Water as a Resource and as a Nuisance

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•GENERALLY when people speak of water as a resource they are considering its good aspects, recognizing that it is essential for life and living. Sometimes, or at some places, or to some people, the same water may be annoying or unpleasant, and thus a nuisance—for example, rain at a picnic, snow at any time except Christmas Eve, groundwater in a basement, floodwater inundating personal property, and any water after it has been polluted by somebody else.

For use in this paper, "water resource" will be defined more broadly and "nuisance" more narrowly. The water resource is part of the natural resource base, as broadly defined by Bauer (1) in the preceding paper to include "all aspects of the land, the air, and the water that must be considered in planning . . . if an environment suitable for the well-being of all life is to be created." A nuisance is a cause of annoyance or inconvenience or injury that is an invasion or disturbance of the rights of some particular person (a private nuisance) or of members of a community (a public nuisance).

The water resource is widely and irregularly distributed on earth, available to man for such enjoyment and development and use as he sees fit, some use being essential to his existence. Natural variations in the quantity and quality of water are inevitable. If these variations cause annoyance or injury to someone, this is accepted as one of the hardships that this planet imposes upon its inhabitants—the variations are recognized as natural, or "acts of God." But if any man or society is partly responsible for the conditions that result in such annoyance or injury, this may be an invasion or disturbance of the rights of others—a nuisance—and perhaps subject to injunctions and damage suits. Legal disputes over water as a nuisance are generally deeply involved with problems of the respective rights of plaintiff and defendant.

THE NATURAL RESOURCE

Water is a replenishing resource. The fresh water on or in the land masses of the earth is replenished by precipitation. The vapor lost from the atmosphere by precipitation is replenished by evaporation of water partly from the land masses but chiefly from the oceans. The net water loss from the oceans by evaporation is replenished by runoff from the land masses. This is the hydrologic cycle, simple in principle but complex in process.

Water from precipitation at any point may (a) accumulate on the surface, (b) infiltrate into the ground, and/or (c) run off overland. Water may accumulate on the surface as snow or ice, or in ponds, lakes, and marshes. It may be intercepted above the surface on vegetation, on buildings, or other structures. It is vulnerable to evaporation and may be returned to the atmosphere as wetted surfaces dry off, or it may disappear by infiltration below the land surface. When water infiltrates into the soil, it is held there until the soil reaches its capacity for retention by molecular attraction, and any excess then percolates downward to become groundwater. In the intervals between storm periods, soil moisture may be depleted by evaporation and transpiration, and this depletion must be made up during subsequent storms before there can be additional downward percolation.

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Overland runoff occurs only when precipitation exceeds the infiltration capacity of the surface layer of soil, organic material, or mantle rock. The water flowing overland may evaporate or infiltrate or accumulate elsewhere, or it may enter streams. Of the water in streams, some may accumulate in lakes and reservoirs; some may return to the atmosphere by evaporation or transpiration of riparian vegetation; some may seep downward into groundwater reservoirs; and some may continue as runoff to the oceans.

Groundwater reservoirs receive water that percolates downward from the soil, and in some places from streams or lakes or surface reservoirs. The groundwater reservoirs are composed of materials sufficiently permeable that water can move through them by gravity. The underground flow may ultimately be discharged into lakes, stream channels, or oceans, or at the land surface by springs or seeps. Most groundwater is safe from loss by evapotranspiration, but some is shallow enough to be reached by the roots of plants or by direct evaporation. Groundwater reservoirs contain far more water than the total in all lakes and surface reservoirs plus the volume of annual runoff in all rivers to the ocean. Only a small proportion of the total groundwater, however, is or can be replenished annually from precipitation—the rest is a stock resource, accumulated in past years and centuries.

Resource Statistics

The average annual precipitation over the United States, excluding Alaska and Hawaii, is equivalent to a layer of water 760 mm thick. About 28 percent of this water, equivalent to a layer 220 mm thick, eventually runs off to the oceans, but in the meantime it constitutes the fresh water potentially available for man's continuing uses and enjoyment. The rest of the gross supply returns to the atmosphere as water vapor, by evaporation from water surfaces and moist land and by transpiration of vegetation, both native and cultivated.

