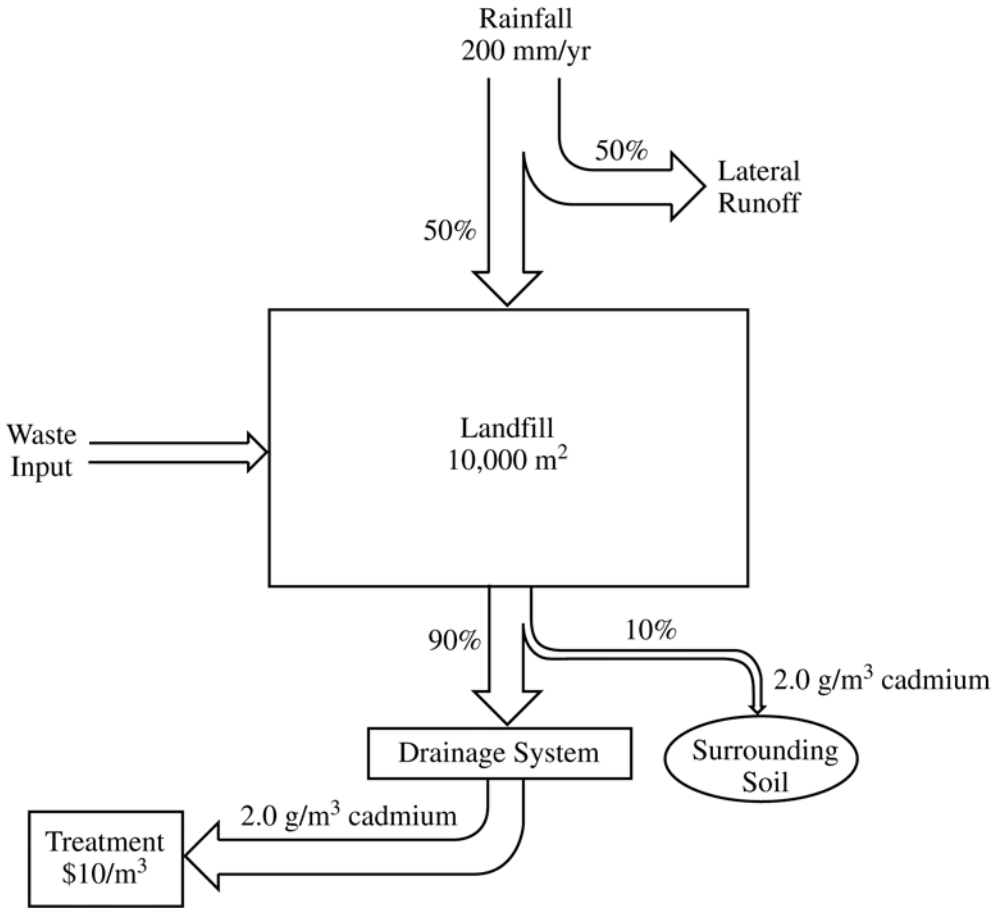

2. The city of Fremont operates a municipal solid-waste landfill. As represented in the diagram above, the annual precipitation in Fremont is 200 mm/year: 50 percent of this water infiltrates through the landfill cover soil into the waste, and 50 percent drains off the landfill. A drainage system withdraws 90 percent of the leachate generated within the landfill for treatment. The rest of the leachate travels through the bottom liner of the landfill into the surrounding soil. Most of the cadmium disposed of in the landfill remains in the landfill; the leachate withdrawn from the landfill by the drainage system has an average cadmium concentration of 2.0 g/m^3. Pumped to a treatment station, the leachate is treated at a cost of \$10/m^3.

   (a) Calculate the volume, in m^3, of each of the following:

      (i) The water infiltrated through the landfill per year

      (ii) The leachate that is treated per year

   (b) Given that the cadmium concentration in the water draining from the landfill is 2.0 g/m^3, calculate the mass, in kg, of cadmium that is released into the surrounding soil per year.

   (c) What is the annual cost of treating the leachate from the drainage system?

