CHAPTER 4

The Nature of Environmental Media

4.1 INTRODUCTION

The objective of this chapter is to present a qualitative description of environmental media, highlighting some of their more important properties. This is done because the fate of a chemical depends on two groups of properties: those of the chemical and those of the environment in which it resides. We find it useful to assemble "evaluative" environments, which are used in later calculations. We can consider, for example, an area of $1 \times 1$ km, consisting of some air, water, soil, and sediment. Volumes and properties can be assigned to these media, which are typical but purely illustrative and will, of course, require modification if chemical fate in a specific region is to be treated. The sequence is to treat the atmosphere, the hydrosphere (i.e., water), and then the lithosphere (bottom sediments and terrestrial soils), each with its resident biotic community.

It transpires that it is convenient to define two evaluative environments. First is a simple four-compartment system that is easily understood and illustrates the application of the general principles of environmental partitioning. Second is a more complex, eight-compartment system that is more representative of real environments. It is correspondingly more demanding of data and leads to more lengthy calculations.

The environments or "unit worlds" are depicted in Figure 4.1. Details are discussed by Neely and Mackay, 1982.

4.2 THE ATMOSPHERE

4.2.1 Air

The layer of the atmosphere that is in most intimate contact with the surface of the Earth is the troposphere, which extends to a height of about 10 km. The temperature, density, and pressure of the atmosphere fall steadily with increasing height.
Figure 4.1 Evaluative environments.

which is a nuisance in subsequent calculations. If we assume uniform density at a
presence of one atmosphere, then the entire troposphere can be viewed as being
compressed into a height of about 6 km. Exchange of matter from the troposphere
through the tropopause to the stratosphere is a relatively slow process and is rarely
important in environmental calculations, except in the case of chemicals such as the
freons, which catalyze the destruction of stratospheric ozone, thus facilitating the
penetration of UV light to the Earth's surface. A reasonable atmospheric volume
over our 1 km square world is thus 1000 x 1000 x 6000 or 6 x 10^9 m^3.

If our environmental model is concerned with a localized situation (e.g., a state,
province, or metropolitan region), it is unlikely that most pollutants would manage to
penetrate higher than about 500 to 2000 m during the time the air resides over the
region. It therefore may be appropriate to reduce the height of the atmosphere
to 500 to 2000 m in such cases. In extreme cases (e.g., over small ponds or fields),
the accessible mixed height of the atmosphere may be as low as 10 m. The modeler
must make a judgement as to the volume of air that is accessible to the chemical
during the time that the air resides in the region of interest.

4.2.2 Aerosols

The atmosphere contains a considerable amount of particulate matter or aerosols
that are important in determining the fate of certain chemicals. These particles may
range in size and composition from water in the form of fog or cloud droplets to
dust particles from soil and smoke from combustion. They vary greatly in size, but
a diameter of a few μm is typical. Larger particles tend to deposit fairly rapidly. The
concentration of these aerosols is normally reported in μg/m^3. A rural area may have
a concentration of about 5 μg/m^3, and a fairly polluted urban area a concentration
of 100 μg/m^3. For illustrative purposes, we can assume that the particles have a
density of 1.5 g/cm^3 and are present at a concentration of 30 μg/m^3. This corresponds
to volume fraction of particles of 2 x 10^-11. The density of these particles is usually
unknown, thus the volume fractions are only estimates. It is, however, convenient
for us to calculate this amount in the form of a volume fraction. In an evaluative air
volume of 6 x 10^9 m^3, there is thus 0.12 m^3 or 120 L of solid material.

These aerosols are derived from numerous sources. Some are mineral dust
particles generated from soils by wind or human activity. Some are mainly organic
in nature, being derived from combustion sources such as vehicle exhaust or wood
fires, i.e., smoke. Some are generated from oxides of sulfur and nitrogen. Some
"secondary" aerosols are formed by condensation as a result of oxidation of hydro-
carbons in the atmosphere to less volatile species. These hydrocarbons can be
generated by human activity such as fuel use, or they can be of natural origin. Forests
often generate large quantities of isoprene which oxidize to give a blue haze, hence
the terms "smokey" or "blue" mountains. These aerosols also contain quantities of
water, the amount of which depends on the prevailing humidity.