Geographically there is a wide range in average annual precipitation, in evapotranspiration, and in the difference between the two. Greatest average annual precipitation of record in the conterminous United States is about 3,000 mm, at Forks, Washington, in the drainage basin of the Hoh River, which has an annual runoff averaging 3,300 mm. Thus our data on precipitation are insufficient to show any loss by evapotranspiration. At the other extreme, Furnace Creek Ranch in Death Valley, California, receives precipitation averaging less than 50 mm a year; the evapotranspiration is similarly low because of the dearth of water, but the evaporation potential is large, as indicated by recorded losses of about 3,800 mm annually from an evaporation pan. At any locality, precipitation may produce surpluses during certain months or seasons, or during specific storms. Evapotranspiration also varies seasonally, commonly increasing (if the water is available) during the growing season to a summer maximum, and then decreasing to a minimum in winter.

Potential evapotranspiration is that which would occur under optimum conditions of soil moisture and vegetal cover at a rate dependent solely on the climate. Where average precipitation is greater than average evapotranspiration, there is a surplus of water, and the more humid the climate the greater the surplus. Where the potential evapotranspiration exceeds the average precipitation, as in arid climates, water deficiency is the rule. A water balance map published by Piper (2), based on average annual precipitation and potential evapotranspiration, indicates the areas and amounts of surplus and deficiency throughout the conterminous United States. The principal areas of perennial surplus are the eastern 31 states, the Pacific Northwest, and several high mountain ranges in the West. Perennial water deficiency is characteristic of most of the western half of the country. In areas of perennial deficiency the natural water economy is xerophilic, and human activities are in response to the water-scarce environment, relying wherever possible on inflows from areas of perennial surplus, regulation and use of seasonal or occasional local surpluses, and depletion of stock resources of groundwater for temporary benefit. In areas of perennial surplus, human activities are adapted to the environment of water abundance, counting on the surpluses for various uses and for carrying away wastes, and managing them to overcome occasional deficiencies and to protect against damaging floods.

HUMAN MODIFICATIONS OF THE NATURAL FLOW SYSTEMS

Thanks to the renewability afforded by the hydrologic cycle, water as a resource serves the continuing needs of mankind and the rest of the biosphere. Beneficial use of water, essential for each individual, is recognized as a social good. Many types of uses of water either reduce the quantity or impair the quality of the natural resource, and this may be detrimental to other individuals or the public. The right to use water, however, is recognized and protected as a property right, so that proving a "nuisance" involves weighing the merits of the respective rights of all parties involved.

The use of water may require substantial structures or other developments: dams to provide storage and regulation of the natural flow; canals and pipelines to divert and distribute water to places of use; collecting systems; treatment plants for impure water; wells to yield groundwater; pumps to lift water; and channels and dredging to provide navigability. All these are intended to modify the natural flow systems for the benefit of mankind. The degree of benefit may vary among individual water users who are dependent upon the development. In some places or to some people the effects of water development may be detrimental and qualify as nuisances.

Effects of Water Use

Technologists are seeking to obtain usable water from every phase of the hydrologic cycle. The oceans, with 97 percent of the water on earth, constitute an inexhaustible reservoir—none of it fit for an ancient mariner to drink—which by desalination can provide fresh water for people, especially in coastal areas and also in some inland areas as soon as the problem of economic feasibility is solved. A by-product of desalination will be saline residues, which in some places may accumulate until they become a nuisance. Research in weather modification is seeking to augment the natural precipitation. Throughout history people have suffered untold hardships during abominable weather, but from experience during the early years of experimental weather modification, those hardships will be told—to the judge—if any man is suspected of responsibility.

At present, practically all water used by man in the United States is from conventional sources—surface water and groundwater. As of 1965, the average withdrawals of fresh water from these sources aggregated about 1.02×10^9 m^3 (billion cubic meters), or 270 bgd (billion U.S. gallons a day), of which 0.30×10^9 m^3, or 78 bgd, was used consumptively (3). This consumptive use would reduce the water resources by an amount equivalent to 7 percent of the average runoff from the conterminous United States. About 85 percent of this consumptive use is for irrigation in water-deficient areas of the West; the resultant reduction in runoff is especially apparent in the Rio Grande and Colorado Rivers, where the rights of downstream users are covered by compacts and treaties; also in the Sacramento-San Joaquin River, where salt water from San Francisco Bay moves upstream during periods of minimum runoff. Most of the smaller streams in the arid region are "fully appropriated" for use, and many in other parts of the country are significantly depleted for consumptive use, particularly during droughts.

