Handbook of Water and Wastewater Treatment Technology

Paul N. Cheremisinoff

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Paul N. Cheremisinoff
New Jersey Institute of Technology
Newark, New Jersey

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Contents

1

Water Characteristics

Both individuals and industry produce liquid and solid wastes. The liquid portion, wastewater, is essentially water supply after it has been fouled by use. From the standpoint of sources of generation, wastewater may be defined as a combination of the liquid of water-carried wastes removed from residences, institutions, and commercial and industrial establishments together with such groundwater, surface water, and storm water as may be present. The ultimate goal in wastewater management is the protection of the environment commensurate with economic, social, political, and health concerns.

With increasing density of population and industrial expansion, the need for treatment and disposal of waste has grown. The specific reasons for sewage and waste treatment are as follows.

HEALTH CONCERNS

Disease-producing organisms, especially those causing diarrhea, may be present in sewage. Little is known about the presence of toxic substances produced by bacterial decomposition of certain organic substances, although a variety of degradation products are formed. From a health standpoint, the greatest problem of pollution is its effect on public water supplies by overloading the treatment devices so that they pass intestinal organisms, and by producing intestinal irritants in water which are not removed by filtration. Sewage pollution of bathing waters and shellfish areas may result in epidemics such as typhoid or other intestinal diseases as well as contamination of the food chain. Sewage treatment which reduces the pollution and kills intestinal organisms assists in the production of a safe drinking water at a lower cost, prevents contamination of shellfish, and permits bathing, water sports, and recreation.

ESTHETIC CONCERNS

The discharge of sewage into streams and water courses produces odors and discoloration, results in nuisances from sludge, and interferes with bathing facilities and recreation.

PROPERTY DAMAGE

The discharge of sewage affects industrial water supplies by changing the character of the water. Odors and gases in sewage affect real estate by causing paints to discolor as well as damage to boats. Some treatment of wastewaters is usually necessary before disposal. The methods of treatment adopted must be sufficient to ensure the necessary degree of purification required to suit the means of disposal.

Most unit operations and processes used for wastewater treatment are constantly undergoing continual and intensive investigation from the standpoint of implementation and application. As a result, many modifications and new operations and processes have been developed and implemented; more need to be made to meet increasingly stringent requirements for environmental enhancement of water. In addition to the developments taking place with conventional treatment methods, alternative treatment systems and technologies are also being developed and introduced.

AVAILABLE TREATMENT SYSTEMS

The treatment process chosen is a function of several factors:

- Flow rate
- Waste strength and toxicity
- Availability of land
- Esthetics
- Discharge standards
- Climatic conditions
- Degree of permanence desired
- Costs

For example, in remote areas where land is inexpensive and climate is favorable, a percolation/evaporation pond may provide simple zero discharge solution, whereas in a suburban community in which the ultimate discharge enters surface waters, an esthetic and high-performance plant which may include some type of tertiary facility would be more appropriate. Table 1 shows the various wastewater treatment options in use. Materials removed during water/wastewater treatment is called sludge, and Table 2 lists the options for its management.

CHARACTERISTICS OF WASTEWATER

An understanding of the nature of wastewater is essential in the design and operation of collection, treatment, and disposal facilities and in the engineering management for environmental quality.

The physical properties and the chemical and biological constituents of wastewater and their sources are listed in Table 3. The important contaminants of interest in wastewater treatment are listed in Table 4. Wastewater characterization studies are conducted to determine the physical, biological, and chemical characteristics and the concentrations of constituents in the wastewater as the best means of reducing the pollutant concentrations.

EFFECTS OF POLLUTION

Effects of pollution can be manifested by many characteristics and variations in degree when pollution enters the aquatic environment. Specific environmental and ecological responses to a pollutant will depend largely on the volume and strength of the waste and the volume of water receiving it. Within each response there can be many changes in magnitude and degree. A classic response that has often been described is the effects of organic wastes that may be discharged from sewage-treatment plants and certain industries. As these wastes enter the receiving water, they create turbidity, decrease light penetration, and may settle to the bottom in substantial quantity to form sludge beds. Wastes are attacked by bacteria and this process of decomposition consumes oxygen from the water and liberates essential nutrients that in turn stimulate the production of some forms of aquatic life.

Upstream from the introduction of organic wastes is a clean water zone or one that is not affected by pollutants. At the point of waste discharge and for a short distance downstream there is formed a zone of degradation where wastes become mixed with the receiving waters and where the initial attack is made on the waste by bacteria and other organisms in the process of decomposition.

