Stream Hydrology

An Introduction for Ecologists

Second Edition

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Contents

Preface to the Second Edition

One of the main purposes in writing the first edition of this book in 1992 was to help improve communication between the disciplines of stream ecology and river engineering and to foster a sense of co-operation in these interdisciplinary efforts. We would like to think that we played a part, however small, in assisting the tremendous growth in interdisciplinary and multidisciplinary research and application that followed over the next decade. But this phenomenon was inevitable anyway; academics, policy makers and managers alike had recognised that river management could not take the next step forward unless the various experts got together and problems were assessed and solved from a broad perspective. An engineer, geomorphologist and ecologist will still have a different emphasis when conceptualising a stream, but these days each viewpoint is cognisant of, and is informed by, the others.

This second edition was a long time in its gestation. The field of river research and management has been evolving so rapidly that it was difficult for us to decide when was an appropriate time to update the book. The background information did not present a real problem, as most of it is grounded in long established principles of hydrology and fluid mechanics. However, the real growth area was in the application of science to stream management; the trial and error approach is no longer acceptable. We feel that now is a good time to take stock of these developments. Many countries have implemented new river laws that require managers to at least maintain the current levels of stream health and be highly accountable for their actions. The ecosystem concept, which originated in ecology as a research paradigm, has now been transferred to the realm of public policy; physico-chemical characteristics are still important, but we now speak of ‘‘stream health’’ and measure it in terms of water quality, habitat availability and suitability, energy sources, hydrology, and the biota themselves. Introduction of the European Union Water Framework Directive in December 2000 has already led to widespread changes in assessment of stream health in Europe. Stream classification is now a routine first step that simplifies the inherent complexity of stream systems, helping to facilitate many aspects of the management process. Research has clearly established the impacts of flow regulation, and the last decade has seen considerable growth in research and assessment of environmental flow needs. River rehabilitation is now one of the central themes of the river management industry. One of our objectives in writing this second edition is to bring some methodological order to these developments. Another objective is to critically evaluate the level of success and failure in efforts to rehabilitate streams. This could not have been done in the first edition, because so few examples existed at that time.

In this second edition we maintain an emphasis on the physical environment. Information has been drawn from the fields of geomorphology, hydrology and fluid mechanics, with examples given to highlight the information of biological relevance. Chapters 1–8, which include tools for studying and describing streams, have been updated by the original authors. Chapter 9, which reviews river management applications, has been totally re-written by Dr. Chris Gippel of Fluvial Systems Pty Ltd. In this final chapter, we could not avoid venturing a little further into the biological realm, and we also drew on a much wider range of source material. Readers expecting mathematical derivations will still be disappointed; we concentrate on presenting principles and demonstrating their practical use.

The software package, AQUAPAK (readers of the first edition will be familiar with the original version) has been completely updated by the original author Dr Rory Nathan of Sinclair Knight Merz Pty Ltd. AQUAPAK can be downloaded at http://www.skmconsulting.com/aquapak and runs in Windows. AQUAPAK has been tailor made for the readers of this book and assumes no prior knowledge on the part of the user other than basic computer keyboard skills. More advanced users may wish to investigate the Catchment Modelling Toolkit available on-line from the Cooperative Research Centre for Catchment Hydrology at http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit.

It is clear now that many mistakes have been made in stream management in the past, leading to what we now call stream degradation. This is a retrospective view, because at the time, river managers were acting under the impression that their work would improve the value of the river from the perspective of the prevailing dominant social view. Other failed works were simply ill-informed from the technical perspective. Streams are now managed for a wider range of values, and advances made in stream management technology certainly hold the promise of ecologically healthier and economically more valuable streams for the future. But we have to remember that stream management is far from simple, and an ill-informed approach, regardless of the best intentions, can fail to produce the expected outcomes. So, as well as learning more about river processes, developing methods for rehabilitation and playing a leading role in implementing science-based management, river professionals have a responsibility to provide honest evaluations of the relative success of works. New knowledge so generated can then be used to improve the next generation of river management. At one extreme some may still hold the view that fundamental science does not have much of a role to play in the practical domain of the on-ground river manager, while at the other extreme, some researchers might still be content to explore rivers with little thought about the implications of how the new knowledge might assist practical management or policy development. We hope that this book provides a resource and inspiration to fellow river management professionals, academics and students whose outlook and passion lies some where between, or who are working to bridge these perspectives.

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The authors would like to express appreciation to a number of individuals for their contributions during the evolution of this text. Mr. Andrew Douch created many of the original drawings and diagrams for Chapters 4–6 in the first edition. The diagrams in this edition were re-drawn or newly prepared by Chandra Jayasuriya and Fatima Basic of the School of Anthropology, Geography and Environmental Studies, the University of Melbourne. We are grateful to Dr Michael Keough of the Department of Zoology, University of Melbourne, for producing the realistic examples of Section 2.5. Many individuals, listed in the first edition, provided general guidance and reviews of draft materials that helped focus the scope of the book and greatly added to its accuracy and applicability. Their assistance is again acknowledged. Several reviewers provided suggestions for improvement which added to the quality of this second edition.

We are very appreciative of the professionalism and helpfulness of the people at John Wiley & Sons, especially Sally Wilkinson, Keily Larkin and Susan Barclay and to the team of Thomson Press (India) Ltd.—Jyoti Narula, Sanjay Jaiswal, M.S. Junaidi, C.P. Kushwaha and Udayan Ghosh—who greatly contributed to the quality of the final product.

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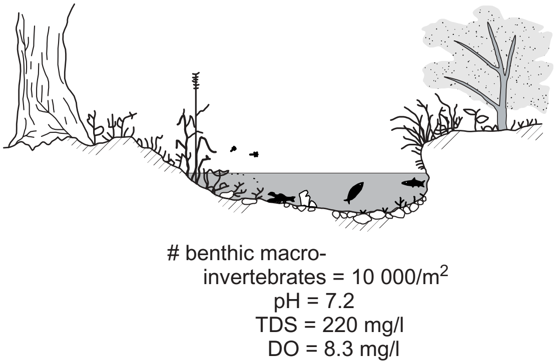
Preface to the First Edition

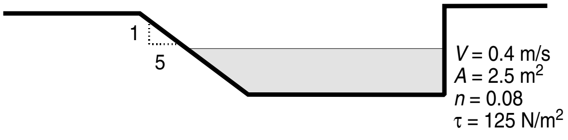
In interdisciplinary applications of stream hydrology, biologists and engineers interact in the solution of a number of problems such as the rehabilitation of streams, the design of operating procedures and fishways for dams, the classification of streams for environmental values and the simulation of field hydraulic characteristics in laboratory flumes to study flow patterns around obstacles and organisms. One of the main purposes in writing this book was to help improve communication between the two disciplines and foster a sense of co-operation in these interdisciplinary efforts.

On the surface, the definitions of ecology and hydrology sound very similar: *ecology* is the study of the interrelationships between organisms and their environment and with each other, and *hydrology* is the study of the interrelationships and interactions between water and its environment in the hydrological cycle. In general, ecology is a more descriptive and experimental science and hydrology is more predictive and analytical. This fundamental difference influences the way streams are studied and perceived in the two disciplines.