The water withdrawn for nonconsumptive uses in the conterminous United States is about 0.72×10^9 m^3 or 190 bgd, equivalent to about 16 percent of the nation's average runoff. Of this, the water used for cooling, about 7 percent of average runoff, carries away heat as "thermal pollution," which becomes a nuisance when temperature becomes intolerable for fish or for natural purification processes. Most of the water used nonconsumptively by cities and industries (5 percent of the average runoff) becomes sewage and industrial waste, in large part degradable, but containing also dissolved inorganic chemicals. Some industries use water for washing and separating materials of economic value from waste materials, and the waste water carries sediment to be contributed to streams or accumulated by ponds or other means on the land surface. About half of the water withdrawn for irrigation (equivalent to 4 percent of average runoff from the nation) is not consumed in the use, and is thereafter laden with fertilizers, nutrients, inorganic chemicals, and sediment. There are of course many

other nonconsumptive uses of water that should have little or no deleterious effect upon the natural resource, such as hydroelectric power, navigation, boating, fishing, and recreation.

The nonconsumptively used waters are the principal contributors to the national pollution problem. These nonconsumptive uses are implicit in many water rights, and a claim by others that the resulting pollutants constitute a nuisance has commonly resulted in a weighing of the respective rights of each party. The right to use water has been very well protected in the past, as for example in a decision that a polluted stream is not a nuisance per se to one who is not a riparian owner. In recent years an increasing number of people have declared themselves in favor of "clean" waters and argued that no one has the right to pollute the nation's water resources.

Effects of Developments for Water Use

Among the most common developments for water use are surface reservoirs (artificial lakes), canals (artificial streams), and wells (which, with pumps, might be called "artificial springs"). Surface reservoirs provide space to store water in times of abundance for subsequent use, and thus regulate the flow of streams. The accumulation of water in the reservoir provides opportunity for saturation of the bed and banks, which may increase the reservoir storage capacity, but may have deleterious effects such as loss from the reservoir by seepage, dissolution of soluble salts, or waterlogged lands bordering the reservior. The reservoir becomes the site for accumulation also of sediment, other debris and organisms, and is as vulnerable to eutrophication as is a natural lake. Sediment may accumulate also in the channel upstream from the reservoir, causing aggradation that may extend for many kilometers. The clear water released from the reservoir may erode and degrade the channel and thus modify the natural regimen downstream.

Canals constructed in unsaturated permeable materials lose water by seepage into the bed and banks. About 20 percent of the water withdrawn for irrigation throughout the nation is lost in conveyance to the fields to be irrigated. The water so lost becomes groundwater, which may be recovered for use by means of wells, or may remain unnoticed, or may cause waterlogging of adjacent lands. If the canal contains saline water, as do several that have been dredged for navigation, seepage may result in contamination of underlying fresh-water aquifers. Conversely, a canal gains by seepage if its bed is in saturated materials below the regional water table, and it may then become analogous to a natural perennial stream, with groundwater maintaining a base flow. Diversions from one hydrologic basin to another, whether by canal or pipeline, change the hydrologic regimes of both. In the source area the streamflow and perhaps groundwater storage are reduced, and people there are more vulnerable to water shortage in time of drought. In the receiving area the increased supplies, if used nonconsumptively, may increase the pollutants in streams or raise the water table under irrigated lands.

Wells have become artificial springs in some areas of artesian flow, where all remnants of the well casing have rotted away and the opening is maintained and enlarged by the rising artesian water. Generally, wells constitute artificial outlets that are alternative to the natural means of discharge from groundwater reservoirs. It is basic that every new well must draw first from storage in such a reservoir, and it may continue to do so for years without ever affecting the natural discharge. As the storage is depleted, some space becomes vacant and may remain so; or the weight of overlying materials may reduce the pore space, so that there is compaction of the sediments and subsidence of the land surface. If the vacant space is in coastal areas and below sea level, inflow of saline water—seawater encroachment—may take place. The well can have a perennial supply only after it has been able to induce more water to enter the reservoir or less water to leave it. This may have the undesirable side effect of reducing the flow of some spring or stream, or the volume of water in some lake or reservoir, in which other people have usufructuary rights.