4.2.3 Deposition Processes

Aerosol particles have a very high surface area and thus absorb (or adsorb or
sorb) many pollutants, especially those of very low vapor pressure, such as the PCEs
or polyaromatic hydrocarbons. In the case of benz(a)pyrene, almost all the chemical
present in the atmosphere is associated with particles, and very little exists in the
gas phase. This is important, because chemicals associated with aerosol particles
are subject to two important deposition processes. First is dry deposition, in which the aerosol particle falls under the influence of gravity to the Earth's surface. This falling velocity, or deposition velocity, is quite slow and depends on the turbulent condition of the atmosphere, the size and properties of the aerosol particle, and the nature of the ground surface, but a typical velocity is about 0.3 cm/s or 10.8 m/h. The result is deposition of 10.8 m/h × 2 × 10^{-11} (volume fraction) × 10^6 m^2 or 0.000216 m/h or 1.89 m^2/year. Second, the particles may be scavenged or swept out of the air by wet deposition with raindrops. As it falls, each raindrop sweeps through a volume of air about 200,000 times its volume prior to landing on the surface. Thus, it has the potential to remove a considerable quantity of aerosol from the atmosphere. Rain is therefore often highly contaminated with substances such as PCBs and PAHs. There is a common fallacy that rain water is pure. In reality, it is often much more contaminated than surface water. Typical rainfall rates lie in the range 0.3 to 1 m per year but, of course, vary greatly with climate. We adopt a figure of 0.8 m/year for illustrative purposes. This results in the scavenging of 200,000 × 0.8 m/year × 2 × 10^{-11} × 10^6 m^2 or 3.2 m^3/year, about twice the dry deposition. Snow is an even more efficient scavenger of aerosol particles. It appears that one volume of snow (as solid ice) may scavenge about one million volumes of atmosphere, five times more than rain, presumably because of its flaky nature with a high surface area and a slower, more tortuous downward journey.

In the four-compartment evaluative environment, we ignore aerosols, but we include them in the eight-compartment version.

4.3 THE HYDROSHERE OR WATER

4.3.1 Water

Seventy percent of the Earth's surface is covered by water. In some evaluative models, the area of water is taken as 70% of the 1 million m^2 or 700,000 m^2. Similarly to the atmosphere, only near-surface water is accessible to pollutants in the short term. In the oceans, this depth is about 100 m but, since most situations of environmental interest involve fresh or estuarine water, it is more appropriate to use a shallower water depth of perhaps 10 m. This yields a water volume of about 7 × 10^6 m^3. If the aim is to mimic the proportions of water and soil in a political jurisdiction, such as a state or province, the area of water will normally be considerably reduced to perhaps 10% of the total, or about 10^5 m^3. We normally regard the water as being pure, i.e., containing no dissolved electrolytes, but we do treat its content of suspended particles.

4.3.2 Particulate Matter

Particulate matter in the water plays a key role in influencing the behavior of chemicals. Again, we do not normally know if the chemical is absorbed or adsorbed to the particles. We play it safe and use the vague term sorbed. A very clear natural water may have a concentration of particles as low as 1 g/m^3 or the equivalent 1 mg/L.
In most cases, however, the concentration is higher, in the range of 5 to 20 g/m³. Very turbid, muddy waters may have concentrations over 100 g/m³. Assuming a concentration of 7.5 g/m³ and a density of 1.5 g/cm³ gives a volume fraction of particles of about $5 \times 10^6$. Thus, in the $7 \times 10^6$ m³ of water, there is 35 m³ of particles.