For example, a diagram of an ecologist's view of a stream might appear as follows:



Here, the focus is on the aquatic biota, their interrelations, and the physical and chemical factors which affect them. An engineering hydrologist, on the other hand, might 'view' the same stream much differently, perhaps more like this:



In this image, the physical dimensions of the stream have been simplified into a few numbers from which estimates can be made of how the stream will respond under different flow conditions.

Neither view is superior to the other; each represents only a fraction of 'all there is to know' about the stream. Interdisciplinary interaction offers a way of merging the information contained in the different views into a more complete picture. It is often at the interface between disciplines, in fact, that new ideas are generated and progress is made. Perhaps like a stereo pair, new 'dimensions' will be revealed when the images are successfully superimposed.

The emphasis of this text is on the physical environment. Information has been drawn from the fields of geomorphology, hydrology and fluid mechanics, with examples given to highlight the information of biological relevance. Mathematical derivations have been omitted; instead, the intent was to provide an intuitive understanding of the principles, demonstrate their practical use and leave the mathematics to a computer. A software package, AQUAPAK, has been provided for this purpose. Omissions and simplifications were necessary in conveying the wide range of subject matter. We can only resort to the blanket statement that everything is more complicated than our description of it, and that ours is merely another 'view' of streams.

A practical approach has been taken, with the chapter on field techniques forming a central part of the text. In other chapters, examples have been given so that the principles can be applied more readily. Field studies in the Acheron River Basin, located approximately 100 km to the east of Melbourne, provided information for examples throughout the book. We did this to maintain continuity, as well as to illustrate how we went about ‘getting to know’ this river system.

The process of getting to know a stream is not unlike that of a doctor learning about a patient and his or her health. A conscientious doctor will look beyond the charts, images and the results of various tests to obtain a sense of what causes the patient’s health to be what it is. In the same manner, hydrological data, aerial photographs, channel surveys and water quality analyses only measure ‘symptoms’ of a stream’s condition, and, as with human health, the underlying causes are complex and nebulous.

Just as patients are more than the sum of their connective tissues and blood vessels, streams, too, should be viewed ‘holistically’ as a continuum from source to sea and as systems which interact with the surrounding environment. This book presents methods for ‘diagnosing’ the physical condition of streams. Criteria for establishing what constitutes physical ‘health’ are yet to be developed. As Leopold (1960) advocated over 30 years ago, benchmark stations free from grazing and other human influences are needed in order to evaluate the effects of humans on ecologic and geologic change. Interdisciplinary studies are essential for establishing these baseline conditions, for determining the sensitivity of a given stream to ‘stress’ and for developing appropriate rehabilitation procedures to ‘cure’ those streams which are found to be in poor condition.

1

Introducing the Medium

1.1 Water as a Fluid

Water is a widespread, life-sustaining substance, comprising some 50–90% of living materials and covering nearly three-fourths of the Earth's surface. Of the Earth's total moisture, however, about 97% is contained in the oceans and less than 0.0002% flows through its rivers and streams. Water is recycled globally, with the relative proportions of ice, water vapour, fresh water and salt water changing as the earth warms and cools. Scientists formerly believed that the total amount of water on Earth was essentially constant, but new evidence points to a small influx of water from 'snowball' comets (Pielou, 1998).

Water is a substance with many unique chemical and physical properties. Unlike most substances that contract when frozen, water expands, allowing ice to float on the surfaces of lakes and streams. It is found as a liquid at temperatures common to most places on Earth. With its great heat capacity it can absorb or lose a large amount of energy before showing a change in temperature. As a universal solvent, it dissolves gases, nutrients and minerals. Its internal cohesion gives rise to surface tension, which allows water striders to traverse a pool's surface or even run upstream. Because of its physical properties, a quite different set of environmental conditions is presented to amoebae and fish that both live in the same waters.

Depending on the temperature, water can exist as either a liquid, a gas (water vapour) or a solid (ice). Combinations such as steam-air mixtures or water with entrained air fall into a specialized category called *two-phase flows*.

The general term *fluid* describes both gases and liquids, examples being oxygen, motor oil, liquid glass and mercury. The differences between fluids and solids are not always obvious. Fluids flow readily under the slightest of forces; they do not have a definite shape and vessels are required to contain them. *Solids* are substances that are considered to have both a definite volume and a definite shape. Thus, the line is drawn between molasses as a fluid and gelatin as a solid.

Liquids are distinguished from gases by their cohesiveness. Whether sitting in a laboratory beaker or in a frog pond, a liquid will have a definite volume. It will also have a free surface, which is horizontal when the fluid is at rest. A *gas*, in contrast, does not have a definite volume, and will expand to fill a container enclosing it.

The next section will introduce some basic principles of physics and the system of units used in the text. These concepts are applied to the description of physical properties of water in Section 1.3.

1.2 The Physics of Fluids

The properties and motion of a fluid, such as water, are measured in terms of four basic quantities: mass, length, time and temperature. The magnitudes of these quantities (e.g. how hot or how large) are expressed in *units*. In the International System of Units (SI), the *fundamental* or *base units* are given as

- kilogram (kg)—mass,
- metre (m)—length,
- second (s)—time,
- Kelvin (K)—temperature.

In studies of aquatic systems, absolute temperatures are not normally of interest, and for the purposes of this text, temperature will be expressed in °C (Celsius), where 273.15 K = 0 °C, and a change of 1 °C is the same as a change of 1 K.

The metre was originally proposed as 10^{-7} of the length of the meridian through Paris (Blackman, 1969). It is now defined in terms of the wavelength of a specific type of orange light. The unit of time, the second, is defined by

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an atomic standard based on caesium. The unit of mass was originally based on the mass of a certain volume of water at prescribed conditions. Thus, conveniently, a litre (0.001 m^3) of water at 4 °C has a mass of about 1 kg.

Whereas these base units are all defined in reference to some standard, there are other quantities, such as velocity, for which standards are impractical. These quantities have units that are defined in terms of the base units and are thus called *derived units*. Some of the quantities associated with the area of physics known as 'mechanics', which are relevant to the study of water, will be discussed. A summary of both fundamental and derived units, their dimensions and associated symbols, is given in Table 1.1. For tables of conversion factors and other information relevant to water resource studies, Van Haveren's (1986) handbook is a highly useful reference.

Velocity

Motion is defined as a change of position. *Speed* refers to the rate at which the position changes with time, i.e. if a raft floats 500 m downstream in 5.5 min, then its average speed is about 1.5 m/s. Technically, *velocity* refers to the speed in a given direction; however, in ordinary speech, no distinction is usually made between velocity and speed.

Discharge or Streamflow

Discharge, or *streamflow*, is the rate at which a volume of water flows past a point over some unit of time. In the SI system it is expressed in metres cubed per second (m^3/s). For example, if a small spring filled a 0.01 m^3 bucket in 2 s, its discharge would be 0.005 m^3/s. Discharge is normally symbolized by Q.