DEVELOPMENT AND USE OF THE LAND

The natural flow systems may be modified by human activities concerned primarily with elements of the natural-resource base other than water. The development and use of the land—or more broadly of the solid earth or lithosphere—is primarily concerned with resources other than water, including the soils for agriculture, fossil fuels, metallic and other minerals for manufacturing, rocks and sediments for construction, and the land surface for occupancy. In such development water, not sought as a resource, may be incidental or accidental, and even a hazard at some times and places. The use of the land may require protection from excesses of water during storms and floods, or drainage of unwanted water. Water may constitute a nuisance if it harms the development and use of the solid-earth resources and invades recognized property rights. Conversely, the development and use of the land resources may have effects on water that interfere with the water rights of others, also a nuisance.

Effects of Extraction of Mineral Resources

The production of metals, fuels, and other minerals and rocks of economic value commonly has by-products of waste materials from stripping, tunneling, sorting, washing, smelting, or refining activities. Accumulated on the land surface, these are vulnerable to erosion by overland runoff and to transportation into streams, of which many in mining areas carry heavy sediment loads. In the 19th century, the hydraulic mining of placer deposits for gold in California contributed so much sediment to rivers draining the Sierra Nevada that the navigability of the Sacramento-San Joaquin River system was impeded. The California Debris Commission, created by the U.S. Congress, has had regulatory jurisdiction since 1893 over hydraulic mining to the extent that it affects navigable waters in that river system. In petroleum production a major by-product is brine, and brine disposal has created many nuisances, both by polluting streams and by seeping into fresh groundwater reservoirs from so-called evaporation ponds, with the result that disposal of brine is strictly regulated in several states.

Groundwater is encountered in mining operations in many areas, and this water may be highly mineralized. Many mining operations require continuous pumping and disposal of mineralized water, and in some areas the flow of acid mine waters into streams has continued long after the mining has ceased.

In mining operations in carbonate rocks (limestone or dolomite) extensive withdrawal of water from the rock and from overlying unconsolidated material has caused surface subsidence or collapse into sinkholes in several places (4). Surface subsidence has also occurred in some oil fields as a result of petroleum extraction.

Effects of Agricultural Use of Land

The development and use of agricultural land has resulted in some major modifications in the resources of soil and water—necessarily so, because of the role of the land surface in determining the proportions of the precipitation that will accumulate, infiltrate, or run off overland. Clearing of native forest and brush, plowing of grassland, grazing, logging, burning, and cultivation have resulted in changes in the vegetative cover, in the permeability of the soil, in the rates of evaporation and transpiration, and in overland runoff and soil erosion. The major changes wrought by man's occupancy of lands in various parts of the world were reported a century ago (5). In recent decades enlightened programs of land management and soil and water conservation throughout the United States have been devoted to the correction of the untoward effects of man's past unwise uses of the land.

Effects of Flood Protection and Drainage

Flood protection and drainage are concerned with water not as a resource but as a menace or detriment to those who seek to utilize the resources of the land. In flood-prone areas water may be an inconvenience or a hardship or a disaster, but it is a nuisance only if some human act can be blamed for the difficulty. If the natural flow of water is changed by the construction of dams or ditches or other works so as to

concentrate the water and discharge it on the land of another, a landowner may have caused a nuisance and be liable for compensatory damages. In many places the obstruction of natural flow by railroads, roads, embankments and other works has been deemed a nuisance when it caused injury to others.

Along the nation's watercourses, protection against floods has been recognized as a public responsibility. Federal investment has amounted to more than $7 billion since a national flood control policy was adopted in 1936. Many flood projects have been built, and they have prevented vast flood damages. However, "vital actions needed to complement the structural protection effort have been absent. In consequence, the nation faces continuation of a dismal cycle of losses, partial protection, further induced (though submarginal) development, and more unnecessary losses"(6).

Effects of Roads and Other Means of Communication

Historically roads and other means of communication have modified the natural land surface and therefore the proportions of water that infiltrate, accumulate, or run off from the area. Infiltration is reduced because of impermeable road surfaces; accumulation may be prevented by development of suitable gradients. The resulting runoff is greater than natural, and may require gutters and drains for control. Where cuts, fills, and embankments are made during road construction, the artificial slopes are subject to erosion during storms, and to deposition of sediment at the foot of the slope or beyond, unless the slope is protected by vegetation or paving. Some roads use flood plains, canyons, gaps, dry lakebeds, shorelines, and other landforms created by water, and they require protection during exceptional periods when the water is "reclaiming its own." Other roads cut across the natural drainage systems, and may obstruct the natural flow in some places and accelerate or redirect the flow in other places.