Following the zone of degradation there is a zone of active decomposition that may extend for miles or days of stream flow, which depends in large measure on the volume of the waste by the stream and the temperature of the water.

Table 1 Wastewater Treatment Options

		Primary treatment		Secondary treatment		
	Pretreatment	Chemical	Physical	Dissolved organics and colloidal material is removed	Suspended solids removal	Advance or tertiary treatment
	Screening and Grit Removal	Neutralization	Flotation	Activated Sludge	Sedimentation	Coagulation Sedimentation
Wastewater	Equalization and Storage	Coagulation	Sedimentation	Contact Stabilization		Filtration
	Oil Separation			Trickling Filter		Carbon Adsorption
		Hydrolysis		Aerated Lagoon		Ion Exchange
				Ozonation		Distillation
						Reverse Osmosis
						Electrodialysis

Table 2 Options for Sludge Management

Disposal	Sludge treatment	Sludge disposal
	Aerobic Digestion	
Chlorination Ozonation	Anaerobic Digestion	Incineration
Receiving Waters or Reuse	Wet Combustion	Land Fill
Controlled or Transported Discharge	Centrifugation	Soil Conditioning
Ocean Disposal	Thickening	Ocean Disposal
Surface Application or Ground Water Seepage	Vacuum Filtration Lagooning, or Drying Beds	
Evaporation + Incineration		

Biological processes that occur within this zone are similar in many respects to those that occur in a typical sewage treatment plant. Within this zone, waste products are decomposed and those products that are not settled as sludge are assimilated by organisms in life processes.

A recovery zone follows the zone of active decomposition. The recovery zone is essentially a stream reached in which water quality is gradually returned to that which existed prior to the entrance of pollutants. Water quality recovery is accomplished through physical, chemical, and biological interactions within the aquatic environment. The zone of recovery may also extend for many miles, and its extent will depend principally on morphometric features of the waterways. The zone of recovery will terminate in another zone of clean water or area unaffected by pollution that is similar in physical, chemical, and biological features to that which existed upstream from the pollution source.

Organic Wastes

The effects of organic wastes on the receiving stream often become confused with a specific stream because additional sources of pollution may enter the environment before the receiving water has been able to assimilate the entire effects of an initial source. When this occurs, the effects of subsequent introductions become superimposed on the initial source and the total effect may confine large reaches of stream to a particular zonal classification.

Effects of organic wastes in the static water environment, as opposed to the flowing water environment, are modified by the features of the receiving water. Zonal changes for flowing water do exist but may be compressed in great measure either laterally or vertically when the discharge is to a lake or estuary. Such compression may tend to decrease the severity of pollution that is often observed in the flowing water environment and, on the other hand, may increase

Table 3 Physical, Chemical, and Biological Characteristics of Wastewater and Their Sources

Characteristic	Sources
Physical Properties	
Color	Domestic and industrial wastes, natural decay of organic materials
Odor	Decomposing wastewater, industrial wastes
Solids	Domestic water supply, domestic and industrial wastes, soil erosion, inflow-infiltration
Temperature	Domestic and industrial wastes
Chemical Constituents	
Organics	
Carbohydrates	Domestic, commercial, industrial wastes
Fats, oils and grease	Domestic, commercial, industrial wastes
Pesticides	Agricultural wastes
Phenols	Industrial wastes
Proteins	Domestic and commercial wastes
Surfactants	Domestic and industrial wastes
Others	Natural decay of organic materials
Inorganics	
Alkalinity	Domestic wastes, domestic water supply, ground water infiltration
Chlorides	Domestic water supply, domestic wastes, ground water infiltration, water softeners
Heavy metals	Industrial wastes
Nitrogen	Domestic and agricultural wastes
pH	Industrial wastes
Phosphorus	Domestic and industrial wastes, natural runoff
Sulfur	Domestic water supply, domestic and industrial wastes
Toxic compounds	Industrial wastes
Gases	
Hydrogen sulfide	Decomposition of domestic wastes
Methane	Decomposition of domestic wastes
Oxygen	Domestic water supply, surface water infiltration
Biological Constituents	
Animals	Open watercourses and treatment plants
Plants	Open watercourses and treatment plants
Protista	Domestic wastes, treatment plants
Viruses	Domestic wastes