Acceleration

Acceleration is the rate at which velocity changes with time. An object dropped off a cliff on Earth will accelerate at 9.807 m/s^2 (this *gravitational acceleration* (g) varies slightly with position on the Earth's surface). The distance h covered by a dropped object (starting at zero velocity) is

$$h = \tfrac{1}{2}gt^2 \tag{1.1}$$

where t is the time in seconds from when it was dropped and h is in metres.

Force

Force is described in terms of its effects. It may cause an object to change its direction of motion, to stop or start, to rise or fall. By Newton's second law of motion, force is proportional to mass multiplied by acceleration. In the SI

Table 1.1. *Common quantities used in the description of fluids. Adapted from Vogel, Steven; Life in Moving Fluids. © 1981 by Willard Grant Press, 1994 revised Princeton University Press. Reprinted by permission of Princeton University Press*

[Text not available in this electronic edition.]

system, the unit of force is the *Newton* (N), defined as the force necessary to accelerate 1 kg at 1 m/s^2:

$$\text{Force (N)} = \text{Mass (kg)} \times \text{acceleration } (\text{m/s}^2) \quad (1.2)$$

A very small ‘Newton’s’ apple with a mass of 0.102 kg experiences a gravitational force on Earth of about 1 N.

The term ‘weight’ does not appear in the SI system, and can create confusion particularly when converting from the Imperial to the SI system. *Mass* is an expression of the amount of matter in something, whether a brick, a balloon or a bucket of water. *Weight* is a gravitational force. If Newton’s apple were taken to the moon, it would still have a mass of 0.102 kg, but its weight (the force due to gravity) would be considerably reduced. On Earth, if an American buys 2.2 pounds (lb) of apples at the supermarket to make a pie and an Australian buys 1 kg of apples at the greengrocer to make apple slices, they will both get the same amount of produce. In this case, the distinction between mass and weight does not matter. However, to a researcher studying the behaviour of fluids, the distinction is essential!

Pressure

The *pressure* at any point is the force per unit area acting upon the point. For example, a human of 70 kg standing on the top of an empty aluminium can with a surface area of 0.002 m^2 would exert a pressure of

$$\left(\frac{70 \times 9.807}{0.002}\right) \approx 343\,000\,\text{N/m}^2 \text{ or } 343 \text{ kilopascals (kPa)}$$

–probably sufficient to crush it.

Shear Stress and Shear Force

Shear stress, like pressure, is force per unit area. The difference is in the direction in which the force is applied. In pressure, the force acts *perpendicular* to a surface, $\overset{\downarrow}{\square}$, whereas a *shear force* acts *parallel* to it, $\overrightarrow{\square}$. For example, a glob of liquid soap rubbed between the hands experiences shearing forces. Shear stress is the shearing force divided by the area over which it acts. For the soap, the shearing force acts over the surface area where the soap contacts the hand. Shear stress, symbolized by τ (tau), has the same unit as pressure, N/m^2.

Energy and Work

Energy and work have the same units. *Work* is a quantity described by the application of a force over some distance, measured in the direction of the force:

$$\text{Work (N m or J)} = \text{Force (N)} \times \text{distance (m)} \quad (1.3)$$

For example, if a force of 500 N is required to push a waterlogged log 10 m across a pond, then the amount of work done is 5000 N m or 5 kilojoules (kJ).

Energy is the capacity for doing work. Thus, the quantity of work that something (or someone) can do is a measure of its energy; e.g. it would take about 700 kJ for a person of average ability to swim 1 km. Energy is usually symbolized by Ω (omega).

Power

Power is the amount of work done per unit time:

$$\text{Power (J/s or Watts)} = \text{Work (J)/time (s)} \quad (1.4)$$

Power is usually symbolized by ω (lower case omega). For a flow of water, Q, falling over a height, h, the relevant formula for calculating power is

$$\omega = \rho g Q h \quad (1.5)$$

where ω has units of Watts, Q has units of m^3/s, h is in metres, ρ (rho) is the density of water (kg/m^3) and g is the acceleration due to gravity (m/s^2). As an approximation, this can be simplified to

$$\omega = 10Qh \quad (1.6)$$

with ω in kilowatts. Thus, if a waterfall of 10 m height is flowing at 1.0 m^3/s, the power of the falling water is 100 kW. If the flow were diverted into a small hydroelectric plant rather than over the waterfall, much of this water power could be converted to electrical power. Because of losses associated with the turbine, electrical generator and diversion works, efficiencies of 70% are common. In this example, then, approximately 70 kW of electricity could be produced.

1.3 Physical Properties of Water

1.3.1 Density and Related Measures

Density

Because the formlessness of water makes mass an awkward quantity, *density*, or mass per unit volume, is typically used instead. Density is normally symbolized by ρ and in the SI system it is expressed in kilograms per cubic metre (kg/m^3).

Table 1.2. *Values of some fluid properties at atmospheric pressure. Adapted from Douglas et al. (1983) and Vogel (1981), by permission of Longman Group, UK, and Princeton University Press, respectively*

	(°C)	Density, ρ (kg/m^3)	Dynamic viscosity, μ (N s/m^2)	Kinematic viscosity, ν (m^2/s)
Fresh water	0[a]	999.9	1.792×10^{-3}	1.792×10^{-6}
	4	1000.0	1.568×10^{-3}	1.568×10^{-6}
	10	999.7	1.308×10^{-3}	1.308×10^{-6}
	15	999.1	1.140×10^{-3}	1.141×10^{-6}
	20	998.2	1.005×10^{-3}	1.007×10^{-6}
	25	997.1	0.894×10^{-3}	0.897×10^{-6}
	30	995.7	0.801×10^{-3}	0.804×10^{-6}
	40	992.2	0.656×10^{-3}	0.661×10^{-6}
Sea water[b]	0	1028	1.89×10^{-3}	1.84×10^{-6}
	20	1024	1.072×10^{-3}	1.047×10^{-6}
Air	0	1.293	17.09×10^{-6}	13.22×10^{-6}
	20	1.205	18.08×10^{-6}	15.00×10^{-6}
	40	1.128	19.04×10^{-6}	16.88×10^{-6}
SAE 30 oil	20	933	0.26	0.279×10^{-3}
Glycerine	20	1263	1.5	1.190×10^{-3}
Mercury	20	13 546	1.554×10^{-3}	0.115×10^{-6}

[a] Ice at 0 °C has a density of 917.

[b] Sea water of salinity 35 ‰. The salinity of sea water varies from place to place.

Pressure can be assumed to have an insignificant effect on the density of water for most hydrological applications. However, water density does change with temperature, decreasing as the temperature increases above 4 °C (i.e. tepid water floats on top of colder water). Water density reaches a maximum at 4 °C under normal atmospheric pressure. As the temperature decreases below 4 °C, water becomes less dense, and upon freezing, it expands (ice floats). The densities of selected fluids at different temperatures are listed in Table 1.2.