The communications networks have negligible direct need for water as a resource, except of course for waterborne transport. In the construction and maintenance of these networks water appears chiefly on the debit side of the ledger: it increases costs because of requirements for bridges, culverts, protective and diversionary devices; it is also a hazard because of its variability, and for economic operation this variability must be quantified as to range and frequency. Wherever the natural flow of water is obstructed or diverted, it is desirable to provide assurance that the change will not be harmful to the interests of water users or users of other lands.

URBANIZATION

"Of all land-use changes affecting the hydrology of an area, urbanization is by far the most forceful" (7). More than two-thirds of the nation's population is currently in urbanized areas occupying about 7 percent of the land. This is a clear majority which, under unifying leadership, could control the destiny of the urban area and also the 93 percent of the land that is relatively vacant. The total population is increasing; however, the urban population is increasing at a more rapid rate. These trends suggest that the urban population in 2000 AD will be three-fourths of the total population and more than the total population today. The urbanized area will also increase to perhaps 10 percent of the land area.

The great majority of urban dwellers are not concerned with individual rights and responsibilities in water as a resource. These rights have necessarily been delegated to the community because individual plots of land are generally too small to provide adequate supply, storage, or disposal of water for its occupants. Thus the city giveth, the city taketh away, and if an individual has trouble, he calls the plumber. On the other hand, water may disrupt the well-ordered urban life—by accumulating as snow or ice on sidewalks or streets, by leaking into buildings, by accumulating in low spots including underpasses, by making mud in unpaved areas, by eroding ground laid bare by construction, by carrying debris and filth, and by damaging property during floods. These are nuisances, and in many instances individual responsibility can be clearly identified. But the natural environment has been modified so thoroughly in many urban areas that the responsibility for specific nuisances may be widely dispersed. Hence the

community, or the public, has assumed increasing responsibility for the correction of and protection against the detrimental effects of water.

The Water Resource

Municipal water supply is at an average daily rate of 600 liters (157 U.S. gallons) per capita throughout the United States. A population of 500,000 thus requires about 100 million cubic meters annually, equivalent to about 70 mgd (million U.S. gallons a day), and there are 35 municipal systems of this size or larger. The demand of the largest municipal systems, in New York City and Chicago, is 15 to 20 times this rate (8).

Of the 35 largest cities, 5 have abundant supplies from the Great Lakes and 10 from major rivers. The others originally depended on wells, springs, or small streams in the vicinity, but with progressively increasing and concentrated demand have had to reach out beyond the urban area for their supplies. Today only 3 of these cities—Miami, San Antonio, and Memphis—obtain their entire municipal supply locally from groundwater. Houston relied upon wells until its population exceeded half a million, and now has a supplemental supply from Lake Houston. Local sources now provide less than 5 percent of New York City's supply, which comes chiefly from the Croton, Catskill, and Delaware systems of reservoirs, as much as 200 km from the city. In California, San Francisco, Oakland, and Los Angeles have long pipelines to the Sierra Nevada for municipal water supply. Los Angeles and San Diego also import water from the Colorado River. Other large cities rely on streams and impoundments less distant, but nevertheless beyond their incorporated areas.

Municipal systems meet the water requirements of the great majority of the people in urban regions, and of most commercial and industrial establishments. But the aggregate withdrawal by these systems is less than one-fifth of the amount withdrawn nationally by "self-supplied" industries. Most of these large industrial users are also in urban areas, and may be in competition with municipal systems for the available water resources.

Municipal and industrial uses of water are chiefly nonconsumptive. Thus large quantities of water can be withdrawn from a river and quickly returned, with little loss in volume and therefore negligible depletion of the flow. But the used water brings to the river dissolved chemicals, organisms, floating debris, sediment, gases, or heat—pollutants that may be detrimental to other water users downstream.

Effects of Land Occupancy

Buildings, streets, sidewalks, parking lots, and other structures provide an impervious cover on the land surface, and thus prevent infiltration into the soil and recharge of groundwater. The water from storms is diverted instead into storm sewers. Years ago, when Brooklyn was troubled by seawater encroachment into some of its wells, part of the explanation was the reduction of recharge caused by the buildings and pavements that covered about half of the total land surface of the borough (9).

Land occupancy, with its quota of impervious cover, commonly extends across natural valleys which, although not occupied by a perennial stream, would carry storm runoff into stream channels. The natural drainage may be replaced by storm sewers. For example, the suburbanized drainage basin of Rock Creek, tributary to the Potomac River in the Washington metropolitan area, had 102 km of natural flowing stream channels in 1913, but only 43 km can be found above ground today (10).

