where they become again subject to resuspension.

Nutrient sorption on sediment is limited almost entirely to phosphatic compounds. The principal organ of these constitrent are in the soil system and in sewage, wasted or discharged into the area of dredging. Disturbance leading to resuspension and redistribution of the bottom sediments encourages solution of the slowly-soluble phosphatic compounds, facilitating excessive algal growth as a result of phosplorous enrialment.

Sorbed secondary and micronutrient such as the compound of copper, nickel manganese, iron, etc. released as a result of disturbance may be a factor in accelerated water degradation. .1

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Leaching from Freshly Exposed Surface

Nutrients

Resuspension of dredged and otherwise excavated materials, particularly those in heavily populated or intensely tilled areas may contain excessive amounts of relatively insoluble nutrients associated with the sediment. These are usually in the form of phosphate compounds originating from industrial processes or agricultural pursuits. A significant percentage of the municipal contribution may stem from small homeowner fertilization of lawns and gardens, flushed into the storm runoff system following heavy precipitation or indiscriminate irrigation. Limited treatment of municipal sewage effects little or no reduction in phosphate compounds and these will subsequently find their way into the water body to either combine chemically with, or be sorbed by, the sediments. Nitrate compounds are much more soluble than phosphates and tend to be removed to more remote areas by currents and wave action.

Disturbance of the bottom sediment along with its sorbed nutrients exposes a surface areas to the surrounding solvent (water) far greater than existed in the undisturbed condition which prevailed within the quiescent sediment-water interface and vastly increases the amount of nutrient

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entering into solution—previously held in the nutrient "bank". This access may cause accelerated eutrophication, particularly if the dredged body is a pond, lake or reservoir. In other instances the sudden or catastrophic increase in nutrient concentration may be toxic to certain aquatic biota.

Metals

Sediments polluted by compounds containing metals are common in highly industrialized areas where discharges have been occurring over long periods of time. These metallic compounds vary widely in character and in their toxicity to aquatic biota, particularly animals. The principal metals are compounds of iron, cadium, copper, chromium, arsenic and nickel. Disturbance resulting from resuspension during dredging displaces, relocates and tends to dissolve these compounds to the detriment of aquatic animal life within their environment. Knowledge of the spoil composition, with particular attention focused on toxic metal content is necessary in order to evaluate the pollution status of the sediment.

Organic Materials

Organic compounds associated with dredge spoil include peat, sludge, organic muck and municipal-industrial wastes. Most of this material is very fine-gained and the components may

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range down to colloidal size. If disposed of in open water, organic material can cause adverse effects such as serious oxygen depletion in addition to the release of toxic and noxious gases such as methane, hydrogen sulfide, etc. Organic spoil commonly contains pesticides originating from both municipal and agricultural sources. Industrial phenols comprise a group of chemicals toxic to aquatic biota and are highly detrimental to municipal and domestic water supplies. Bottom sediments may also contain undesirable quantities of organic carbon—now believed to be an important factor in accelerated eutrophication.

Habitat Destruction in Dredge and Spoil Disposal Areas

Direct effects of dredging on biological communities and/or water quality are the result of the physical disturbance and chemical pollutional effects on the aquatic biota. The principal concern is ordinarily with the direct effect on biological communities but long-term effects cannot be ignored. Destruction or impairment of the benthic environment and its inhabitants comprise a very serious problem associated with dredging. The effects may vary greatly. The possibility of benthic extermination or, at a minimum, extensive damage, is greater in those locales where "new" work has been instituted than in old or maintenance areas. The reason for this difference is that areas previously disturbed repeatedly have discouraged extensive benthic development.

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The direct effect of dredging activity confined to the project area, and usually short-term, are:

Turbidity Effects	aesthetically displeasing; reduction of light penetration; flocculation of planktonic algae; and reduction of availability of flood in the initial stage of the food chain.
Sediment Buildup	destruction of spawning areas; smothering of benthic organisms, reduction of benthic habitat diversity and reduction of food supplies.
Oxygen Depletion	suffocation of organisms; release of toxic and noxious gases such as methane, sulfides and metallic compounds.
Removal of substrate where Benthic Organisms Grow, results in:	destruction of bottom dwellers; destruction of burrowing forms; destruction of spawning areas.

Resuspension of Solids and burial or organisms including direct destruction of fish eggs.