Materials dissolved or suspended in water, such as salt or sediment or air, will also affect its density. Thus, fresh water will float above salt water in estuarine environments or where saline groundwater enters a stream. Density is reduced in the frothy whitewater of rapids, under waterfalls or in other areas where large quantities of air are entrained in the water. Swimmers have more trouble staying afloat or propelling themselves in these regions; hence, fish tend to 'jump' towards their upstream destinations from less-aerated areas (Hynes, 1970).

Specific Weight

Specific weight is a non-SI measure, but is commonly used in practice in the Imperial system in place of density. Usually symbolized by γ (gamma), specific weight is equal to the product of density and gravitational acceleration, ρg. Thus, in the Imperial system, where the specific weight of water (at 4 °C) is 62.4 lb/ft^3, one can calculate the weight of water in a 10 ft^3 aquarium as $62.4 \times 10 = 640$ lb. This measure will not be used in this text, and is included here only because it appears so often in the literature.

Relative Density

Relative density is usually defined as the ratio of the density of a given substance to that of water at 4 °C. It is thus a dimensionless quantity (it has no units). For example, the relative density of quartz is about 2.68. Relative density is equivalent to *specific gravity*, used in the Imperial system, where specific gravity is defined as the ratio of the specific weight of a substance to that of water.

Example 1.1

Calculate (a) the mass of a 5 L volume of 15 °C fresh water and (b) the gravitational force (weight) it experiences on Earth:

$$\text{(a)}\ (5\,\mathrm{L})\left(\frac{.001\,\mathrm{m}^3}{\mathrm{L}}\right)\left(999.1\,\frac{\mathrm{kg}}{\mathrm{m}^3}\right) = 5.0\,\mathrm{kg}$$

$$\text{(b)}\ 5.0\,\mathrm{kg}\left(9.807\,\frac{\mathrm{m}}{\mathrm{s}^2}\right) = 49.0\,\frac{\mathrm{kg\,m}}{\mathrm{s}^2} = 49.0\,\mathrm{N}$$

1.3.2 Viscosity and the 'No-slip Condition'

Viscosity is a property that is intuitively associated with motor oil and the relative rates with which honey and water pour out of a jar. It is related to how rapidly a fluid can be 'deformed'. When a hand-cranked ice cream maker is empty the handle can be turned relatively easily. If it is then filled with water, the amount of effort increases, and if the water is replaced with molasses, the handle becomes extremely difficult to turn. Viscosity, or more precisely, *dynamic* or *absolute viscosity*, is a measure of this increasing resistance to turning. It has units of Newton seconds per square metre ($\mathrm{N\,s/m^2}$) and is symbolized by μ (mu). Of interest to aquatic organisms and aquatic researchers is the fact that there is almost no liquid with viscosity lower than that of water (Purcell, 1977).

The dynamic viscosity of water is strongly temperature dependent. Colder water is more 'syrupy' than warmer water. For this reason, it takes less effort for a water boatman to row across a tepid backyard pond in summer than the equivalent distance in a frigid high-country lake. It also takes more work for wind to produce waves on a water surface when the water is colder. Dynamic viscosity of fresh water can be calculated directly from temperature using the Poiseulle relationship, given as follows (Stelczer, 1987):

$$\mu = \frac{0.0018}{(1 + 0.0337T + 0.00022T^2)} \tag{1.7}$$

Eq. (1.7) will give slightly different values than those listed in Table 1.2 for fresh water. It should be noted that salt water has a higher dynamic viscosity than fresh water at the same temperature. Vogel (1981) describes instruments for measuring the viscosity of fluids for which published values are not available.

The influence of viscosity is perhaps most significant in the region where fluids come into contact with solids. It is here that fluids experience the equivalent of friction, which develops entirely within the fluid. When a solid slides across another solid, like shoes across a carpet, friction occurs at the interface between the two solids. When a fluid encounters a solid, however, the fluid sticks to it. There is no movement at the interface. According to this *no-slip condition*, at the point where a viscous fluid contacts a solid surface like a cobble on a streambed or a scale on a fish, its velocity is the same as that of the solid.

Thus, when water flows by a stationary solid object, the velocity of the water is zero where it contacts the solid surface, increasing to some maximum value in the 'free stream'—the region 'free' of the influence of the solid boundary.

Kinematic viscosity, symbolized by ν (nu), is the ratio of dynamic viscosity to density:

$$\text{Kinematic viscosity } (\nu) = \frac{\text{Dynamic viscosity } (\mu)}{\text{Density } (\rho)} \tag{1.8}$$

where ν has units of $\mathrm{m^2/s}$. This ratio shows up frequently in important measures such as the Reynolds number, and is another way of describing how easily fluids flow. The quantity was introduced by engineers to simplify the expression of viscosity (kinematic viscosity has dimensions only of length and time).

From Table 1.2 it can be seen that the kinematic viscosities of air and water are much more similar than their relative dynamic viscosities. The similarities in the behaviour of air and water make it convenient to model air currents, chimney plumes or aircraft in water tanks (after applying appropriate scaling factors).

1.3.3 Surface Tension

A whirligig beetle darting across the surface of a pool, beads of dew on a waxy leaf, the curve of water spilling over a weir and the creep of water upwards from the groundwater table into fine-grained soils—are all illustrations of the phenomenon, *surface tension*. Surface tension can be regarded as the stretching force per unit length (or energy per unit area) required to form a 'film' or 'membrane' at the air–water interface (Streeter and Wylie, 1979). It is symbolized by σ (sigma), and has units of Newton per metre (N/m).

Surface tension of water in contact with air results from the attraction of water molecules to each other. Within a body of water, a water molecule is attracted by the molecules surrounding it on all sides, but molecules at the surface are only attracted by those beneath them. Therefore, there is a net pull downwards which puts tension on the water surface. The surface region under tension is commonly known as the *surface film*. Because this film is under tension, any change in shape which would add more surface area (and further increase the tension) is resisted. Water drops and submerged air bubbles, as examples of air–water interfaces, are almost perfectly spherical because a sphere has less surface area per unit of volume than other shapes.

The surface tension of water is temperature-dependent. It decreases as temperature rises by the following relationship (Stelczer, 1987):