This particulate matter consists of a wide variety of materials. It contains mineral matter, which may be clay or silica in nature. It also contains dead or decaying organic matter, which is often referred to as humin, humic acids, and fulvic acids or, more vaguely, as organic matter. It is relatively easy to measure the total concentration of organic carbon (OC) in water or particles by converting the carbon to carbon dioxide and measuring the amount spectroscopically. Alternatively, the solids can be dried to remove water, then heated to ignition temperatures to burn off organic matter. The loss is referred to as loss on ignition (LOI) or as organic matter (OM). Thus, there are frequent reports of the amount of dissolved organic carbon (DOC) or total organic carbon (TOC) in water. These humic and fulvic acids have been the subject of intense study for many years. They are organic materials of variable composition that probably originate from the ligninous material present in vegetation. They contain a variety of chemical structures including substituted alkane, cycloalkane, and aromatic groups, and they have acidic properties imparted by phenolic or carboxylic acids. They are, therefore, fairly soluble in alkaline solution in which they are present in ionic form, but they may be precipitated under acidic conditions. The operational difference between humic and fulvic acids is the pH at which precipitation occurs.

It is important to discriminate between organic matter (OM) and organic carbon (OC). Typically, OM contains 50 to 60% OC, thus an OM analysis of 10% may also be 5% OC. A mass basis, i.e., g/100 g, is commonly used. For convenience in our evaluative calculations, we will treat OM as 50% OC, and we will assume the density of both OM and OC as being equal to that of water.

Concentrations of these suspended materials may be defined operationally by using filters of various pore size, for example, 0.45 μm. There is a tendency to describe material that is smaller than this, i.e., that passes through the filter, as being operationally “dissolved.” It is not clear how we can best discriminate between “dissolved” and “particulate” forms of such material, since there is presumably a continuous size spectrum ranging from molecules of a few nanometers to relatively large particles of 100 or 1600 nm. It transpires that the organic material in the suspended phases is of great importance, because it has a high sorptive capacity for organic chemicals. It is therefore common to assign an organic carbon content to these phases. In a fairly productive lake, the OM content may be as high as 50%, but, for illustrative purposes, a figure of 33% for OM or 16.7% OC is convenient. In each cubic metre of water, there is thus 2.5 g or cm³ of OM and 5.0 g or 2.5 cm³ of mineral matter, totaling 7.5 g or 5.0 cm³, giving an average particle density of 1.5 g/cm³.

### 4.3.3 Fish and Aquatic Biota

Fish are of particular interest, because they are of commercial and recreational importance to users of water, and they tend to bioconcentrate or bioaccumulate
metals and organic chemicals from water. They are thus convenient monitors of the contamination status of lakes. This raises the question, “What is the volume fraction of fish in a lake?” Most anglers and even aquatic biologists greatly overestimate this number. It is probably, in most cases, in the region of 10⁻⁴ to 10⁻⁵, but this is somewhat misleading, because most of the biotic material in a lake is not fish—it is material of lower trophic levels, on which fish feed. For illustrative purposes, we can assume that all the biotic material in the water is fish, and the total concentration is about 1 part per million, yielding a volume of “fish” of about 7 m³. It proves useful later to define a lipid or fat content of fish, a figure of 5% by volume being typical.

In summary, the water thus consists of 7 × 10⁶ m² of water containing 35 m³ of particulate matter and 7 m³ of “fish” or biota.

In shallow or near-shore water, there may be a considerable quantity of aquatic plants or macrophytes. These plants provide a substrate for a thriving microbial community, and they possess inherent sorptive capacity. Their importance is usually underestimated. Because of the present limited ability to quantify their sorptive properties, we ignore them here.