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Suburbanization

The development of or the addition to, existing urban areas increases the likelihood of pollution of sediments by municipal and industrial wastes. Potential pollutants also stem from domestic usage of fertilizers and pesticides on lawns and gardens. Spoil is often placed near or adjacent to urban centers or in congested areas as fill. In the past many fill areas developed as a result of a secondary or indirect (by-product) effects of dredging. In more recent years such fill was intentionally carried out to reclaim or improve land. This practice is proceeding at an accelerated rate. Under these conditions spill is confined or contained and tends to limit destruction that ordinarily occurs 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 recreational areas where poor foundation conditions prevail, (i.e., wetlands and marshes) due to the proximity of the groundwater table. Disposal in these locales is further aggravated by the fact that drainage is poor. In the initial stage of a new fill, seepage may be excessive and must be controlled. Seepage through and beneath containment dikes should be analyzed to determine the pollution potential. The extent of possible groundwater contamination should be established and remedial measures adopted. Spoil containing a high percentage of fine-grained organic material yields very compressible and weak (incompetent) foundation. The unstable condition is aggravated when the fill is placed on wet, organic and compressible subsurface soils, many of which are found in reclaimed areas such as marshlands, wetlands and low-lying coastal areas of the continental margins.

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Increased Commercial and Recreational Use --

Land environments adjacent to the ocean, estuaries, and major streams offer valuable sites for commercial, industrial and recreational development. Spoil disposal practices in these areas can be very useful if properly managed. The construction of spoil islands to provide additional habitat for fish and wildlife is a worthwhile method of utilizing spoil. Spoil islands, particularly on the Atlantic and Gulf Coast have attracted a wide variety of waterfowl and other forms of wildlife, both migratory and sedentary. In addition to the creation of artificial habitat, spoil 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.

Fills created specifically for land development including commercial and industrial purposes need be composed of competent material inasmuch as foundation requirements relating to heavy loads for structures such as industrial plants and multistory buildings are relatively severe. This places a requirement for "cleaner" spoil, i.e., sand, gravel and medium grained soils, and may create a necessity for development of "new" work areas which, in turn, will create water pollution problems.

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METHODS OF POLLUTANT TRANSPORT

Instream Activities

Pollutants stemming from dredging operations are transported both in the solid and dissolved phase. This is true whether the removed and redeposited material is discharged into water or transferred onto land.

If the discharge is into water, the solids will be carried in the direction of current movement. In a river, the downstream effects of the pollutant are a function of the quantity, particle size, particle density, current velocity and amount and type of turbulence. Additional factors affecting travel are slope of channel, irregularity of stream bottom, slope or gradient, depth, and discharge volume. The rate of change of velocity is an inportant factor regarding the range of sediment travel. In streams of low velocity laminar flow predominates and at this rate sediment, along with other pollutants, may be transported along the maximum cross-section over considerable distances. Sorbed pollutants and those in solution follow the same pattern.

Spoil discharged into large water bodies such as estuaries, harbors and bays form turbidity plumes whose extent and geometry are a function of the water movements with which they come in contact. Restoration of lakes, either partial or total, is accompanied by removal of sediment, nutrients, organic and

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toxic materials. Dredging, then, is a method of in-lake (or reservoir) treatment and eutrophication control measures. Lake deposits are largely a product of the adjacent land. Sediments derived from sheet, gully and shoreline erosion constitute the inorganic phase of bottom particles. A lake is also the storage basin for products or organic composition, soluble and relatively insoluble nutrients, domestic sewage, sorbed and free pesticides and entrapped gasses ordinarily the products of decomposition of the aggregate whole (collectively referred to as "muck").

Dredging disturbs the bottom material and may release entrapped gasses along with toxic substances which may be poisonous to aquatic biota and domestic water supplies. Sediment, along with sorbed pollutants may be distributed by lake currents and wave action to fish spawning areas. Aesthetic and recreational pastimes such as boating, swimming and fishing may be adversely affected by resuspension of sediments created by dredging operations. Care must be exercised during the operation in order to avoid disturbance, rupture or removal of any sedimentery bottom seal in areas where the lake immediately overlies porous formations into which the contents could drain by percolation.

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Runoff from Disposal Sites Including Ieachates

On-land dredge spoil disposal sites, unless carefully chosen, are frequently instrumental in polluting both adjacent water bodies and the groundwater environment beneath the landfill. In addition to objectionable odors, spoil masses, if fine - grained, may retain their high water content and remain slurry - like for considerable periods of time. This condition results in a high degree of instability, particularly in marginal areas destined for residential, commercial, and industrial sites and often creates intolerable and ever dangerous foundation problems.

Where disposal takes place in a containment area, consideration must be given to outlet structures such as outfalls and return ditches necessary to discharge and convey the fluid fraction of the spoil. The return flow is commonly contaminated and may contain a high percentage of suspended solids, dissolved chemicals and sorbed pollutants. Removal efficiency of these pollutants in the fill area is often very low due to limited retention time. A large percentage of the escaping solids are colloidal and essestially impossible to remove by relatively inexpensive, conventional, procedures. Channelization at the outlet works and further erosion of the land surface by discharged water may occur. The fill area often becomes a mosquito breeding ground and haven for undesirable forms of wildlife. High

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bacteria counts are frequently encountered in the fill area.