$$\sigma = 0.0755 - 0.000\,156\,9T \tag{1.9}$$

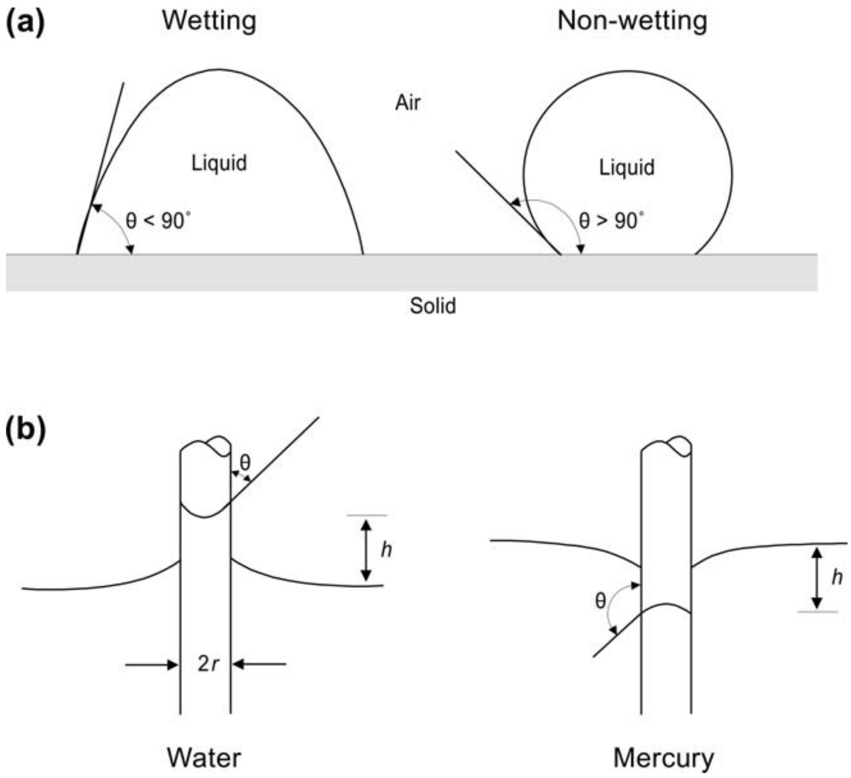

Figure 1.1. Effects of surface tension (a) on the angle of contact, θ, in wetting and non-wetting liquids and (b) on capillarity in circular glass tubes of radius r, where h is capillary rise or depression

Surface tension also affects whether a droplet will bead up or spread out on a solid surface. The angle of contact between a liquid and a solid is related not only to the *cohesion* of the water molecules (attraction to each other), but also to the *adhesion* of the liquid to the solid. If this contact angle (θ in Figure 1.1(a)) is less than 90°, the liquid is said to 'wet' the solid. If the angle is greater than 90°, the liquid is 'non-wetting'.

Water is wetting to a clean glass surface or a bar of soap but does not wet wax (White, 1986). Non-wettable objects with a higher density than water can be supported by the surface film up to a certain point. For example in water at 18 °C, a dry sewing needle of 0.2 g will 'float', whereas at 50 °C, it will sink. Near sandy streambanks, patches of fine dry sand may likewise be supported by the water surface. Insects that dart around on the water surface tend to have a waxy coating which functions as a water repellant (Vogel, 1988).

Adding a wetting agent such as detergent to the water will reduce the surface tension, making it more difficult for mosquitoes to 'attach' to the surface film from the underside or for water-striding insects to walk across it. If a baby duck is placed in a tub of soapy water, the water-repelling oil in its feathers dissolves, releasing air trapped within the feathers, and it sinks (Bolemon, 1989). Cormorants do not have water-repellent feathers, and must spread their wings out to dry after diving for fish.

Wetting agents are added to liquid pesticides to make them spread out and cover more surface area on plant leaves. Similarly, laundry detergents reduce surface tension, allowing water to penetrate more readily through dry clothes (Vogel, 1988).

Another important implication of surface tension is that pressure within a droplet of water in air—or within an air bubble under water—is higher than the pressure outside. The increase in pressure is given by (White, 1986)

$$\Delta p = \frac{2\sigma}{r} \tag{1.10}$$

where Δp is the increase in pressure (in N/m^2) due to surface tension and r is the radius (in metres) of the droplet or bubble. It can be seen that the pressure becomes larger as the radius gets smaller. Because of the increased pressure, the air held in small bubbles will tend to go into solution and the bubble will shrink. Thus, very small air bubbles will quickly collapse and disappear. Vogel (1988) offers a fascinating discussion on how bubbles form at scratched surfaces in beer glasses and other biologically related implications of surface tension.

Capillarity is another phenomenon caused by surface tension. Capillarity, which causes water to rise in plant stems, soil pores and thin glass tubes, results from both adhesion and cohesion. Its height is positive (capillary rise) if liquids are wetting and negative (capillary depression) if liquids are non-wetting, as shown in Figure 1.1(b). Also, the meniscus (curve of the liquid's surface) is concave for wetting liquids and convex for non-wetting.

The formula for capillary rise (or depression), h (m), is (White, 1986)

$$h = \frac{2\sigma \cos\theta}{\rho g r} \tag{1.11}$$

where r is the radius (m) of the tube or the mean radius of soil pores, ρ is the density of the water (kg/m^3) and the other symbols have been explained earlier in this section.

From Eq. (1.11) it can be seen that capillarity decreases as the tube or pore radius gets bigger. For water in glass tubes with diameters over about 12 mm, capillary action becomes negligible (Daugherty *et al.*, 1985). It can also be seen that h is positive for $\theta < 90°$ (wetting liquids) and negative for $\theta > 90°$ (non-wetting). For open-water surfaces and soil pores the simplification $\theta = 0$ is usually made so that the ($\cos\theta$) term drops off (Stelczer, 1987). In soils, organic matter and certain mineral types can increase the contact angle above 90°, in which case the soil will not wet. For example, soils can become 'hydrophobic' after intense fires, preventing water from infiltrating (Branson *et al.*, 1981).

1.3.4 Thermal Properties

Temperature has an effect on other properties of water, such as density, viscosity and dissolved oxygen concentration. Temperatures vary seasonally in streams and with the water source (e.g. snowmelt or industrial outfall). Because of turbulence, the thermal stratification characteristic of lakes is uncommon in streams and they respond more quickly to changes in air temperature. Biologically, temperature has an important influence on decomposition and metabolic rates, and thermal cues may exist for reproduction or migration; therefore, aquatic organisms will survive and thrive within specific temperature ranges.

Streams, as a rule, exist between the temperature extremes of ice floes and boiling hot springs. Pure water freezes at 0 °C and boils at 100 °C. The presence of dissolved solids raises the boiling point and depresses the freezing point as compared with pure water. Since aquatic organisms normally concentrate salts in different proportions to those in the surrounding solution, their 'boiling' and 'freezing' temperatures will be different from those of the surrounding medium, and some primitive organisms such as blue-green algae and bacteria can tolerate great extremes of temperature.

In studies of aquatic systems, temperature data are sometimes converted to *degree-days* to correlate temperature with snowmelt, plant germination times or developmental times for aquatic insects, where

$$\text{degree-days} = nT_{\text{avg}} \tag{1.12}$$

Here, n is the number of days from a given starting date and T_{avg} is the mean daily temperature above some base, usually 0 °C (Linsley *et al.*, 1975b). Four days with individual mean temperatures of 20, 25, 25 and 30 °C would therefore represent 100 degree-days above 0 °C.

The amount of heat a body of water absorbs depends on the amount of heat transferred to it from the air and streambanks, as well as the *thermal capacity* of the water. The thermal capacity of water is very high in comparison with other substances, meaning that it can absorb a large amount of heat before its temperature increases substantially. Thermal capacity, T_c, has units of J/°C, and is defined as (Stelczer, 1987)

$$T_c = cM \tag{1.13}$$

where M is the mass of water (kg) and c is the specific heat of the water (J/kg °C). *Specific heat* is the amount of heat required to raise the temperature of a unit mass of water by 1 °C. As shown in Table 1.3, it is

Table 1.3. *Values of specific heat for water at various temperatures. From Stelczer (1987), Reproduced by permission of Water Resources Publications, LLC*

Water temperature (°C)	Specific heat (J/kg °C)
Ice	2.039
0	4.206
10	4.191
20	4.181
30	4.176
40	4.177
50	4.183

temperature-dependent, reaching a minimum at 30 °C. Thus, a kilogram of water at 10 °C would require 4.19 J of heat energy to raise its temperature to 11 °C.