4.3.4 Deposition Processes

The particulate matter in water is important, because, like aerosols in the atmosphere, it serves as a vehicle for the transport of chemical from the bulk of the water to the bottom sediments. Hydrophobic substances tend to partition appreciably on to the particles and are thus subject to fairly rapid deposition. This deposition velocity is typically 0.5 to 2.0 m per day or 0.02 to 0.08 m/h. This velocity is sufficient to cause removal of most of the suspended matter from most lakes during the course of a year. Thus, under ice-covered lakes in the winter, the water may clarify. Some of the deposited particulate matter is resuspended from the bottom sediment through the action of currents, storms, and the disturbances caused by bottom-dwelling fish and invertebrates. During the summer, there is considerable photosynthetic fixation of carbon by algae, resulting in the formation of considerable quantities of organic carbon in the water column. Much of this is destined to fall to the bottom of the lake, but much is degraded by microorganisms within the water column.

Assuming, as discussed earlier, 5 × 10⁻⁶ m³ of particles per m² of water and a deposition velocity of 200 m per year, we arrive at a deposition rate of 0.001 m²/m² of sediment area per year or, for an area of 7 × 10³ m², a flow of 700 m³/year. We examine this rate in more detail in the next section.

4.4 BOTTOM SEDIMENTS

4.4.1 Sediment Solids

Inspection of the state of the bottom of lakes reveals that there is a fairly fluffy or nepheloid active layer at the water-sediment interface. This layer typically consists of 95% water and 5% particles and is often highly organic in nature. It may consist of deposited particles and focal material from the water column. It is stirred
by currents and by the action of the various biota present in this benthic region. The sediment becomes more consolidated at greater depths, and the water content tends to drop toward 50%. The top few centimeters of sediment are occupied by burrowing organisms that feed on the organic matter (and on each other) and generally turn over (bioturbate) this entire "active layer" of sediment. Depending on the condition of the water column above, this layer may be oxygenated (aerobic or oxic) or depleted of oxygen (anaerobic or anoxic). This has profound implications for the fate of inorganic substances such as metals and arsenic, but it is relatively unimportant for organic chemicals except in that the oxygen status influences the nature of the microbial community, which in turn influences the availability of metabolic pathways for chemical degradation. The deeper sediments are less accessible, and ultimately the material becomes almost completely buried and inaccessible to the aquatic environment above. Most of the activity occurs in the top 5 cm of the sediment, but it is misleading to assume that sediments deeper than this are not accessible. There remains a possibility of bioturbation or diffusion reintroducing chemical to the water column.

Bottom sediments are difficult to investigate, can be unpleasant, and have little or no commercial value. They are therefore often ignored. This is unfortunate, because they serve as the depositories for much of the toxic material discharged into water. They are thus very important, are valuable as a "sink" for contaminants, and merit more sympathy and attention.

Fast-flowing rivers are normally sufficiently turbulent that the bottom is scoured, exposing rock or consolidated mineral matter. Thus, their sediments tend to be less important. Sluggish rivers have appreciable sediments.

4.4.2 Deposition, Resuspension, and Burial

It is possible to estimate the rate of deposition, i.e., the amount of material that falls annually to the bottom of the lake and is retained there. This can be done by sediment traps, which are essentially trays that collect falling particles, or by taking a sediment core and assigning dates to it at various depths using concentrations of various radioactive metals such as lead. Nuclear events provide convenient dating markers for sediment depths. The measurement of deposition is complicated by the presence of the reverse process of resuspension caused by currents and biotic activity. It is difficult to measure how much material is rising and falling, since much may be merely cycling up and down in the water column. Burial or net deposition rates vary enormously, but a figure of about 1 mm per year is typical. Much of this is water, which is trapped in the burial process.

Chemicals present in sediments are primarily removed by degradation, burial, or resuspension back to the water column.

For illustrative purposes we adopt a sediment depth of 3 cm and suggest that it consists of 67% water and 33% solids, and these solids consist of about 10% organic matter or 5% organic carbon. Living creatures are included in this figure. Some of this deposited matter is resuspended to the water column, some of the organic matter is degraded (i.e., used as a source of energy by benthic or bottom-living organisms), and some is destined to be permanently buried. The low 5% organic
carbon figure for deeper sediments compared to high 17% for the depositing material implies that about 75% of the organic carbon is degraded.