Leaching of Materials into Ground Waters

Damage to the groundwater province beneath, and adjacent to fill areas through leaching of soluble minerals, chemicals, nutrients and toxic substances is an ever-present hazard associated with any landfill operation. Once contaminated, damage to the aquifer may be "permanent" -- or at best -- long term and may result in the ultimate abandonment of water wells. Water quality effects on the aquifer in a proposed fill area should be carefully evaluated prior to disposal.

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Magnitude and Variation

To date over 22,000 miles of waterways have been modified for commercial navigation and over 19,000 miles of waterways and some 1,000 harbor projects are currently being maintained by the Corps of Engineers. Annual quantities of material being removed are currently averaging about 300,000,000 cubic yards in maintenance dredging and about 80,000,000 cubic yards in new work dredging. Total annual costs are now exceeding $150,000,000.00.[1] The volumes of material removed at a single project may vary from a few thousand cubic yards in a harbor maintenance project to many millions of cubic yards in channel development projects. Variation in the nature of the material removed ranges from clean sand and gravel to organic muck, sludge and municipal and industrial wastes or any combinations thereof.

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Figure 1, illustrates the average annual quantities of spoil generated by CE district and methods of disposal; figure 2, illustrates the average annual quantities of spoil type generated by CE District; and figure 3 illustrates the amount of polluted spoil generated in maintenance dredging operations by deposition area and district,

The following criteria for determining the acceptability of dredged spoil for disposal to the nation's waters have been developed by the EPA:

Criteria

The decision whether to oppose plans for disposal of dredged spoil in United States waters must be made on a case-by-case basis after considering all appropriate factors; including the following.

(a) Volume of dredge material.

(b) Existing and potential quality and use of the water in the disposal area.

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Fig. 1. Disposition of dredge spoil generated in maintenance dredging operations and average annual quantities of spoil disposed by area by District (After Boyd, et al., 1972)

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Fig. 2 Grain-size classification of spoil generated by maintenance dredging operations and average annual quantities of spoil by type by District (After Boyd, et. al., 1972)

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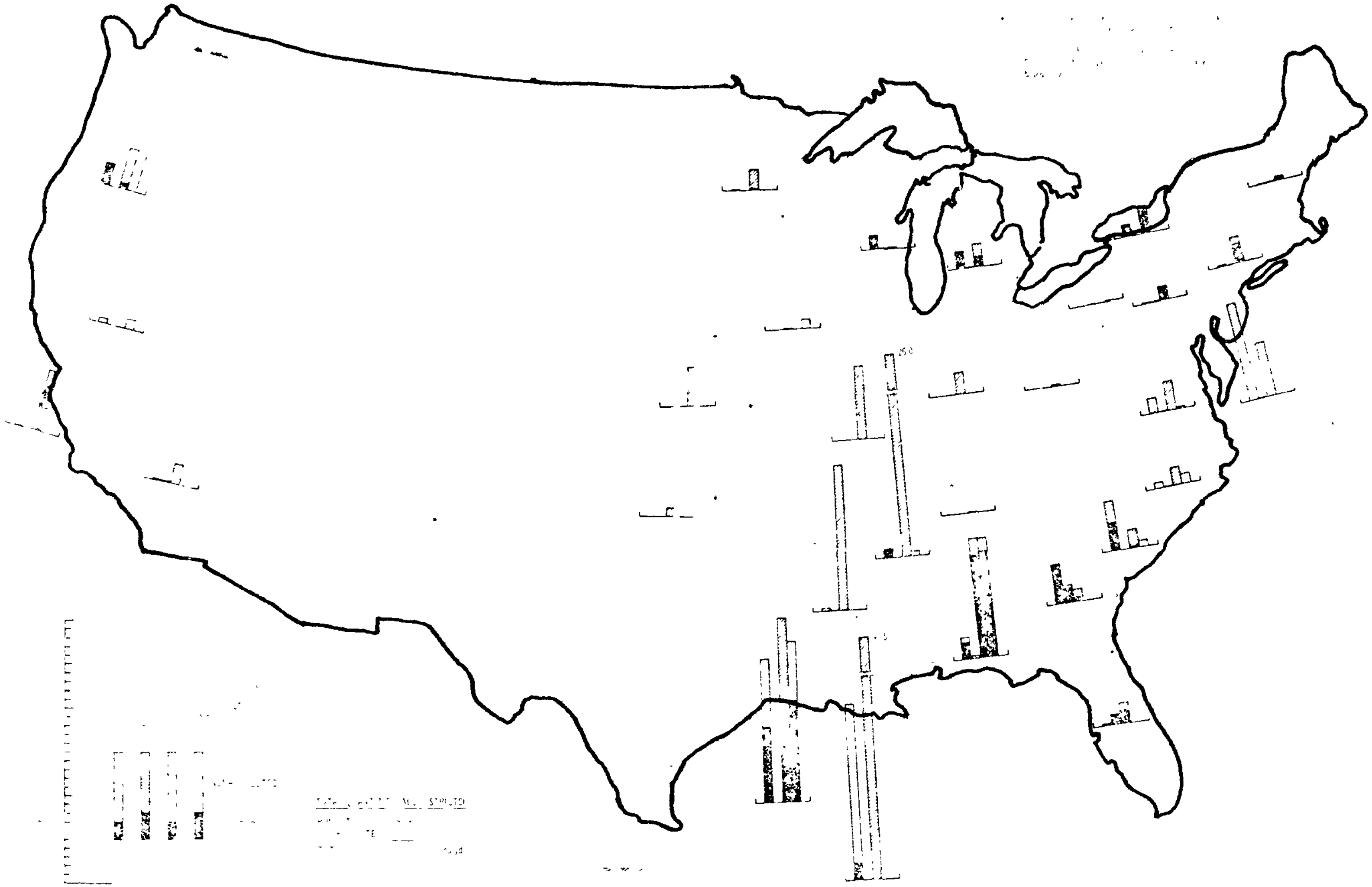