Table 4 Important Contaminants of Concern in Wastewater Treatment

Contaminants	Reason for importance
Suspended solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment.
Biodegradable organics	Composed principally of proteins, carbohydrates, and fats, biodegradable organics are measured most commonly in terms of BOD and COD. If discharged untreated to the environment, their biological stabilization can lead to the depletion of natural oxygen resources and to the development of septic conditions.
Pathogens	Communicable diseases can be transmitted by the pathogenic organisms in wastewater.
Nutrients	Both nitrogen and phosphorus, along with carbon, are essential nutrients for growth. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, they can also lead to the pollution of ground water.
Refractory organics	These organics tend to resist conventional methods of wastewater treatment. Typical examples include surfactants, phenols, and agricultural pesticides.
Heavy metals	Heavy metals are usually added to wastewater from commercial and industrial activities and may have to be removed if the wastewater is to be reused.
Dissolved inorganic solids	Inorganic constituents such as calcium, sodium, and sulfate are added to the original domestic water supply as a result of water use and may have to be removed if the wastewater is to be reused.

substantially the development of biotic nuisances such as algae or rooted aquatic plants that may develop from the nutrients released with and decomposed from the introduced organic materials.

Organism communities that may be related to pollution principally are those that are usually associated with the bed or bottom of the waterway; those that attach themselves to objects such as rocks, aquatic plants, brush, or debris submerged in the water; those that are essentially free floating and are transported by currents and wind, such as plankton and other microscopic forms; and those motile free-swimming organisms such as fish. Considering each of these common organism groups, a number of observations can be made on their reaction to the introduction of organic wastes to a flowing stream.

Upstream from waste sources such limiting factors as food and intense competition among organisms and among organism groups, predation, and available habitat for a particular species will limit organism populations to those that can be sustained by the particular environment. Most often the limiting factor will be available food. Within this population, however, there will exist a great number of organism species. Thus, the old biological axiom for an environment unaffected by pollution is one that supports a great number of species with the total population delimited largely by food supply.

Introduction of organic wastes causes conditions of existence for many organisms that become substantially degraded. Increased turbidity in the water reduces light penetration, which in turn will reduce the volume of water capable of supporting photosynthesizing plants. Particulate matter in settling will flocculate small floating animals and plants from the water. As the material settles, sludge beds are formed on the stream bed and many of the areas that formerly could have been inhabited by bottom-associated organisms become covered and uninhabitable.

The zone of degradation is the transition area between the clean water unaffected reach and a zone of decomposition of organic wastes. The dissolved oxygen may be diminished but not completely removed. Sludge deposits may be initiated but are not formed in maximum magnitude or extent. Conditions of existence become impaired, and typically there is a reduction in both the organism population and the number of species that can tolerate this environment.

Within the zone of active decomposition conditions of existence for aquatic life are at their worst. Breakdown of organic products by bacteria may have consumed available dissolved oxygen. Sludge deposits may have covered the stream bed and thus eliminate dwelling areas for the majority of bottom-associated organisms that could be found in an unaffected area. Fish spawning areas have been eliminated, but perhaps fish are no longer present because of diminished dissolved oxygen and substantially reduced available food. Here aquatic plants will not be found in large numbers, because they cannot survive on the soft shifting blanket of sludge. Turbidity may be high and floating plants and animals destroyed. Water color may be substantially affected. When organic materials are decomposed as the food supply is liberated for those particular organisms that are adapted to use this food source. Bacterial and certain protozoan populations may increase to extremely high levels. Bottom-associated organisms such as sludgeworms, bloodworms, and other wormlike animals may also increase to tremendous numbers, because they are adapted to burrowing within the sludge, deriving their food therefrom, and existing on sources and amounts of oxygen that may be essentially nondetectable by conventional field investigative methods. Within the zone of active decomposition, the organism species that can tolerate the environment are reduced to extremely low levels. Under some conditions, those bottom-associated animals that are visible to the unaided eye may be completely eliminated. Because of the tremendous quantity of food that is available to those organisms that are adapted to use it, the numbers of individuals of the surviving species may become great.

The zone of recovery is essentially the downstream transition zone between the zone of active decomposition and an environment that is unaffected by pollution. This zone features a gradual cleaning up of the environment, a reduction in those features that form adverse conditions for aquatic life, an increase in organism species, and a gradual decrease in organism population because of decreased food supply and the presence of some of the predators that are less sensitive individually to pollutional affects.