It is now possible to assemble an approximate mass balance for the sediment mineral matter (MM) and organic matter (OM) and thus the organic carbon (OC). This is given in Table 4.1.

<table>
<thead>
<tr>
<th>Mineral matter</th>
<th>Organic matter</th>
<th>Total</th>
<th>Organic carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deformation</td>
<td>600</td>
<td>500</td>
<td>1100</td>
</tr>
<tr>
<td>Resuspension</td>
<td>200</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>OM conversion</td>
<td>300</td>
<td>233</td>
<td>533</td>
</tr>
<tr>
<td>Burial (solids)</td>
<td>720</td>
<td>72</td>
<td>792</td>
</tr>
</tbody>
</table>

Total burial is 1000 cm³/year or 1420 g/year, corresponding to a "velocity" of 1 mm/year. This sediment thus has a density of 1.42 g/cm³ or 1420 kg/m³.

Assumed densities are: mineral matter 2.4 g/cm³, organic matter 1 g/cm³.

Organic matter is 50% (mass) organic carbon.

On a 1 m² basis, the deposition rate is 0.001 m³ per year or 1000 cm³ per year.

With a particle density of 1.7 g/cm³, this corresponds to 1700 g/year of which 500 g is OM, and 1200 g is MM. We assume that 40% of this is resuspended, i.e., 200 g of OM and 480 g of MM. Of the remaining 300 g OM, we assume that 233 g is digested or degraded to CO₂ and 67 g is buried along with the remaining 720 g of MM. Total burial is thus 1420 g, which consists of 720 g of MM, 67 g of OM, and 633 g of water. The total volumetric burial rate of solids is 367 cm³/year. Now, associated with these solids is 633 cm³ of pore water; thus, the total volumetric burial rate of solids plus water is approximately 1000 cm³/year, corresponding to a rise in the sediment-water interface of 1 mm/year. The mass percentage of OC in the depositing and resuspending material is 15%, while in the buried material it is 4.2%. The bulk sediment density, including pore water, is 1420 kg/m³.

On a 7 × 10² m² basis, the deposition rate is 700 m³/year, resuspension is 280 m³/year, burial is 257 m³/year, and degradation accounts for the remaining 163 m³/year. The organic and mineral matter balances are thus fairly complicated, but it is important to define them, because they control the fate of many hydrophobic chemicals.

It is noteworthy that the burial rate of 1 mm/year coupled with the sediment depth of 3 cm indicates that, on average, it will take 30 years for sediment solids to become buried. During this time, they may continue to release sorbed chemical back to the water column. This is the crux of the "in-place contaminated sediments" problem, which is unfortunately very common, especially in the Great Lakes Basin.

In the simple four-compartment environment, we treat only the solids but, in the eight-compartment version, we include the sediment pore water. In the interests of simplicity, we assign a density of 1500 kg/m³ to the sediment in the four-compartment model.
4.5 SOILS

4.5.1 The Nature of Soil

Soil is a complex organic matrix consisting of air, water, mineral matter (notably clay and silica), and organic matter, which is similar in general nature to the organic matter discussed earlier for the water column.

The surface soil is subject to diurnal and seasonal temperature changes and to marked variations in water content, and thus in air content. At times it may be completely flooded, and at other times almost completely dry. The organic matter in the soil plays a crucial role in controlling the retention of the water and thus in ensuring the viability of plants. The organic matter content is typically 1 to 5%, but peat soils and forest soils can have much higher organic matter contents. Depletion of organic matter through excessive agriculture tends to render the soil infertile, which is an issue of great concern in agricultural regions. Soils vary enormously in their composition and texture and consist of various layers, or horizons, of different properties. There is transport vertically and horizontally by diffusion in air and in water, flow, or advection in water and, of course, movement of water and nutrients into plant roots and thence into stems and foliage. Burrowing animals such as worms can also play an important role in mixing and transporting chemicals in soils.

