PROBLEMS

Answers to odd-numbered problems will appear at the end of the book.

1. A farmer has a reservoir with vertical sides and a surface area of 2.5 ac. Following the rainy season, the reservoir is filled to a depth of 3.0 m. During the dry season, the reservoir loses 2.5 in. of water per week (wk) to evaporation. If the average irrigation demand during the dry season is 0.23 ac-ft per day, for how many weeks can the farmer irrigate from the reservoir? **3.6 weeks**

2. How long must a pump with a capacity of 12 gal/min pump to fill a tank with a capacity of 37 m³? **13.6 hr**

3. A circular water transmission pipe has a diameter of 1.0 ft and is 8.3 mi long. How much water does it take to fill the pipe? **117.5 m³**

4. If the water is flowing into the pipe of Problem 3 at a velocity of 1.3 feet per second (ft/s), what is the rate at which the pipe is transmitting water? **0.03 m³/sec**

5. A small urban watershed has an area of 16.34 mi². A summer storm drops an average of 1.50 in. of rain over the entire watershed. If 50% of the rainfall runs off the watershed into surface-water bodies, what is the volume of runoff?
   A. In cubic inches? **4,920,000,000 ft³**
   B. In cubic feet? **135,200,000 ft³**
   C. In cubic meters? **6,070,000 m³**

1.1. The annual evaporation from a lake, with a surface area of 1600 hectares, is 3 meters. Determine the average daily evaporation rate in hectare-centimeters per day during the year. **135.2 ha-cm/day**

1.2. Rainfall takes place at an average intensity of 1 cm/h over a 250-hectare area for 3 days. Determine the average rate of rainfall in cubic meters per second (m³/s). Determine the 3-day volume of rainfall in hectare-cm and hectare-meters. Also determine the 3-day volume of rainfall in centimeters of equivalent depth over the 250-hectare area. **1.86 x 10⁷ m³**

1.3. Water is to be supplied from a reservoir fed by a stream with a discharge of 2 m³/s to meet domestic requirements of an area with a population of 150,000. The average daily consumption is 300 liters per person. The lowest discharge of the stream is 0.25 m³/s for a period of 15 days. Determine the reservoir size in km³ and the rate of outflow when the reservoir is full. **Minimum reservoir size = 35,100 m³ = 0.00351 km³**

1.4. Compute the time required to fill the reservoir in Exercise 1.3 when the demand of the population is being simultaneously fed by the stream and the reservoir is empty after a drought period. The stream discharge is 1.75 m³/s. **331 days = 79,331 hours**

1.5. An area is being irrigated by a stream with a drainage area of 300 km². The drainage area contribution is 0.1 m³/s/km². Determine the discharge of the channel and the area irrigated if 0.37 m³/s are required per 1000 hectares. **Channel Q = 50 m³/sec**

1.6. The average monthly precipitation in a watershed of 4500 km² is 46 cm. If the cumulative losses are 20% of precipitation, determine the area of Exercise 1.5 that can be irrigated with the remaining water. Also calculate the channel discharge.

1.7. Estimate the storage capacity of a reservoir for Exercise 1.6 when the average precipitation is 28 cm for a period of 20 days. The area calculated above is to be continuously supplied with its full demand. **1.0 x 10⁶ m³**

1.8. Water is to be supplied to an area for both domestic and agricultural purposes. The population is 200,000 and the area to be irrigated is 3600 hectares. Water is to be pumped from the river. If the average daily consumption is 320 liters per person and the agricultural demand 0.33 m³/s/1000 hectares, find the number of pumps required when 30% of the pumps are required to be standby. Also calculate the minimum discharge in the river to meet the above demand. The individual pump capacity is 0.1 m³/s. **Total pumps needed = 27 (19 active, 8 standby); Minimum river Q = 1.93 m³/sec**
The map above shows an outline of a drainage basin or watershed. The data points represent locations of rain gage stations. The numbers show the total 24-hour rainfall amounts (inches) for each station. Draw an isohyetal contour map (contour map with lines connecting points of equal rainfall) using a contour interval of 0.5 inches (i.e. draw contour lines for the following isohyets: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5). Remember to follow the rules of contour and to interpolate the lines between data points as necessary.

