1) Risk of drinking toxicane

(a) Incremental cancer risk.

Risk in Malasuerte $= \frac{30 \text{ cases}}{36{,}000 \text{ people}} = 8.33 \times 10^{-4}$

Risk in Buenafortuna $= \frac{6 \text{ cases}}{36{,}000 \text{ people}} = 1.67 \times 10^{-4}$ ... "background"

Incremental lifetime risk $= 8.33 \times 10^{-4} - 1.67 \times 10^{-4} = \underline{\underline{6.7 \times 10^{-4}}}$

(b) Slope factor

Lifetime risk = CDI * slope factor

We know risk from part (a) ... if we know CDI, we can get the slope factor

$$CDI = \frac{(2\ L/d)(0.100\ mg/L)}{70\ kg} \cdot \frac{40\ yrs}{70\ yrs} \cdot \frac{350\ d}{365\ d} = 0.001566\ \frac{mg}{kg \cdot d}$$

Assumptions: person drinks 2 L/d of contaminated water;
person drinks the water 350 d each year
(out of town for the other 15 days)

Risk = CDI * slope factor

$$(6.67 \times 10^{-4}) = \left(0.001566\ \frac{mg}{kg \cdot d}\right)(SF)$$

$$\underline{\underline{SF = 0.43\ (mg/kg \cdot d)^{-1}}}$$ ... OK if you got 0.42 due to rounding

ALTERNATE VERSIONS:

v2) $Risk = \frac{40}{36{,}000} - \frac{8}{36{,}000} = \frac{32}{36{,}000} = 8.9 \times 10^{-4}$

$CDI = \frac{(2)(0.1)}{(70)}\left(\frac{35}{70}\right)\left(\frac{350}{365}\right) = 1.37 \times 10^{-3}\ mg/kg \cdot d$

$SF = (8.889 \times 10^{-4}) / (1.37\ mg/kg \cdot d) = 0.65\ (mg/kg \cdot d)^{-1}$

v3) $Risk = \frac{50}{36{,}000} - \frac{9}{36{,}000} = \frac{41}{36{,}000} = 1.1 \times 10^{-3}$

$CDI = \frac{(2)(0.1)}{(70)}\left(\frac{25}{70}\right)\left(\frac{350}{365}\right) = 9.785 \times 10^{-4}\ mg/kg \cdot d$

$SF = (1.139 \times 10^{-3}) / (9.785 \times 10^{-4}\ \frac{mg}{kg \cdot d}) = 1.2\ (mg/kg \cdot d)^{-1}$ ... OK if you said 1.1

2) Oxygen depletion in Jensen River

ⓐ River velocity

We know the dead zone occurs at a downstream <u>distance</u> of 25 km.

What <u>travel time</u> corresponds to that distance?

Then we can just say $U = x/t$ !

So use Streeter-Phelps equation

$$t_{crit} = \frac{1}{k_2 - k_1} \ln \left\{ \frac{k_2}{k_1} \left[ 1 - \frac{D_0 (k_2 - k_1)}{k_1 L_0} \right] \right\}$$

Given $k_2 = 0.45\ d^{-1}$

$k_1 = 0.20\ d^{-1}$

$L_0 = 20.0\ mg/L$

How about $D_0$?

$T = 22°C$

$[O_2]^{sat} = 8.83\ mg/L$ from p. 2

$[O_2]_{x=0} = 7.00\ mg/L$

$D_0 = 1.83\ mg/L$

$$t_{crit} = \frac{1}{0.45\ d^{-1} - 0.20\ d^{-1}} \ln \left\{ \frac{0.45\ d^{-1}}{0.20\ d^{-1}} \left[ 1 - \frac{(1.83 \frac{mg}{L})(0.25\ d^{-1})}{(20 \frac{mg}{L})(0.20\ d^{-1})} \right] \right\}$$

$= 2.758\ d$

So river takes 2.758 d to travel 25 km

$U = (25\ km)/(2.758\ d) = \underline{\underline{9.1\ km/d}}$ river velocity

(b) Concentration of D.O. in the dead zone

$$D = \frac{k_1 L_0}{k_2 - k_1}\left[e^{-k_1 t} - e^{-k_2 t}\right] + D_0 e^{-k_2 t}$$

$$D = \frac{(0.20\ d^{-1})(20.6\ mg/L)}{(0.45\ d^{-1} - 0.20\ d^{-1})}\left[e^{-(0.20\ d^{-1})(2.758\ d)} - e^{-(0.45\ d^{-1})(2.758\ d)}\right]$$

$$+ \left(1.83\ \frac{mg}{L}\right) e^{-(0.45\ d^{-1})(2.758\ d)}$$

$$D = (16\ mg/L)(0.57603 - 0.28907) + (1.83\ mg/L)(0.28907)$$

$D = 5.12\ mg/L$ at the dead zone

$$[O_2] = 8.83\ mg/L - 5.12\ mg/L$$

$$= \underline{\underline{3.71\ mg/L}}$$ in the dead zone

(apparently this concentration of D.O. is low enough that all the fish moved out of the neighborhood)