Because of variation in response among species to conditions of existence within the environment, and because of inherent difficulties in aquatic invertebrate taxonomy, the ecological evaluation of the total organism community is the acceptable approach in water pollution control studies. Investigators tend to place organisms in broad groups according to the general group response to pollutants in the environment. For example, the general group known as "sludgeworms" is found in both the unpolluted as well as the organically polluted environment. Value as a group lies in the fact that the numbers of individuals within the group are exceedingly low in unpolluted water, whereas in the organically polluted environment, its numbers may be very high. Examples of organisms that may inhabit both the unpolluted and polluted environments are listed in Table 5.

The converse of the effects of pollution on organisms is the effects of organisms on pollutants. Organic wastes, especially, the supply food which in turn produces an abundance of a few types of organisms produced in an unpolluted environment. When consuming organic wastes, the organisms stabilize the waste in a given number of feet or miles of horizontal stream in a manner similar to that in a vertical trickling filter that is designed especially for maximum stabilizing efficiency by the organisms.

As organic wastes become stabilized, other organism types predominate within the aquatic animal community. Midge larvae have been found to taint stream beds a brilliant red with their undulating bodies. Caddisfly larval populations greater than 1000 per square foot of stream bed or mayfly nymphs numbering more than 300 per square foot have been found. Figures 1–3 show representative stream bed–associated animals.

Inorganic Silts

Inorganic silts in the environment reduce severely both the types of organisms present and their populations. Particulate matter settling to the bottom can blanket the substrate and form undesirable physical environments for organisms that would normally occupy a habitat. Erosion silts change environments chiefly by screening out light, by changing heat radiation, by blanketing the stream bottom and destroying living spaces, and by retaining organic materials and other substances that can create unfavorable conditions. Developing eggs of fish and

Table 5 Examples of Organisms Sensitive and Tolerant to Polluted Water, Respectively

Clean water organisms		Clean or polluted water organisms	
Algae	*Cladophora* (green)	Iron Bacteria	*Sphaerotilus*
	Ulothrix (green)	Fungi	*Leptomitus*
	Navicula (diatom)	Algae	*Chlorella* (green)
Protozoa	*Trachelomonas*		*Chlamydomonas* (green)
Insects	*Plecoptera* (stoneflies)		Oscillatoria (blue-green)
	Negaloptera (hellgrammites, alderflies, and fishflies)		Phormidium (blue-green)
		Protozoa	*Carchesium* (stalked) colonial ciliate)
	Trichopetera (caddisflies)		*Colpidium* (noncolonial ciliate)
	Ephemeroptera (mayflies)	Segmented Worms	*Tubifex* (slugeworms)
			Limnodrilus (slugeworms)
Clams	*Unionidae* (pearl button)	Leeches	*Helobdeall stagnalis*
Fish	*Etheostoma* (darter)	Insects	*Culex pipiens* (mosquito)
	Notropis (shiner)		*Chironomus (Tendpipes) plumosus* (bloodworms)
	Chrosomus (dace)		*Tubifera (Eristalis tenax)* (rat-tailed maggot)
		Snail	*Physa integra*
		Clam	*Sphaerium* (fingernail clam)
		Fish	*Cyprinus carpio* (carp)

other organisms may be smothered by deposits of silt. Fish feeding may be hampered by silt deposits. Direct injury to fully developed fish, however, by nontoxic suspended matter occurs only when concentrations are higher than those commonly found in natural water or associated with pollution.

Toxic Metals

Wastes containing heavy metals, either individually or in combination, may be destructive to aquatic organisms and have a severe impact on the aquatic community. A severely toxic substance will eliminate aquatic biota until dilution, dissipation, or volatilization reduces the concentration below the toxic threshold. Generally toxic materials will reduce the aquatic biota except those species that are able to tolerate the observed concentration of the toxicant. Because toxic materials do not offer an increased food supply, such as organic wastes, there is no sharp increase in the population of those organisms that may tolerate a