Calculate the following data parameters for the watershed:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum 24-hour Rainfall Recorded</td>
<td>5.76 in</td>
</tr>
<tr>
<td>Minimum 24-hour Rainfall Recorded</td>
<td>0.09 in</td>
</tr>
<tr>
<td>Average 24-hour Rainfall Recorded</td>
<td>3.27</td>
</tr>
<tr>
<td>Standard Deviation of 24-hour Rainfall Rec'd</td>
<td>1.90</td>
</tr>
<tr>
<td>Median of 24-hour Rainfall Recorded</td>
<td>1.75</td>
</tr>
<tr>
<td>Total Number of Gage Stations</td>
<td>13</td>
</tr>
</tbody>
</table>
Environmental Geology Lab 1 - Watershed Rainfall Data

<table>
<thead>
<tr>
<th>24-hr Rainfall (in)</th>
<th>Minimum Value</th>
<th>Median Value</th>
<th>Maximum Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.09</td>
<td></td>
<td>1.75</td>
<td>5.76</td>
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<tr>
<td>0.21</td>
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<td>0.46</td>
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<td>1.03</td>
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<td>3.45</td>
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<td>3.86</td>
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<tr>
<td>4.11</td>
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<td></td>
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<tr>
<td>4.81</td>
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<td></td>
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<tr>
<td>5.76</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Sum: 29.53
- Total N: 13
- Mean: 2.27
- Standard Deviation: 1.90
- Median: 1.75
Environmental Geology - Lab 1

Step 1 - Convert all units to metric! (Use Conversion Charts)

1. Surface Area = 2.5 ac

   Dry Season Evap. = 2.5 m³/wk

   Water Depth After Rainy Season = 3 m

   Reservoir Surface Area = 2.5 ac \( \times \frac{4047 \text{ m}^2}{\text{ac}} = 101,175 \text{ m}^2 \)

   Reservoir Water Depth = 3 m

   Reservoir Water Volume = Area \times Depth = (101,175 \text{ m}^2)(3 \text{ m}) = 303,525 \text{ m}^3

   Dry Season Evaporation Rate = \( \frac{2.5 \text{ m}^3}{\text{wk}} \times \frac{0.0254 \text{ m}}{\text{m}^3} = 0.0635 \text{ m}^3/\text{wk} \)

   Dry Season Evaporation Volume Loss = (Evap. Rate) \times (Area) = \( (0.0635 \text{ m}^3/\text{wk}) \times 101,175 \text{ m}^2 = 6425 \text{ m}^3/\text{wk} \)

   Dry Season Irrigation Volume Use = \( \frac{0.23 \text{ ac-ft}}{\text{day}} \times \frac{1233.5 \text{ m}^3}{\text{ac-ft}} \times \frac{7 \text{ day}}{\text{wk}} = 1986 \text{ m}^3/\text{wk} \)

Total Volume Reduction per Week = Evaporation Vol. + Irrigation Vol. =

\[ 6425 \text{ m}^3/\text{wk} + 1986 \text{ m}^3/\text{wk} = 8411 \text{ m}^3/\text{wk} \]

Dry Season Life of Reservoir = \( \frac{\text{Initial Vol.}}{\text{Weekly Loss}} = \frac{303,525 \text{ m}^3}{8411 \text{ m}^3/\text{wk}} = 36 \text{ weeks} \)
2) **Step 1 - Convert All Units to Metric!!**

\[
Pump \ Rate = 12 \frac{gal}{min} \times 3.78 \times 10^{-3} \frac{m^3}{gal} = 0.04536 \frac{m^3}{min} = 2.72 \frac{m^3}{hr}
\]

**Tank Volume = 37 m³**

**Time to Fill Tank =** \[
\frac{Tank \ Volume}{Pump \ Rate} = \frac{37 \ m^3}{0.04536 \ m^3/min} = 816 \ min = 13.6 \ hr
\]

3) **Pipe Dimensions**

\[
Pipe \ Diameter = 1.0 \ ft \left(0.3048 \ m \right) = 0.3048 \ m
\]

\[
Pipe \ Length = 1 \ mi \left(1610 \ m \right) = 1610 \ m
\]