A typical soil may consist of 50% solid matter, 20% air, and 30% water, by volume. The dry soil thus has a porosity of 50%. The solid matter may consist of about 2% organic carbon or 4% organic matter. During and after rainfall, water flows vertically downward through the soil and may carry chemicals with it. During periods of dry weather, water tends to return to the surface by capillary action, again moving the chemicals.

Later, we set up equations describing the diffusion or permeation of chemicals in soils. When doing so, we treat the soil as having a constant porosity. In reality, there are channels or "microporous" areas formed by burrowing animals and decayed roots, and these enable water and air to flow rapidly through the soil, bypassing the more tightly packed soil matrix. This phenomenon is very difficult to address when compiling models of transport in soils and is the source of considerable frustration to soil scientists.

Most soils are, of course, covered with vegetation, which stabilizes the soil and prevents it from being eroded by wind or water action. Under dry conditions, with poor vegetation cover, considerable quantities of soil can be eroded by wind action, carrying with it sorbed chemicals. Sand dunes are an extreme example. In populated regions, of more concern is the loss of soil in water runoff. This water often contains very high concentrations of soil, perhaps as much as a volume fraction of 1 part per thousand of solid material. This serves as a vehicle for the movement of chemicals, especially agricultural chemicals such as pesticides, from the soils into water bodies such as lakes.

4.5.2 Transport in Soils

In most areas, there is a net movement of water vertically from the surface soil to greater depths into a pervious layer of rock or aquifer through which groundwater
flows. The quality of this groundwater has become of considerable concern recently, especially to those who rely on wells for their water supply. This water tends to move very slowly (i.e., at a velocity of meters per year) through the porous sub-surface strata. If contaminated, it can take decades or even centuries to recover. Of particular concern are regions in which chemical leachate from dumps or landfills has seeped into the groundwater and has migrated some distance into rivers, wells, or lakes. It is quite difficult and expensive to investigate, sample, and measure contaminant flow in groundwater. It may not even be clear in which direction the water is flowing or how fast it is flowing. Chemicals associated with groundwater generally move more slowly than the velocity of the groundwater. They are retarded by sorption to the soil to an extent expressed as a "retardation factor," which is essentially the ratio of (a) the amount of chemical that is sorbed to the solid matrix to (b) the amount that is in solution. Sorption of organic chemicals is usually accomplished preferentially to organic matter; however, clays also have considerable sorptive capacity, especially when dry. Polar, and especially ionic, substances may interact strongly with mineral matter. The characterization of migration of chemicals in groundwater is difficult, and especially so when a chemical is present in an non-aqueous phase, for example, as a bulk oil or emulsified oil phase. Considerable effort has been devoted to understanding the fate of nonaqueous phase liquids (NAPLs) such as oils, and dense NAPLs (DNAPLs) such as chlorinated solvents that can sink in the aquifer and are very difficult to recover.

For illustrative purposes, we treat the soil as covering an area 1000 m x 300 m x 15 cm deep, which is about the depth to which agricultural soils are plowed. This yields a volume of 45,000 m$^3$. This consists of about 50% solids, of which 4% is organic matter content or 2% by mass organic carbon. The porosity of the soil, or void space, is 50% and consists of 20% air and 30% water. Assuming a density of the soil solids of 2400 kg/m$^3$ and water of 1000 kg/m$^3$ gives masses of 1200 kg solids and 300 kg water per m$^3$ (and a negligible 0.2 kg air), totaling 1500 kg, corresponding to a bulk density of 1500 kg/m$^3$. Rainwater falls on this soil at a rate of 0.8 m per year, i.e., 0.8 m$^3$/m$^2$ year. Of this, perhaps 0.3 m evaporates, 0.3 m runs off, and 0.2 m percolates to depths and contributes to groundwater flow. This results in water fluxes of 90,000 m$^3$/year by evaporation, 90,000 m$^3$/year by runoff, and 60,000 m$^3$/year by percolation to depths totaling 240,000 m$^3$/year. With the runoff is associated 90 m$^3$/year of solids, i.e., an assumed high concentration of 0.1% by volume. Again, it must be emphasized that these numbers are entirely illustrative.