   (d) Discuss TWO viable methods for reducing the amount of cadmium entering the municipal waste input.

   (e) Explain a shortcoming of ONE of the methods that you identified in part (d).

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Question 2

(a) Calculate the volume, in m^3, of each of the following:

(Two points can be earned in each of parts (a)(i) and (a)(ii): 1 point for a correct setup, and 1 point for the correct answer.)

(i) The water infiltrated through the landfill per year

$$200 \text{ mm rain} \times \frac{1 \text{ m}}{1{,}000 \text{ mm}} = 0.2 \text{ m rain}$$

$$\frac{10{,}000 \text{ m}^2 \mid 0.2 \text{ m} \mid \text{50\% infiltrated water}}{\mid \mid \text{100\% water}} = \mathbf{1{,}000\ m^3}$$

(ii) The leachate that is treated per year

$$1{,}000 \text{ m}^3 \times 0.9\ (90\%) = \mathbf{900\ m^3}$$

Note: If the answer to (a)(i) is incorrect, then 0.9 times that answer still earns full credit in (a)(ii).

(b) Given that the cadmium concentration in the water draining from the landfill is 2.0 g/m^3, calculate the mass, in kg, of cadmium that is released into the surrounding soil per year.

(Two points can be earned: 1 point for the correct setup, and 1 point for the correct answer.)

Note: The student can either begin with the difference between the answers for (a)(i) and (a)(ii) or take 10 percent of the answer from (a)(i). Metric conversions do not necessarily have to be shown.

$$\frac{100 \text{ m}^3 \text{ drainage water} \mid 2.0 \text{ g Cd} \mid 1 \text{ kg}}{1 \text{ year} \mid 1 \text{ m}^3 \mid 1{,}000 \text{ g}} = \mathbf{0.2\ kg\ Cd/year}$$

(c) What is the annual cost of treating the leachate from the drainage system?

(Two points can be earned: 1 point for the correct setup, and 1 point for the correct answer.)

Note: The student must use the answer from (a)(ii).

$$\frac{900 \text{ m}^3 \text{ treatable leachate} \mid \$10}{\mid 1 \text{ m}^3 \text{ leachate}} = \mathbf{\$\ 9{,}000\ year}$$

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Question 2 (continued)

(d) Discuss TWO viable methods for reducing the amount of cadmium entering the municipal waste input.

(Two points can be earned: 1 point for a discussion of each viable method. Only the first two methods are scored.)

Category of Reduction	Method or Action
Disposal options	• Sort waste stream for cadmium-containing products (batteries, e-waste, paints and pigments, stabilizers, pesticides) headed to landfills • Deposit these materials at a dropoff site or recycling facility, or return to manufacturer
New/substitute technology or alternate materials	Avoid use of cadmium-containing products by: • using rechargeable batteries (e.g., lithium rechargeable) • applying new technology and/or alternate materials that do not use cadmium
Incentives and/or disincentives	• Place restrictions on disposal of materials that contain cadmium (batteries, e-waste, paints and pigments, stabilizers, pesticides) • Pass cradle-to-grave (RCRA) legislation • Provide rebate incentives for using cadmium-free products • Provide incentives for manufacturing cadmium-free products (e.g., research grants) • Place a deposit (payable on return) or surcharge on cadmium-containing products
Education	Make the public aware of (any one of the following): • concerns (health, environmental) associated with cadmium • methods of cadmium-containing product/battery reduction/recycling • availability of new/substitute technology

Question 2 (continued)

(e) Explain a shortcoming of ONE of the methods that you identified in part (d).

(One point is earned for an explanation that is linked to an accepted method described in part (d).)

Difficulty and/or expense identified with:

- educating the public about benefits of recycling waste that contains cadmium
- providing efficient systems for cadmium waste pickup (recycling/reuse)
- sorting
- achieving 100 percent cadmium removal from waste or 100 percent replacement
- safe disposal, new technology, and substitute material development
- enforcement/regulations/compliance
- recycling (e.g., energy requirements)
- determining if a product contains cadmium