**Volume of a Cylinder =** \[
(0.7854 \ m) \left(1610 \ m \right) \left(0.3048 \ m \right)^2 = 117.5 \ m^3
\]

4) This is analogous to calculating water discharge in a stream using the continuity equation:

\[
Q = AV \quad \text{where} \quad Q = \text{discharge}, \ A = \text{cross-sectional area}, \ V = \text{velocity of water flow}
\]

\[
\text{Velocity} = 1.3 \frac{ft}{sec} \left(0.3048 \ m \right) = 0.39 \frac{m}{sec}
\]

**Area of Pipe = Area of Circle =** \[
(0.7854 \ m) \left(0.3048 \ m \right)^2 = 0.073 \ m^2
\]

\[
Q = AV = (0.073 \ m^2) \left(0.39 \ m/sec \right) = 0.03 \ m^3/sec = 0.073 \frac{gal}{min}
\]
Watershed Area = 16,34 m² (2,79 x 10⁷ ft²) = 4,56 x 10⁸ ft²

Avg. Rain = 1.5 in \frac{1 \text{ ft}}{12 \text{ in}} = 0.125 \text{ ft}

Total Rain Volume = (Avg. Precip) (Watershed Area) = (0.125 \text{ ft}) (4,56 x 10⁷ \text{ ft}³) = 5.7 x 10⁷ \text{ ft}³

Runoff = 50% of Total = (0.5) (5.7 x 10⁷ \text{ ft}³) = 2.85 x 10⁷ \text{ ft}³

\text{Runoff} = \left( \frac{2.85 \times 10^7 \text{ ft}^3}{\text{ft}^3} \right) \left( \frac{1728 \text{ in}^3}{\text{ft}^3} \right) = 4.92 \times 10^{10} \text{ in}^3

\text{Runoff} = \left( \frac{2.85 \times 10^7 \text{ ft}^3}{\text{ft}^3} \right) \left( \frac{0.02832 \text{ m}^3}{\text{ft}^3} \right) = 8.07 \times 10^5 \text{ m}^3

Annual Evaporation = 3 \text{ in}

Area = 1600 \text{ ha}

Area of Lake = 1600 \text{ ha}

Annual Evaporation = 3 \text{ m} \left( \frac{100 \text{ cm}}{\text{m}} \right) = 300 \text{ cm/yr}

\text{Daily Evaporation Rate} = \frac{300 \text{ cm}}{\text{yr}} \left( \frac{1 \text{ yr}}{365 \text{ days}} \right) = 0.822 \text{ cm/day}

\text{Daily Evaporation Volume} = (\text{Area})(\text{Evap. Rate}) = (1600 \text{ ha})(0.822 \text{ cm/day}) = 1315.2 \text{ ha-cm/day}
(r.i.) Rainfall Intensity = \( \frac{1 \text{ cm}}{\text{hr}} \left( \frac{1 \text{ m}}{100 \text{ cm}} \right) = 0.01 \text{ m/hr} \)

Area = 250 ha \( \left( \frac{1 \times 10^4 \text{ m}^2}{1 \text{ ha}} \right) = 2.5 \times 10^6 \text{ m}^2 \)

Total Time = \( (3 \text{ days}) \left( \frac{24 \text{ hr}}{\text{day}} \right) = 72 \text{ hr} \)

Hourly Rate of Rainfall = \( (\text{r.i.})(\text{Area}) = 0.01 \text{ m/hr} \times 2.5 \times 10^6 \text{ m}^2 = 25,000 \text{ m}^3/\text{hr} \)

Daily Rate of Rainfall = 25,000 m³ \( \left( \frac{24 \text{ hr}}{\text{day}} \right) = 600,000 \text{ m}^3/\text{day} \)

Rate of Rainfall per Second = \( 25,000 \text{ m}^3/\text{hr} \left( \frac{1 \text{ hr}}{3600 \text{ sec}} \right) = 6.94 \text{ m}^3/\text{sec} \)

3-Day Volume

\( \left( \frac{1 \text{ cm}}{\text{hr}} \right) \left( \frac{72 \text{ hr}}{3 \text{ days}} \right) \frac{250 \text{ ha}}{} = \frac{18,000 \text{ ha-cm}}{3 \text{ days}} \)

\( \left( \frac{0.01 \text{ m}}{\text{hr}} \right) \left( \frac{72 \text{ hr}}{3 \text{ days}} \right) \frac{250 \text{ ha}}{} = \frac{180 \text{ ha-m}}{3 \text{ days}} \)