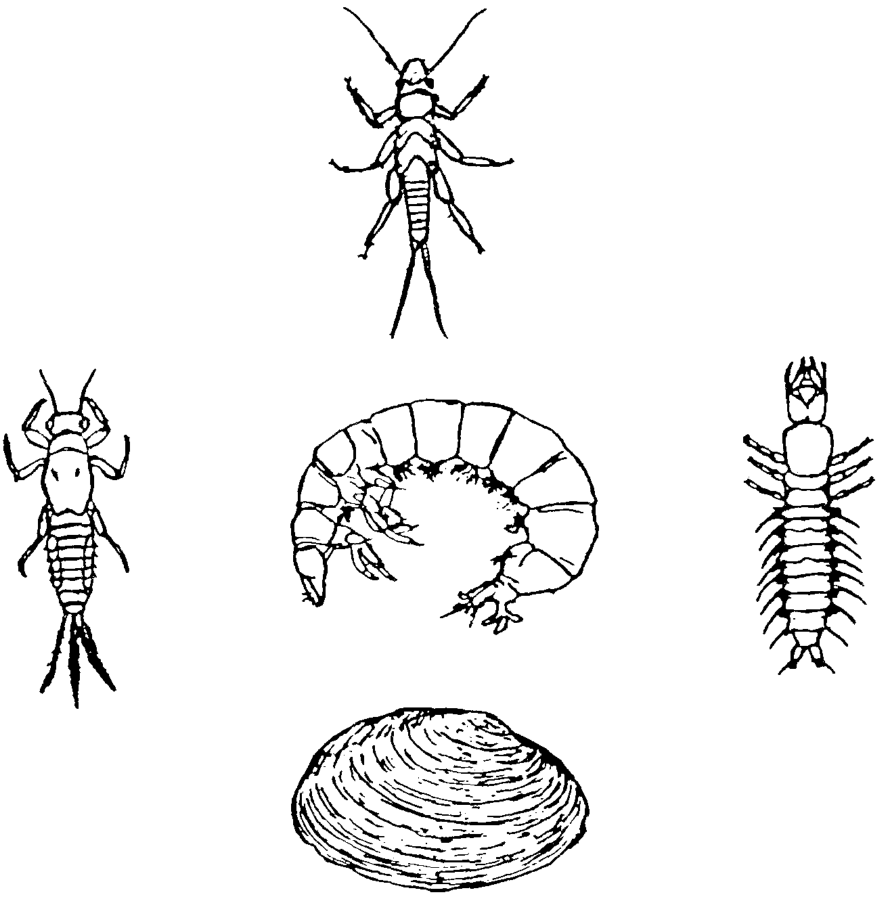

Figure 1 Clean water [sensitive] animals associated with stream beds include the stonefly nymph, mayfly naiad, caddisfly larva, and hellgrammite unionid clam.

specific concentration. The bioassay is an important tool in the investigation of these wastes, because the results from such a study indicate the degree of hazard to aquatic life of particular discharges; interpretations and recommendations can be made from these studies concerning the level of discharge that can be tolerated by the receiving aquatic community.

Temperature

Temperature is a regulator of natural processes within the water environment. It governs physiological functions in organisms, and acting directly or indirectly