Energy is released when water freezes, a fact known by citrus fruit growers who spray their trees with water to protect them from frost damage. The *latent heat of fusion*, the energy needed to melt ice or the energy which must be taken away for it to freeze, is 335 kJ/kg for water at 0 °C.

At the other extreme, additional energy is required when water reaches the boiling point to get it to vaporize. Vaporization reduces the temperature of the remaining water. The *latent heat of vaporization* for water at 100 °C is 2256 kJ/kg. These latent heat values are relatively high in the natural world and are caused by hydrogen bonding. Hydrogen bonding is also responsible for the unusual behaviour of water density near the freezing point.

1.3.5 Entrained Air and Dissolved Oxygen

Dissolved oxygen (DO) is actually a chemical property of water, but is included because it is affected by physical properties such as temperature and turbulence, and because of its biological relevance. Oxygen enters water by diffusion at the interface between air and water at the surface of a stream or at the surface of air bubbles. It can also be produced from the photosynthesis of aquatic plants.

Table 1.4. *Dissolved oxygen saturation concentrations at atmospheric pressure 760 mm Hg and zero salinity. Generated from USGS DOTABLES program (USGS, 2001), Reproduced by permission of U.S. Geological Survey*

Water temperature (°C)	Oxygen saturation (mg/L)
0	14.6
5	12.7
10	11.3
15	10.1
20	9.1
25	8.2
30	7.5
40	6.4

Entrainment of air under waterfalls and in the frothy whitewater of rapids increases the amount of interface area where diffusion can occur. Most of this entrained air soon escapes, however, and it is the escape of these air bubbles which produces the roar of rapids and the murmur of meandering brooks (Newbury, 1984). The amount of air remaining in the water is determined by the gas-absorbing capacity of water, which is dependent upon temperature and ambient pressure.

Under normal atmospheric pressure and a temperature of 20 °C, water will contain about 2% (by volume) dissolved air (Stelczer, 1987). As temperatures rise, the gas-absorbing capacity of water decreases rapidly, reaching zero at 100 °C. Although the concentration of oxygen (O_2) in the atmosphere is about 21%, oxygen is more

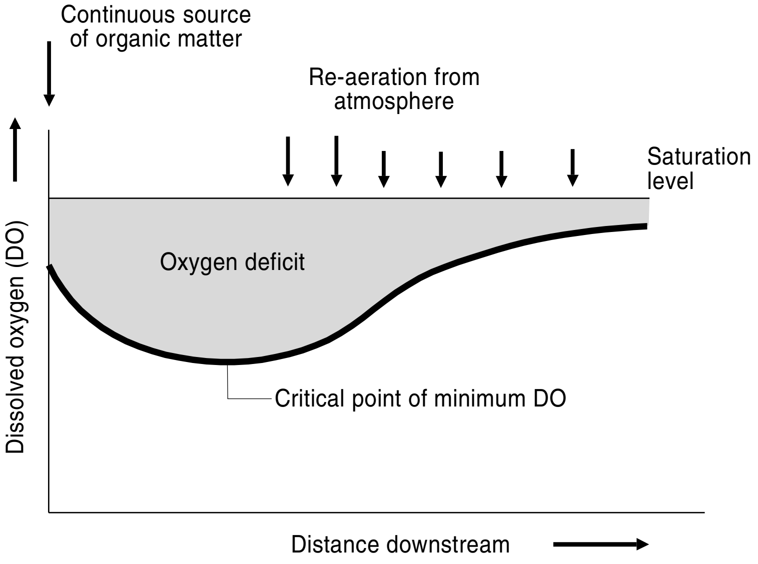

Figure 1.2. *Dissolved oxygen sag curve*

soluble in water than nitrogen, and dissolved air contains from 33% to 35% O_2, depending on the temperature—a fact which has no doubt played an evolutionary role in the dimensions of gills and other respiratory mechanisms.

The maximum amount of dissolved oxygen that water can hold at a given temperature, atmospheric pressure and salinity is termed *oxygen saturation.* Table 1.4 gives oxygen saturation values for a range of water temperatures.

The amount of DO actually present in the water can be expressed as a percentage of the saturation value (% sat)

$$\%\,\mathrm{sat} = \frac{\text{Actual DO concentration}}{\text{Saturation concentration}} \times 100 \qquad (1.14)$$

Concentrations are usually given in milligrams per litre (mg/L). For example, if a 20 °C water sample has a DO content of 8.2 mg/L, then % sat = (8.2/9.05) × 100 = 90.6%.

Organic matter in streams is assimilated by bacteria that use dissolved oxygen for the aerobic processing of organic materials. An increase in the amount of organic matter (e.g. sewage, detritus stirred up by dredging or an overload of autumn leaves in temperate climate zones) stimulates bacterial growth. If the organic load is extremely excessive, nearly all the dissolved oxygen can be used up by the bacteria, leading to anaerobic conditions. In these streams, conditions can become unfavourable to forms of aquatic life sensitive to oxygen levels (Best and Ross, 1977).

The process of de-oxygenation and re-aeration of streams produces a pattern in the DO concentration known as the *dissolved oxygen sag*, first described by Streeter and Phelps in 1925 (Clark *et al*., 1977). A sag curve is illustrated in Figure 1.2, representing the dissolved oxygen deficit (amount below saturation level) as it varies with distance downstream. A light organic load and adequate aeration will only cause a slight dip in the curve with a quick recovery, whereas a heavy load and low re-aeration rate may cause DO to decrease to 0%, from which it recovers only slowly. Equations for estimating the sag curve are given by Clark *et al*. (1977, pp. 296–298), and require field studies to determine the degree of organic pollution and the re-aeration characteristics of the stream.

2

How to Study a Stream

2.1 Focusing on Physical Habitat

Before beginning, the definitions of the terms *river*, *stream* and *catchment* should be clarified. In general, rivers are larger paths of moving water (i.e. too large to wade or jump across) and streams or creeks are smaller. This relative definition will be retained, but the word 'stream' will be used as a generic term for flowing waters throughout the text. A *catchment* is the area above a specific point on a stream from which water drains towards the stream. Catchments and their characteristics will be described further in Chapter 3.

At the interface between aquatic ecology and hydrology, studies of streams fall roughly into the following categories:

1. Description or classification of aquatic habitats based on their biota and environmental characteristics. Descriptions of the flowing environment are also needed for simulating the same conditions in laboratory flumes.
2. Monitoring programs to determine variability in the natural environment over time or to detect some trend due to environmental deterioration or recovery (Green, 1979).
3. Comparison of conditions at one place/time with conditions at another place/time; e.g. comparing effects of management or of some experimental treatment, either between sites or at the same site at different times (Platts *et al.*, 1987).
4. Development of relationships between variables, e.g. local water velocity and blackfly larvae populations, or catchment area and stream width, in order to estimate or predict one from the other(s).