This soil runoff rate of 90 m$^3$/year does not correspond to the deposition rate of 700 m$^3$/year, partly because of the contribution of organic matter generated in the water column, but mainly because of the low ratio of soil area to water area.

### 4.5.3 Terrestrial Vegetation

Until recently, most environmental models have ignored terrestrial vegetation. The reason for this is not that vegetation is unimportant, but rather that modelers currently have enormous difficulty calculating the partitioning of chemicals into plants. This topic is receiving more attention as a result of the realization that consumption of contaminated vegetation, either by humans, domestic animals, or wildlife, is a major route or vector for the transfer of toxic chemicals from one

...
species to another, and ultimately to humans. Plants play a critical role in stabilizing soils and in inducing water movement from soil to the atmosphere, and they may serve as collectors and recipients of toxic chemicals deposited or absorbed from the atmosphere. They can also degrade certain chemicals and increase the level of microbial activity in the root zone, thus increasing the degradation rate in the soil.

Amounts of vegetation, in terms of quantity of biomass per square metre, vary enormously from near zero in deserts to massive quantities that greatly exceed accessible soil volumes in tropical rain forests. They also vary seasonally. If it is desired to include vegetation, a typical “depth” of plant biomass might be 1 cm. This, of course, consists mainly of water, cellulose, starch, and ligneous material. There is little doubt that future, more sophisticated models will include chemical partitioning behavior into plants. But at the present state of the art, it is convenient (and rather unsatisfactory) to regard the plants as having a volume of 3000 m³, containing the equivalent of 1% lipid-like material and 50% water.

We ignore vegetation in the simple four-compartment model, treating the soil as only a simple solid phase.

### 4.6 SUMMARY

These evaluative volumes, areas, compositions, and flow rates are summarized in Table 4.2. From them is derived a simple four-compartment version. Also suggested is an alternative environment that is more terrestrial and less aquatic, and it reflects more faithfully a typical political jurisdiction. It is emphasized again that the quantities are purely illustrative, and site-specific values may be quite different. All that is needed at this stage is a reasonable basis for calculation.

Scientists who have devoted their lives to studying the intricacies of the structure, composition, and processes of the atmosphere, hydrosphere, or lithosphere will undoubtedly be offended at the simplistic approach taken in this chapter. The environment is very complex, and it is essential to probe the fine detail present in its many compartments. But, if we are to attempt broad calculations of multimedia chemical fate, we must suppress much of the media-specific detail. When the broad patterns of chemical behavior are established, it may be appropriate to revisit the media that are important for that chemical and focus on detailed behavior in a specific medium. At that time, a more detailed and site-specific description of the medium of interest will be justified and required.

Our philosophy is that the model should be only as complex as is required to answer the immediate question, not every question that could be asked. As questions are answered, new questions will surface and new, more complex models can be developed to answer these questions.

### 4.7 CONCLUDING EXAMPLE

Select a region with which you are familiar; for example, a county, watershed, state, or province. Calculate the volumes of air to a height of 1000 m; soil to a depth
## Table 4.2 Evaluative Environments

### A. Four-compartment, 1 km² environment

<table>
<thead>
<tr>
<th>Areas (m²)</th>
<th>Volumes (m³)</th>
<th>Densities (kg/m³)</th>
<th>Compositions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air–water</td>
<td>7 × 10⁴</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Air–soil</td>
<td>3 × 10⁴</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water–sediment</td>
<td>7 × 10⁵</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depths (m)</th>
<th>Volumes (m³)</th>
<th>Densities (kg/m³)</th>
<th>Compositions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>6000</td>
<td>6 × 10⁴</td>
<td>1.2</td>
</tr>
<tr>
<td>Water</td>
<td>10</td>
<td>7 × 10⁴</td>
<td>1000</td>
</tr>
<tr>
<td>Soil</td>
<td>0.16</td>
<td>4.5 × 10⁴</td>
<td>1500</td>
</tr>
<tr>
<td>Sediment</td>
<td>0.03</td>
<td>2.1 × 10⁴</td>
<td>1500</td>
</tr>
</tbody>
</table>