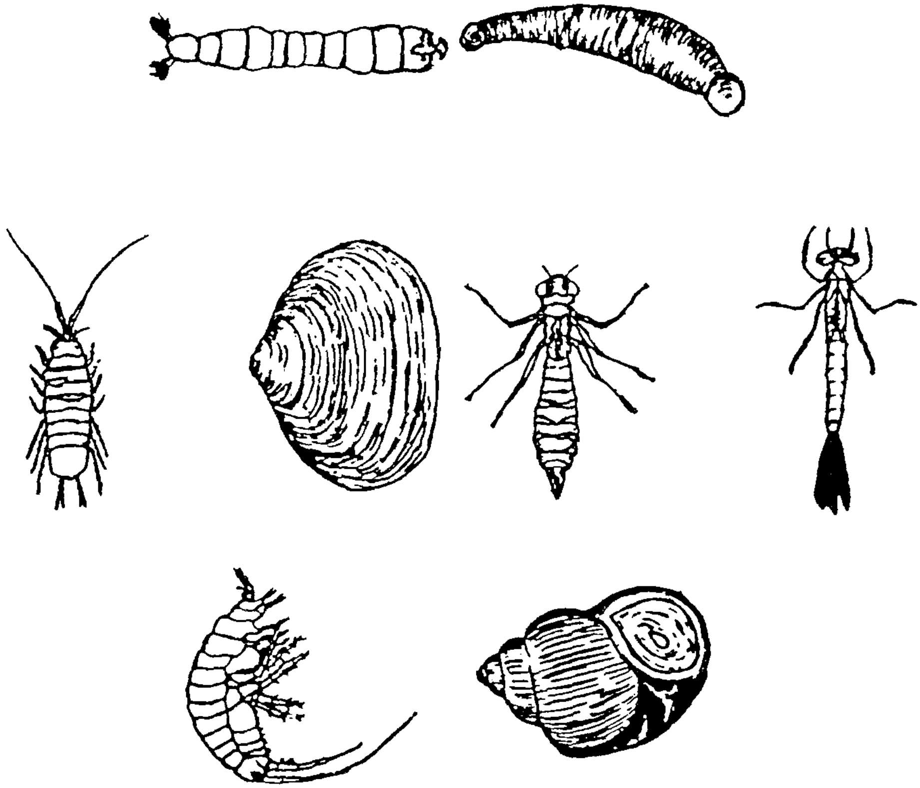

Figure 2 Intermediately tolerant animals associated with stream beds include the scud, sowbug, blackfly larvae, fingernail clam, damselfly nymph, dragonfly nymph, leech, and snail.

in combination with other water quality constituents, temperature affects aquatic life with each change. The effects of temperature changes include, for example, chemical reaction rates, enzymatic functions, molecular movements, and molecular exchanges between membranes within and between the physiological systems and organs of an animal. Because of the complex interactions involved, and often because of the lack of specific knowledge or facts, temperature effects as they pertain to an animal or plant are most efficiently assessed on the basis of net influence on the organism. Depending on the extent of environmental temperature change, organisms can be activated, depressed, restricted, or killed.

Temperature determines those aquatic species that may be present. It controls spawning and the hatching of young, regulates their activity, and stimulates or suppresses their growth and development. Temperature can attract and kill when the water becomes heated or chilled too suddenly. Colder water

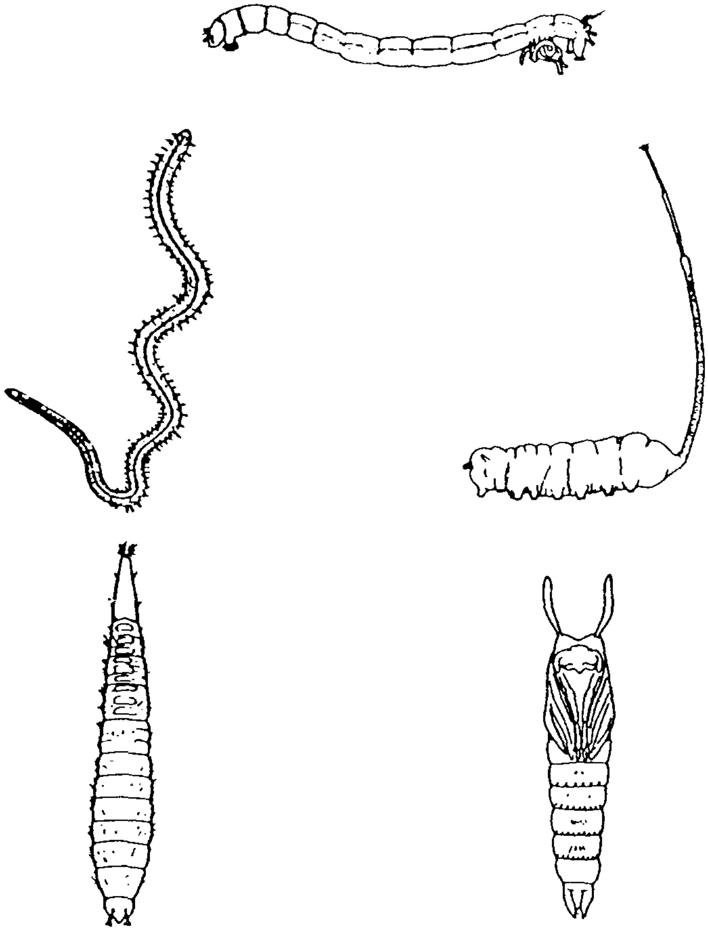

Figure 3 Very tolerant animals associated with stream beds include the bloodworm, midge larvae sludgeworm, rat-tailed maggot, sewage fly larva, and sewage fly pupa.

generally suppresses development and warmer water generally accelerates activity.

Temperature regulates molecular movement and thus determines the rate of metabolism and activity of all organisms, both those with a relatively constant body temperature and those whose body temperature is identical to, or follows closely, the environmental temperature. Because of its capacity to determine metabolic rate, temperature may be the most important single environmental entity to life and life processes.

Variations in temperature of streams, lakes, estuaries, and oceans are