A variety of factors control the abundance, distribution and productivity of stream-dwelling organisms such as competition for space, predation, chemical water quality, temperature, nutrient supplies, the presence of waterfalls or dams and flow variability. An individual species will have a range of tolerance to any given factor, with some factors more critical than others. Thus, studies of streams may involve the measurement and analysis of biological, chemical and physical parameters. The emphasis throughout this text, however, will be on physical habitat: those factors which form the 'structure' within which an organism makes its home. Physical factors are generally more predictable, less variable and more easily measured than biological or chemical ones, and are thus preferable for general, consistent descriptions of streams.

Following is a discussion of the physical factors which are of the most ecological significance: streamflow, current (velocity), channel shape, substrate and temperature. Dissolved oxygen and salinity, although chemical factors, have been included since they are influenced by physical factors, they have high ecological relevance and they can be measured relatively easily. Vegetation has also been included as a related factor because of its influence on the physical nature of streams. These factors should be considered when planning a stream study (Section 2.2) and developing a sampling design (Sections 2.3–2.5).

More information on the effects of physical factors on the distribution of biota can be obtained from texts on aquatic biology or stream ecology such as Allan (2001), Barnes and Mann (1980), Bayly and Williams (1973), Brown (1971), DeDeckker and Williams (1986), Fontaine and Bartell (1983), Goldman and Horne (1983), Hynes (1970), Maitland (1978), Moss (1988), Resh and Rosenberg (1984), Townsend (1980), Uhlmann (1979) and Welch (1935).

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Streamflow

As a general trend, streamflow increases and channels get larger in the downstream direction. Patterns of physical habitats are created along a stream and within the pools, riffles and boulder clusters within particular stream reaches. These habitats and their inhabitants vary with patterns of streamflow. Ephemeral streams (Section 4.1.3), for example, usually (but not always) support different species than perennial streams. Snowmelt-fed and spring-fed streams generally have more predictable and less variable flow patterns than rainfall-fed ones, and their flora and fauna will be different. In highly variable streams, organisms may require more flexibility in their feeding, growth and/or reproductive behaviours. Fish community patterns also tend to be influenced more by the streamflow in variable streams, and more by biological factors such as competition, predation or food resources in stable streams (Pusey and Arthington, 1990).

Floods and droughts can have significant impacts on riverine species. Periodic scouring of banksides and inundation of floodplains regulate plant growth and nutrient input to the stream. Patterns of flooding affect the distribution of plant species within the stream and along a gradient from the river's edge to upland areas. Prolonged flooding of wetlands is needed for waterbirds to feed, rest and reproduce. The survival of juvenile fish may also depend on the inundation of floodplains, billabongs and backwaters. Moreover, floods serve as a signal for some fish species that it is time to spawn. Floods turn over rocks, altering the configuration of the streambed and 'resetting' the ecosystem by allowing a succession of organisms to re-colonize the substrate.

During low flows, temperature and salinity levels may rise, and plant growth within the channel can increase. Some species may rely on low flow periods for a part of their life history; for others, it is a time of stress. The stream may dry to a series of scattered pools connected only by sub-surface flows, limiting movement and increasing predation and competition for nutrients and space within the remaining waters. Intermittent streams experience a greater range of physical and chemical variation (e.g. in temperature and dissolved oxygen levels), and thus support unique biologic communities. These streams generally have a lower species richness as compared to perennial ones (Lake *et al*., 1985). To cope with temporary waters, some organisms have developed special adaptations, such as dormant phases, which allow them to survive. Some larvae of aquatic insects, for example, burrow deep into the streambed to find sufficient moisture. Other species have drought-resistant eggs or spores and quick regenerative powers for the time when favourable conditions return. If only part of a stream runs dry, the affected reaches can be re-populated from remaining pools or upstream tributaries. Williams (1987) provides additional information on the ecology of intermittent streams.

Streamflow is a particularly important factor in the study of regulated waters, where modifications to natural flow patterns can have marked effects on the stream's flora and fauna.

Current

As stated by Hynes (1970, p. 121), 'current is the most significant characteristic of running water, and it is in their adaptations to constantly flowing water that many stream animals differ from their still-water relatives'. Some species have an innate demand for high water velocities, relying on them to provide a continual replenishment of nutrients and oxygen, to carry away waste products and to assist in the dispersal of the species. At a given temperature, the metabolic rate of plants and animals is generally higher in running water than in still water (Hynes, 1970). However, it takes a great deal of energy to maintain position in swift waters, and most inhabitants of these zones have special mechanisms for avoiding or withstanding the current.

On average, water velocity tends to increase in the downstream direction, even though mountain torrents give the impression of high speeds in comparison to the more sluggish-looking lowland streams. Within a particular region, however, local variations create a mosaic of patterns which support species with different preferences. The velocities actually encountered, then, are of more relevance than average velocities (Armour *et al*., 1983). As flow levels increase, velocity patterns will shift, forcing organisms to find refuge in calmer backwaters, behind rocks or snags, within vegetation stands or beneath the streambed.

At a finer scale, the leaves and stems of plants or the arrangements of rocks can vary the local flow environment, creating 'micro-habitats' for other organisms. Moving even closer to the surfaces of these features, very small animals such as protozoans can live in a thin fluid layer of near-zero velocity. Complex communities of bacteria, fungi, protozoans and other microscopic organisms form 'biofilms' on surfaces within the stream, which constantly grow and slough off under the influence of the current.

A factor related to velocity patterns is turbulence, which is important in the aeration of waters and the ability of a stream to carry sediments. Turbulence has a 'buffeting' effect on organisms exposed to the current. Near the streambed, organisms may feed at the edges of small turbulent vortices that stir up the substrate and circulate foodstuffs.

Current affects the distribution of sediments on the streambed through its influence on lift and drag forces. Organisms subject to these same forces often show morphological adaptations such as streamlined or flattened bodies or the presence of hooks or suckers for clinging to the substrate. Blackfly larvae (Diptera: Simuliidae), characteristic of very fast waters, attach to the substrate with hooks and have a silk 'lifeline' with which to reel themselves in when they are dislodged. Stream-dwelling mollusc species have heavier, thicker shells than still-water forms, perhaps for ballast as well as protection from moving stones (Hynes, 1970). Species of fish which must negotiate strong currents tend to be streamlined, whereas those which spend almost all of their time near the streambed are more flattened from top to bottom (Townsend, 1980).

Species unable to tolerate high currents may use behavioural mechanisms to escape by burrowing into the streambed, hiding under rocks or building shelters. Fish and eels utilize the dead water regions behind rocks for shelter, moving in short bursts from one to the next.

The distribution of current within a stream can be considerably affected by channel modifications such as de-snagging or straightening. The comparison of velocity distributions in modified and unmodified streams is valuable in stream rehabilitation work.