Storm runoff is substantially modified by the impervious cover and the storm sewers that are introduced by urbanization. The volume of runoff is governed by infiltration characteristics. Lag time—from the peak of rainfall to the peak of runoff—is decreased by the impermeable surfaces and by storm sewers. Using data from studies of the effects of urbanization in various areas and plotting the percentage of area sewered against the percentage of the area rendered impervious by urbanization, Leopold (7, p. 6) states that "for unsewered areas the differences between 0 and 100 percent impervious will increase peak discharge on the average 2.5 times. For areas that are

100 percent sewered, peak discharge for 0 percent impervious will be about 1.7 times the mean annual flood and the ratio increases to about eight for 100 percent impervious areas."

Urbanization, by modifying infiltration rates and storm runoff, reduces the groundwater recharge and also causes adjustment in the stream channels to accommodate the flows. As channels are enlarged by the increased floods, they may develop unstable and unvegetated banks and scoured or muddy beds. The low flows may be less than under natural conditions, following reductions in groundwater recharge.

A significant percentage of the nation's population and tangible property is concentrated on flood-prone areas. In New York a recent survey shows that of 330 communities having populations greater than 2,500, 260 or 79 percent have problems of local flooding or drainage. Much urban growth in the United States is by encroachment upon the floodplains, which are the river's natural freeways for discharge of exceptional floodwaters. Flood damages are a direct consequence of floodplain investment actions, both private and public.

Effects of Surface Revisions

Preparation of land for use commonly involves clearing, grading or leveling, digging for foundations, and perhaps landscaping. During these activities, as Wolman (11) points out, "Because construction denudes the natural cover and exposes the soil beneath, the tonnage of sediment derived by erosion from an acre of ground under construction in developments and highways may exceed 20,000 to 40,000 times the amount eroded from farms and woodlands in an equivalent period of time." Construction activities commonly cover very small proportions of most urban areas at any one time, and as a rule the rate of sediment yield decreases with increasing drainage area. Anderson and McCall (12) report a positive correlation between urban development and sediment yield throughout New Jersey. In the urbanized northeastern part of the state sediment yield is three to five times greater than in the rural and forested northwesterr part, and many times greater in the vicinity of Trenton and in the urban area adjacent to New York City. Also, the average turbidity of the Passaic River in 1965 was more than twice as great as in 1954, a reflection of increasing urbanization.

During excavations some materials can maintain stable walls until the construction is completed. Others remain stable as long as they remain dry, but water—from rain, overland flow, or shallow groundwater—may lubricate clayey elements enough to cause sliding or caving. The instability of walls or steep slopes composed in part of materials that can be lubricated by water has its natural counterpart in areas of landslides or potential landslides. In several places natural landslide areas have been subjected to urban development. Indeed, some of the earliest records concerning landslides are of those occurring within the City of Bath, England, in 1790 and again in the extremely wet year of 1799. William "Strata" Smith, credited with fatherhood of the science of geology in England, achieved considerable fame for his remedial work, which included tunneling into the hillside to intercept groundwater. Thorough drainage of the landslide area and development of public gardens has prevented further sliding. Although the land slopes are generally in the range of 12 deg to 15 deg, they are stable if they are adequately drained and not subject to increased loading (13).

Some materials, though unstable when wet, may nevertheless be included in urban development, and not reveal their hazardous character until some triggering geologic event. That was the position of Anchorage on March 27, 1964, where the principal earthquake damage was from landslides, ground fracturing, lurching, and shaking. In its recovery from the effects of that earthquake, and in future land development for human needs, the Borough of Anchorage is insuring that the planning is based on understanding of the geologic environment (14).

Many excavations penetrate below the water table, and water is pumped out to permit continuation of activities. As has been seen in many areas of intensive pumping and groundwater depletion, the dewatering of some sediments is accompanied by compaction, resulting in subsidence of the land surface. Very recently subsidence has been reported (15) in the construction of a depressed section of Interstate-5 in Sacramento along the Sacramento River.

A common type of excavation near urban areas is for the purpose of obtaining construction materials, whether rock, gravel, sand, or clay. If these excavations penetrate below the water table, water will accumulate to form a pool or pond after the extraction has ceased, and the landowner may be accused by neighboors of maintaining a nuisance—an "attractive nuisance" that lures children to play, wade, and swim dangerously.