Fig. 3. Pollution status of spoil generated in mainteral ce dredging operations by disposition area by District (after Boyd, et al., 1972)

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(c) Other conditions at the disposal site such as depth and currents.

(d) Time of year of disposal (in relation to fish migration and spaqning, etc.)

(e) Method of disposal and alternatives.

(f) Physical, chemical, and biological characteristics of the dredged material.

(g) Likely recurrence and total number of disposal requests in a receiving water area.

(h) Predicted long and short term effects on receiving water quality. When concentrations, in sediments, of one or more of the following pollution parameters exceed the limits expressed below, the sediment will be considered polluted in all cases and, therefore, unacceptable for open water disposal.

Sediments in Fresh and Marine Waters   Conc % (dry wt basis)

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*Volatile Solids	6.0
Chemical Oxygen Demand (C.O.D)	5.0
Total Kjeldahl Nitrogen	0.10
Oil-Grease	0.15
Mercury	0.001
Lead	0.005
Zinc	0.005

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*When analyzing sediments dredged from marine waters, the following correlation between volatile solids and C.O.D. should be made:

$$T.V.S.\% \text{ (dry)} = 1.32 + 0.98 \text{ (C.O.D.\%)}$$

If the results show a significant deviation from this equation, additional samples should be analyzed to insure reliable measurements.

The volatile solids and C.O.D. analyses should be made first. If the maximum limits are exceeded the sample can be

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characterized as polluted and the additional parameter would not have to be investigated.

Dredged sediment having concentrations of constituents less than the limits stated above will not be automatically considered acceptable for disposal. A judgement must be made on a case-by-case basis after considering the factors listed in (a) through (h) above.

In addition to the analyses required to determine compliance with the stated numberical criteria, the following additional tests are recommended where appropriate and pertinent:

Total Phosphorus	Sulfides
Total Organic Carbon (T.O.C)	Trace Metals (iron, cadmium, copper, chromium, arsenic, and nickel)
Immediate Oxygen Demand (I.O.D)	Pesticides
Settleability	Bioassay

The first four analyses would be considered desirable in almost all

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instances.

They may be added to the mandatory list when sufficient experience with their interpretation is gained.

For example, as experience is gained, the T.O.C. test may prove to be a valid substitute for the volatile solids and C.O.D. analyses.

Tests for trace metals and pesticides should be made where significant concentrations of these materials are expected from known waste discharges.

Prediction Methods

To predict the potential for water pollution from a dredging program requires the consideration of a number of interacting factors involving the hydraulics of the altered channel, the adjacent waters and the spoil pile; and the chemistry of the spoil, the water involved and the newly exposed surfaces.

Prediction of the flow patterns and associated bank scouring, silt deposition, bottom scouring and flooding is facilitated by mathematical modeling and, where the data, resources and time available are adequate, scale modeling is an excellent tool.

In those instances that involve the scalping of an aquifer, or the alteration of the flow of groundwater, hydrogeological investigations are also in order which may involve surface geological mapping, stratigraphic drill core analyses, pumping tests and mathematical or analog modeling.

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Very little work has been done in the 'effects on groundwater' area.

Groups currently involved in predictive studies include:

United States Geological Survey

Environfmental Protection Agency

United States Army Engineers

North Carolina State University

Skidway Institute of Oceanography

Clemson University

Northwestern University

Oklahoma State University

Texas A & M University

University of Hawaii

University of Rhode Island

University of Southern Mississippi

University of Maryland

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