Water Depth and Width

A stream's depth and width is related to the amount of water flowing through it. However, variations in channel form such as pools and riffles, wide meander loops and sand bars will create variation in water width and depth even where the streamflow is the same.

Water depth has an influence on water temperature, since shallow water tends to heat up and cool down more rapidly. It affects light penetration (more so in turbid waters), influencing the depth at which aquatic plants have enough energy for photosynthesis. Hydrostatic pressures also increase with depth, affecting the internal gas spaces in both plants and animals.

Depth affects the distribution of benthic invertebrates, with most preferring relatively shallow depths (Wesche, 1985). Both depth and width affect the physical spacing between predator and prey species. In general, larger fish prefer to live in pools and smaller fish in shallower water. Depth may become a limiting factor for fish migration when the water is too shallow for passage. Changes in water level can also affect the survival of species (e.g. by stranding fish or eggs, or inundating seedlings at the wrong time).

According to Pennak (1971), the width of a stream determines much of its biology. Migrating birds may require open riverine corridors for navigation and a certain width of water not obstructed by trees for landing and take-off. For resting and nesting, some waterbirds need a water 'barrier' of a certain width to protect them from predators. Mammals such as beavers also have specific requirements for width, depth and slope (Statzner *et al.*, 1988). For terrestrial animals, width and depth will affect their ability to migrate from one side of a stream to the other.

Geomorphologically, width increases in the downstream direction and the shading of streams by overhanging streamside vegetation decreases. Thus, as streams increase in width downstream, organic input from riparian vegetation becomes less significant and instream photosynthesis increases.

Substrate

In a stream, 'substrate' usually refers to the particles on the streambed, both organic and inorganic. Inorganic particle sizes generally decrease in the downstream direction. On a more local scale, larger particles (gravel, cobble) are associated with faster currents and smaller particles (sand, silt, clay) with slower ones. Generally, streambeds composed of smaller particles are less stable, but this will also depend on the mix of particle sizes and shapes. Studies of substrate composition should consider the average and range of particle sizes, the degree of packing or imbeddedness and the irregularity or roundness of individual particles.

Substrate is a major factor controlling the occurrence of benthic (bottom-dwelling) animals. A fairly sharp distinction exists between the types of fauna found on hard streambeds such as bedrock or large stones and soft ones composed of shifting sands. Slow-growing algae, for example, require stable substrates such as large boulders (Hynes, 1970). Additionally, a whole complex of micro-fauna can occur quite deep within streambeds (in the *hyporheic* zone). These may carry out most or all of their life histories underground.

In general, lowland streams with unstable beds tend to have a lower diversity of aquatic animals. Aquatic plants, however, may prefer finer substrates, the plants then becoming substrates for other organisms. Silt substrates may support high populations of burrowing animals, particularly if the silt is rich in organic matter. Freshwater mussels, for example, mostly occur in silty or sandy beds. Clay substrates typically become compacted into 'hardpan' (Pennak, 1971), supporting little except encrusting algae and snails.

The greatest numbers of species are usually associated with complex substrates of stone, gravels and sand. The mix of coarser particles in riffles provides the richest aquatic insect habitat, and is considered the 'fish food' production zone in upland streams. Larger substrate materials provide firmer anchoring surfaces for aquatic insects and more shelter is available in the form of crevices and irregular-shaped stones. Crustaceans such as freshwater crayfish also require rock crevices for shelter.

Fish require substrates that provide shelter from the current, places for hiding from predators and sites for depositing and incubating eggs. Salmonids, for example, dig nest-like redds in gravel substrates by lifting particles with a vacuum-generating sweep of their tails. Successful incubation of the deposited eggs depends on circulation of water through the gravels to supply oxygen and carry away waste products.

Streambed particles are subject to dislodgement during floods, from dredging or other human disturbances and to a much lesser extent when the activities of bottom-feeding fish or burrowing animals stir up sediments. Suspended sediments reduce light penetration and thus plant growth; they can also damage the gills of insects and fish. Larger grains in suspension can have a 'sandblasting' effect on organisms, and rolling stones can crush or scour away benthic plants and animals.

The composition of stream substrates can be altered by sediment influxes from upland erosion and by channel modification. Excessive siltation of gravel and cobble beds can lead to suffocation of fish eggs and aquatic insect larvae and can affect aquatic plant densities. This, in turn, can result in changes in mollusc, crustacean and fish populations. Generally, these changes tend to cause a shift towards downstream conditions (i.e. unstable beds of fine materials), effectively extending lowland river ecosystems further upstream.

Temperature

In general, water temperature increases in the downstream direction, to a point where the water reaches an equilibrium with air temperatures. Water temperature changes both seasonally and daily, but to a lesser degree than air temperature. Seasonal fluctuations tend to be more extreme in lowland streams whereas daily fluctuations may be more extreme in the smaller, upland ones, especially where they are unprotected by vegetation or other cover. In temperate or cold climates, upstream reaches may actually remain warmer in the winter than those downstream, particularly when these upper reaches are spring-fed.

Local variations in shade, wind, stream depth, water sources (e.g. hot springs) and the presence of impoundments will alter the general trends caused by geographical position. Many organisms take advantage of these local variations. For example, Wesche (1985) cites studies which have shown that some trout species select spawning sites in areas with groundwater seepage, where the warmer waters protect eggs from freezing and reduce hatching times.

When water cools (above 4 °C), it becomes denser and sinks. In most stream reaches, turbulence keeps the water well mixed, but temperature stratification can occur where waters are more stagnant, such as in deep pools. One of the unique properties of water is that it is less dense as a solid. In winter, ice and snow can form an insulating blanket over streams, under which aquatic life can continue. Ice usually starts forming when the entire water mass nears 0 °C, beginning with low-velocity areas near the edges of streams, along the streambed and on the underwater surfaces of plants.

The temperature of a stream is critical to aquatic organisms through its effects on their metabolic rates and thus growth and development times. With the exception of a few aquatic birds and mammals, most aquatic animals are cold blooded, i.e. their internal temperatures closely follow that of the surrounding water. As a general rule, a rise of 1 °C increases the rate of metabolism in cold-blooded aquatic animals by about 10%. Thus, these aquatic organisms will respire more and eat more in warmer waters than in colder ones. Each organism will have maximum and minimum temperatures between which they can survive, and these limits may change with each life stage. For fish, unusually high temperatures can lead to disease outbreaks, cause the inhibition of growth and cause fish to stop migrating (Platts, 1983).

Water temperature is thus an important factor in regulating the occurrence and distribution of riparian vegetation, fish, invertebrates and other organisms. Because temperature also affects other properties of water such as viscosity and concentrations of nutrients and dissolved oxygen, it can be difficult to separate the direct effects of temperature from the indirect effects of these other properties. Stream classification systems (Chapter 9) often include water temperature as a factor.

Dissolved Oxygen

Dissolved oxygen (DO) is essential for respiration in aquatic animals as well as being an important component in the cycling of organic matter within a stream. Since gas solubility generally decreases as the water temperature rises, this can lead to lower DO levels during the summer.