Abandoned quarries, pits, strip mines, and spoil banks are among the less desirable land areas for urban development, along with such natural features as steep hills, narrow ravines, and undrained depressions. Propinquity to an urban area may induce the owners to make wholesale rearrangement of these surfaces because of the higher land value that may be anticipated. This rearrangement involves cutting into natural materials at various places and filling at others, with problems of stabilization comparable to and perhaps more difficult than those in highway construction. Some of the problems will be caused by water because of interruptions or modifications of the natural flow system—changes in rates of infiltration and overland runoff, and changes from the natural drainage and groundwater movement.

Some revisions of the land surface involve development of artificial lakes to enhance the quality of the urban evironment and incidentally the values of land in the vicinity. These may range from a waterhole on a golf course to a lagoon in a city park to a lake for boating, fishing, and other recreation in a suburban area. Although these artificial lakes become "water developments" and preclude occupancy of their area for other uses, they represent investments by owners of adjacent land or of land in the community. As many people have learned after they construct swimming pools on their property, these water bodies can be resources if they are properly maintained and supervised; otherwise, they can become nuisances. The artificial lake also becomes an element in the hydrologic flow system, which may be vulnerable to flooding, sedimentation, accumulation of floating debris, fertilizers, and other chemicals washed from adjacent lands, septic wastes or other dissolved solids contributed by groundwater, and growth of algae or other undesirable organisms.

The Problem of Wastes

Each individual must dispose of some wastes, whether by individual or community effort. The average per capita daily waste load of organic materials from food resources is about 100 grams in sewage and 400 grams in garbage. To this basic load must be added the waste end-products of mineral, wood and fiber, and other natural resources after use. This load varies more widely from one individual to another because it increases with increasing affluence and capability to depreciate the "old" and purchase the "new." A further load is the by-products of the materials and energy used in developing, processing, and maintaining the desired products of our natural resources. Inexorably, the total volume of waste products increases with increasing population and economic growth. These wastes are portions of our natural resources that are considered to have no value, or even negative value because of their present position. Nevertheless they are among the products, perhaps the grossest products, of our gross national product.

For disposal of his wastes primitive man had the alternatives of burning them, resulting in smoke to be dissipated by the atmosphere and ashes to remain on the ground; placing them on land or underground and perhaps covering them, where they might decompose, remain unchanged, or be added to soil or groundwater; or discharging them into stream, lake, or ocean, where liquid and dissolved materials would be mixed with other water, and solids would float or sink to the bottom and their subsequent disposition would depend on the action of the water. Modern man has developed only one other alternative, and currently he has more than 1100 individual items circling the globe as satellites. With increasing population, per capita allotments of air and water for dilution, and of unwanted land, are becoming progressively less—and per capita we have more to dispose of. Because of the concentrations of people, economic production, and wastes for disposal, the problem is most critical in urban areas.

Here we are concerned with water as a resource, in which wastes, whether dissolved, floating, or suspended, might have nuisance value, and might be in sufficient

concentration that the water itself could be deemed a nuisance. However, water pollution is only one aspect of the overall problem of disposal of urban wastes. As the campaigns for clean water, clean air, and better environmental quality coalesce, their common objective must be to develop technologies for conversion of unwanted materials to wanted materials wherever possible, and to dispose of the rest in a form and place in which they will be least detrimental to mankind.

In the first stages of change from rural to urban conditions, septic tanks may be the principal means of disposal of domestic wastes, and these continue to operate and increase in number until the suburbanites are numerous enough to finance sewerage systems. Sparse data indicate that water from septic tanks is cleansed of pathogenic bacteria in unsaturated soil at a rate and effectiveness depending upon type of soil. Drain fields should not be too close to groundwater, nor closer than 100 meters to a stream channel. These precautions do not prevent pollution by dissolved inorganic materials, which may become nutrients to algae and other organisms.

The disposal of solid wastes, whether by sanitary landfill or unsanitary dump, may also cause pollution of groundwater by infiltration of rain, snowmelt or overland flow, and leaching of soluble organic or inorganic materials. This is true particularly if the dump is in an abandoned pit or other depression where some of the waste may be saturated by groundwater. Landfills in valley floors may contribute pollutants to streams in time of floods.