3) Filtration of river water with granular media

Given $Q = 3.1 \times 10^6 \frac{L}{hr} = 0.861\ m^3/s$

Divide Q into n filters operating in parallel

Flow rate thru each filter is $Q/n$.

The area A of each filter is $25\ m^2$.

The "filter velocity" through each filter is therefore $V = \frac{Q/n}{A}$.

We know Q, we know A ... if we can get V, then we can calculate n.

Use Ergun equation

$$\Delta h = K_V \left(\frac{V L}{d^2}\right) \frac{(1-\epsilon)^2}{\epsilon^3} \frac{\mu}{\rho g} + K_I \left(\frac{L V^2}{d g}\right) \frac{(1-\epsilon)}{\epsilon^3}$$

We know the max allowable $\Delta h = 1.0\ m$

Assume $K_V = 113$ $K_I = 2.3$ for sand ... You may have chosen other values, that's ok if you stated it clearly

We know $L = 0.80\ m$

$d = 0.40\ mm = 4.0 \times 10^{-4}\ m$

$\mu = 1.002 \times 10^{-3}\ kg/(m \cdot s)$ at $20°C$

$\rho = 998.2\ kg/m^3$ at $20°C$

$g = 9.81\ m/s^2$

$\epsilon = 0.42$ when filter is clean

$$1.0\ m \geq (113)\, V \frac{(0.80\ m)}{(4.0 \times 10^{-4}\ m)^2} \frac{(1-0.42)^2}{(0.42)^3} \frac{(1.002 \times 10^{-3}\ kg/m \cdot s)}{(998\ kg/m^3)(9.81\ m/s^2)}$$

$$+ (2.3)\, V^2 \frac{(0.80\ m)}{(4.0 \times 10^{-4}\ m)(9.81\ m/s^2)} \frac{(1-0.42)}{(0.42)^3}$$

$$1.0\ m \geq (262.5\ s^{-1})\, V + (3671\ s^{-2}\, m^{-1})\, V^2$$

So if we have V in units m/s, we have

$$3671\, V^2 + 262.5\, V - 1 \leq 0$$

$$V_{crit} = \frac{-262.5 + \sqrt{(262.5)^2 - (4)(3671)(-1)}}{(2)(3671)} = 0.003626\ \frac{m}{s}$$

So to maintain $\Delta h \le 1.0$ m, choose $V \le 0.003626$ m/s

Thus $\dfrac{Q/n}{A} \le 0.003626 \, \dfrac{m}{s}$

Re-arranging, $n \ge \dfrac{Q/A}{0.003626 \text{ m/s}}$

$$n \ge \frac{(0.861 \text{ m}^3/\text{s}) / (25 \text{ m}^2)}{0.003626 \text{ m/s}} \Rightarrow n \ge 9.5$$

$\boxed{\text{Operate at least } \underline{\underline{10}} \text{ filters in parallel to ensure that the clean-filter head loss is less than 1.0 m}}$

Alternate versions of the question — Note: there were different versions of this question.

If $d_g = 0.5$ mm instead of 0.4 mm,

$2937 \, v^2 + 168 \, v - 1 \le 0$

$v \le 0.005436$ m/s

$n \ge (0.0344 \text{ m/s}) / (0.005436 \text{ m/s}) \Rightarrow n \ge 6.3$

Operate at least $\underline{7}$ filters in parallel

If $d_g = 0.6$ mm instead of 0.4 mm or 0.5 mm,

$2447 \, v^2 + 117 \, v - 1 \le 0$

$v \le 0.007417$ m/s

$n \ge (0.0344 \text{ m/s}) / (0.007417 \text{ m/s}) \Rightarrow n \ge 4.6$

Operate at least $\underline{\underline{5}}$ filters in parallel

By the way ... in practice, typical filter velocities are 5-15 $\frac{m}{hr}$, which is equivalent to 0.0014 – 0.0042 m/s. For this problem, that would correspond to 8-25 filters operating in parallel. So the estimate of 10 is pretty reasonable. The others might be a little low.