WORKING IT OUT 3.2

Average Residence Time (ART)

The *average residence time* (ART) for a chemical element or compound is an important concept in evaluating many environmental problems. ART is defined as the ratio of the size of a reservoir or pool of some material—say, the amount of water in a reservoir—to the rate of transfer through the reservoir. The equation is

$$\text{ART} = S/F$$

where S is the size of the reservoir and F is the rate of transfer.

Knowing the ART for a particular chemical in the environment—as, for example, a pollutant in the air, water, or soil—allows for a more quantitative understanding of that pollutant. We can better evaluate the nature and extent of the pollutant in time and space, assisting the development of strategies to reduce or eliminate the pollutant.

Let's look at a simple example. Figure 3.13 shows a map of Big Lake, a reservoir of water impounded by a dam. The lake has three rivers that feed a combined 10 m^3/sec of water into the lake, and the outlet structure releases an equal 10 m^3/sec. We assume evaporation of water from the lake is negligible in this simplified example. A water pollutant, MTBE (methyl tertiary-butyl ether), is also present in the lake. MTBE is added to gasoline to help reduce emissions of carbon monoxide. It is toxic; in small concentrations of 20–40 µg/l (thousandths of grams per liter) in water, it smells like turpentine and is nauseating to some people. MTBE readily dissolves in water and so travels with it. Sources of MTBE in Big Lake are urban runoff from Bear City gasoline stations, gasoline spills on land or in the lake, and boats in the lake with gasoline-burning engines. Concern over MTBE in California has led to the decision to stop adding it to gasoline. We can ask several questions concerning the water and MTBE in Big Lake.

1. What is the ART of water in the lake?
2. What is the amount of MTBE in the lake, the rate (amount per time) of MTBE being put into the lake, and the ART of MTBE in the lake? Because the water and MTBE move together, their ARTs should be the same—we can verify this.

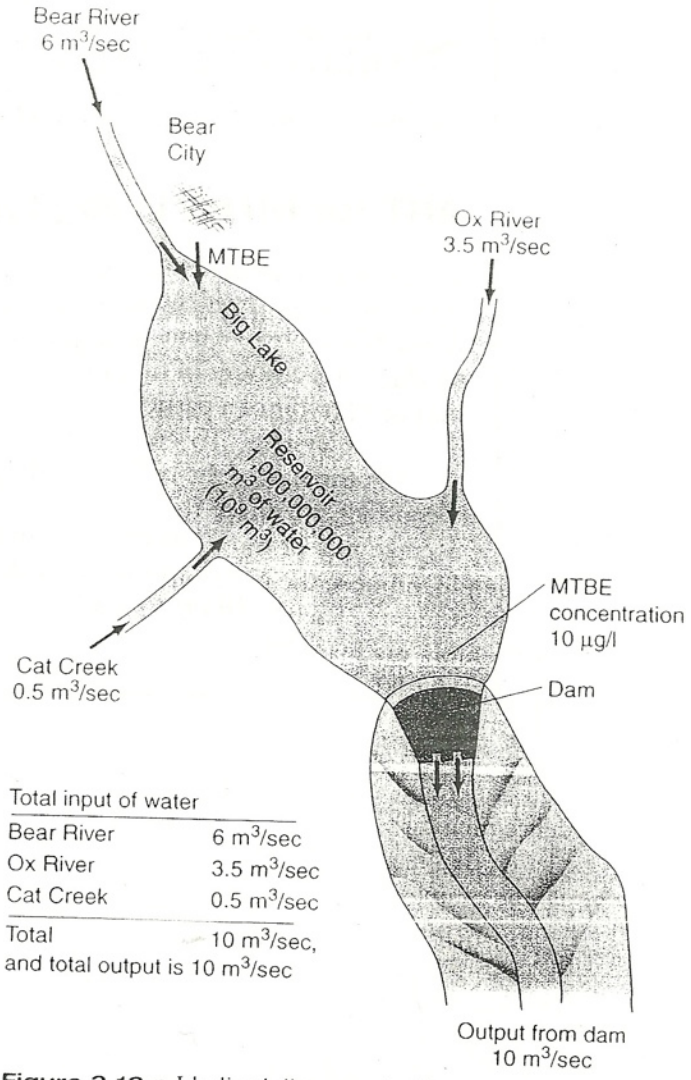

Figure 3.13 ■ Idealized diagram of a lake system with MTBE contamination.

ART of Water in Big Lake

For these calculations, use multiplication factors and conversions in Appendices B and C at the end of this book.

$$\text{ART}_{\text{water}} = \frac{S}{F} = \text{ART}_{\text{water}} = \frac{1{,}000{,}000{,}000\ \text{m}^3}{10\ \text{m}^3/\text{sec}}$$

$$\text{or } \frac{10^9\ \text{m}^3}{10\ \text{m}^3/\text{sec}}$$

The units m^3 cancel out and

$$\text{ART} = 100{,}000{,}000 \text{ sec or } 10^8 \text{ sec}$$

Convert 10^8 sec to years:

$$\frac{\text{seconds}}{\text{year}} = \frac{60\ \text{sec}}{1\ \text{minute}} \times \frac{60\ \text{minute}}{1\ \text{hour}} \times \frac{24\ \text{hour}}{1\ \text{day}} \times \frac{365\ \text{day}}{1\ \text{year}}$$

Canceling units and multiplying, there are 31,536,000 sec/year, which is

$$3.1536 \times 10^7 \text{ sec/year}$$

(*Continued*)

Then the ART for Big Lake is

$$\frac{100{,}000{,}000 \text{ sec}}{31{,}536{,}000 \text{ sec/yr}} \quad \text{or} \quad \frac{10^8 \text{ sec}}{3.1536 \times 10^7 \text{ sec/yr}}$$

The ART for water in Big Lake is 3.17/year.

ART for MTBE in Big Lake

Concentration of MTBE in water near the dam is measured as 10 μg/l. Then the total amount of MTBE in the lake (size of reservoir or pool of MTBE) is the product of volume of water in the lake and concentration of MTBE:

$$10^9 \text{ m}^3 \times \frac{10^3 \text{ l}}{\text{m}^3} \times \frac{10 \text{ μg}}{\text{l}} = 10^{13} \text{ μg or } 10^7 \text{ g}$$

which is 10^4 kg, or 10 metric tons, of MTBE.

The output of water from Big Lake is 10 m^3/sec, and this contains 10 μg/l of MTBE; the transfer rate of MTBE (g/sec) is

$$\text{MTBE/sec} = \frac{10 \text{ m}^3}{\text{sec}} \times \frac{10^3 \text{ l}}{\text{m}^3} \times \frac{10 \text{ μg}}{\text{l}} \times \frac{10^{-6} \text{ g}}{\text{μg}}$$

$$= 0.1 \text{ g/sec}$$

Because we assume that input and output of MTBE are equal, the input is also 0.1 g/sec.

$$\text{ART}_{\text{MTBE}} = \frac{S}{F} = \frac{10^7 \text{ g}}{0.1 \text{ g/sec}} = 10^8 \text{ sec, or } 3.17 \text{ years}$$

Thus, as we suspected, the ARTs of the water and MTBE are the same. This results because MTBE is dissolved in the water. If it attached to the sediment in the lake, the ART_{MTBE} would be much longer. Chemicals with large reservoirs or small rates of transfer tend to have long ARTs. In this exercise we have calculated the ARTs of water in Big Lake as well as the input, total amount, and ART of MTBE.