Industrial wastes have contaminated groundwater reservoirs seriously enough in some places to reduce their suitability for use. An example is the Baltimore Harbor area, which a century ago had many flowing artesian wells. A shallow aquifer has become contaminated by sulfuric acid and copper sulfate from acid and metal-refining plants. The acid water has corroded the casings of many wells, leaked through them into a deeper aquifer, and contaminated it locally. Heavy draft upon the wells encouraged contamination also from brackish water in the harbor. Because of the high cost of maintaining wells in the corrosive shallow zone and the deteriorated quality of some of the water, the pumpage from wells was reduced by half between 1940 and 1955 (16). The Baltimore municipal supply system was adequate and available as a replacement.

Many urban areas are served by sanitary sewer systems and sewage treatment adequate at the time they were built for the needs of the service areas and a reasonable expansion of population. Commonly this is combined with the storm-sewer system, and this works out well to the extent that flushing the streets carries the wastes through the treatment plant. There must be facilities for bypassing the treatment plant during periods of excessive storm runoff. Unfortunately, some of the sanitary sewage then also bypasses treatment. It became evident to many people that adequate pollution control would require separation of the sanitary-sewer system from the storm-sewer system. Further study has brought second thoughts: first, recognition that such separation in many cities at this time would be exceedingly disruptive and costly; second, realization that the storm sewers would not carry pristine waters, but rather all the crud that had been washed from the atmosphere, roofs, pavements, and streets of the area served. That water should also be treated. Thus a proposed solution is impoundment of excess water during flood runoff, with subsequent release according to the capacity of treatment facilities. Because urban land is at premium prices, cities are beginning to look for space underground. Currently there are two proposals for the Chicago area: one, by the Sanitary district, would provide a network of tunnels in the Galena and Platteville Formations, about 200 meters below the surface; another, by the City, would place tunnels in the Niagara Dolomite, less than 100 meters below the surface, and line the tunnels adequately to seal them from usable groundwater reservoirs. The water and wastes temporarily stored in these tunnels would be pumped out and treated and then discharged into streams.

Subsurface disposal of industrial wastes, by means of deep wells, is undertaken in several places, especially in Texas, Louisiana, and Michigan, but also in some other states (17). If these wastes are toxic, radioactive, or otherwise noxious, safe disposal requires permanent isolation from all usable water resources. Without adequate studies of all the geologic, engineering, and chemical parameters at each project, and

constant monitoring of the effects of the disposal, underground disposal can create serious problems.

SUMMARY

Water as a resource is available for use and enjoyment by mankind, subject to natural variations from time to time and from place to place, both in quantity and quality of water. Consumptive uses reduce the quantity and nonconsumptive uses may impair the quality of water available for use by others; hence various laws and customs define and protect the respective rights of individuals in water use. Although water rights are protected as property rights, there is increasing recognition of rights of the public in the water resource, and the responsibilities of water users for maintenance of satisfactory quality.

Many human activities are concerned with development and use of the land and its resources other than water, but these activities nevertheless affect the natural water flow system or are affected by it. Water may constitute a nuisance if it harms the development and use of the land and solid-earth resources and invades recognized property rights. Conversely, the development and use of the land resources may have effects on water that interfere with the water rights of others, thus causing a nuisance.

In urbanized areas, water as a resource becomes increasingly inadequate to meet the requirements of the concentrated population and industry—it must be imported from other areas, along with the food, fuel, and other materials essential for urban existence. Waters used nonconsumptively contribute pollutants to the natural water resources, but this is only one aspect of the grand problem of waste disposal in urban areas—whether on the land, in the ground, in the air, in lakes or streams, or in the sea. Generally in urban areas the responsibilities for water supply and for disposal of "used" water have become public responsibilities.

Urbanization causes some drastic changes in the natural hydrologic system. Buildings and pavements inhibit groundwater recharge and promote instant runoff from storms. Increased flood peaks cause erosion and sediment transport, as do various construction activities. Vulnerability to floods is increased by urban encroachment upon floodplains. In these and many other ways water can cause inconvenience or annoyance to urban life and damage to property, and thus constitute a nuisance. However, the natural environment has been modified so thoroughly that placing responsibility for specific nuisances is difficult.

Urbanization may change the hydrology of an area profoundly—notably in total runoff and in peak flow characteristics, in the quality of water, and in the appearance of lakes, stream valleys, and other features. To predict, ameliorate, or otherwise cope with these changes, there is urgent need for additional research in urban hydrology, and for adequate data to document these changes.

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