### B. Eight-compartment, 1 km² environment, areas as in A above

<table>
<thead>
<tr>
<th>Volumes (m³)</th>
<th>Densities (kg/m³)</th>
<th>Compositions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>6 × 10⁴</td>
<td>1.2</td>
</tr>
<tr>
<td>Water</td>
<td>7 × 10⁵</td>
<td>1000</td>
</tr>
<tr>
<td>Soil (50% solids, 20% air, 30% water)</td>
<td>4.5 × 10⁴</td>
<td>1500</td>
</tr>
<tr>
<td>Sediment (30% solids)</td>
<td>2.1 × 10⁴</td>
<td>1500</td>
</tr>
<tr>
<td>Suspended Sediment</td>
<td>35</td>
<td>1500</td>
</tr>
<tr>
<td>Aerosols</td>
<td>0.12</td>
<td>1500</td>
</tr>
<tr>
<td>Aquatic Biota</td>
<td>7</td>
<td>1000</td>
</tr>
<tr>
<td>Vegetation</td>
<td>3000</td>
<td>1000</td>
</tr>
</tbody>
</table>

Rain Rate: 0.8 m/year or 800,000 m³/year; 660,000 m³ to water; 240,000 m³ to soil

Aerosol Deposition Rates (total)
- Dry deposition: 216 × 10⁻⁶ m³/h or 1.89 m³/year
- Wet deposition: 365 × 10⁻⁶ m³/h or 3.2 m³/year

Sediment Deposition Rates
- Deposition: 700 m³/year solids 17% OC
- Resuspension: 280 m³/year solids 17% OC
- Net deposition (burial): 267 m³/year solids 5% OC

Rate of Water in Soil
- Evaporation: 90,000 m³/year
- Runoff to water: 90,000 m³/year
- Percolation to groundwater: 60,000 m³/year
- Solids runoff: 90 m³/year
Table 4.2 (continued)

C. Regional, 100,000 km² environment as used in the EGC model of Mackay et al. (1996b)

<table>
<thead>
<tr>
<th></th>
<th>Volume (m³)</th>
<th>Area (m²)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>10¹²</td>
<td>100 X 10²</td>
<td></td>
</tr>
<tr>
<td>Aerosols</td>
<td>2000</td>
<td>-</td>
<td>(2 X 10⁻¹¹ vol fr)</td>
</tr>
<tr>
<td>Water</td>
<td>2 X 10¹¹</td>
<td>10 X 10⁸</td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>9 X 10⁸</td>
<td>90 X 10⁶</td>
<td>2% OC</td>
</tr>
<tr>
<td>Sediment</td>
<td>10⁹</td>
<td>10 X 10⁶</td>
<td>4% OC</td>
</tr>
<tr>
<td>Suspended sediment</td>
<td>10⁶</td>
<td>-</td>
<td>20% OC</td>
</tr>
<tr>
<td>Fish</td>
<td>2 X 10⁵</td>
<td>-</td>
<td>5% lipid</td>
</tr>
</tbody>
</table>

For details of other properties see Mackay et al. 1996b.

of 10 cm; water and bottom sediment to a depth of 3 cm, and vegetation. Obtain data on average temperature, rain rate, water flows, and wind velocity, and calculate air and water residence times. Attempt to obtain information on typical concentrations of aerosols, suspended solids in water, and the organic carbon contents of soils, bottom, and suspended sediments. Prepare a summary table of these data similar to Table 4.2.

These basic environmental data can be used in subsequent assessments of the fate of chemicals in this region.