Equivalent Depth for 3 Days = \( \frac{\text{Total 3-Day Volume}}{\text{Area}} \)

Total 3-Day Volume = \( \frac{1 \text{ cm}}{\text{hr}} \times 72 \text{ hr} \times 18,000 \text{ ha-cm} \)

\( \frac{250 \text{ ha}}{} \)

Equivalent Depth = \( \frac{18,000 \text{ ha-cm}}{250 \text{ ha}} = 72 \text{ cm} \)
Normal Inflow
Reservoir capacity = \(2 \, \text{m}^3 \text{ sec} \div 60 \, \text{sec min} \div 60 \, \text{min hr} \div 24 \, \text{hr day} = 172,800 \, \text{m}^3 \text{ day} \)

Average daily consumption = \(300 \, \text{K person/day} \div 1 \, \text{K person/day} = 0.3 \, \text{m}^3 \text{ person/day} \)

Total daily volume consumption = \(\text{Avg. consumption rate} \times \text{total population} = (0.3 \, \text{m}^3 \text{ person/day}) \times 150,000 \, \text{person} = 45,000 \, \text{m}^3 \text{ day} \)

Minimum Rate of Outflow = Rate of Consumption by People = 45,000 \, \text{m}^3 \text{ day} \)

Lowest rate of Inflow = 0.25 \, \text{m}^3 \text{ sec} \div 8.64 \times 10^4 \, \text{ sec day} = 21,600 \, \text{m}^3 \text{ day} \)

Total volume of Inflow, at lowest rate, over 15 days = \((\text{Rate}) \times \text{Time} = 21,600 \, \text{m}^3 \text{ day} \times 15 \, \text{day} = 324,000 \, \text{m}^3 \)

Total volume consumed over 15 days = \(\frac{45,000 \, \text{m}^3 \text{ day}}{15 \, \text{day}} = 675,000 \, \text{m}^3 \text{ day} \)

Minimum Reserve Capacity = 675,000 \, \text{m}^3 - 324,000 \, \text{m}^3 = 351,000 \, \text{m}^3 \text{ day} \div \frac{1 \, \text{Km}^3}{10^9 \, \text{m}^3} = 0.000351 \, \text{Km}^3 \)

(cont.)
When Reservoir Is Full - and Maintained

At full, the rate of outflow over spillway =
Rate of Inflow from Stream

Stream Inflow = 172,800 m³/day

Outflow = 172,800 m³/day

To maintain the reservoir at full:
The minimum rate of Inflow must
equal the rate of Consumption = 45,000 m³/day

\( \text{Minimum Reservoir Volume} = 351,000 \text{ m}^3 \)

Daily Consumption Rate = 45,000 m³/day

Rate of Stream Inflow = \( 1.75 \text{ m}^3 \left( \frac{8.64 \times 10^4 \text{ sec}}{\text{day}} \right) = 151,200 \text{ m}^3/\text{day} \)

Effective, Net Inflow = Rate of Stream Inflow -
Daily Consumption Rate =

\[ \left( 151,200 \text{ m}^3/\text{day} - 45,000 \text{ m}^3/\text{day} \right) = 106,200 \text{ m}^3/\text{day} \]

Time to Fill Reservoir = \( \frac{\text{Volume}}{\text{Effective Rate}} = \frac{351,000 \text{ m}^3}{106,200 \text{ m}^3/\text{day}} = 3.31 \text{ days} = 79.3 \text{ hrs.} \)
Watershed Area = 300 km²

Unit discharge = 0.1 m³/sec/km²

Channel discharge = (Area) (Unit discharge) =

\[ (300 \text{ km}^2) \times (0.1 \text{ m}^3/\text{sec/km}^2) = 30 \text{ m}^3/\text{sec} \]

Irrigation Rate = \(\frac{1000 \text{ ha}}{0.37 \text{ m}^3/\text{sec}}\)

Area irrigated = (Irrigation Rate) × (Channel Discharge) =

\[ \left(\frac{1000 \text{ ha}}{0.37 \text{ m}^3/\text{sec}}\right) \times 30 \text{ m}^3/\text{sec} = 81,081 \text{ ha} \]

Total watershed area = 4,500 km² \(\left(\frac{10^6 \text{ m}^2}{\text{km}^2}\right)\) = 4.5 \times 10^9 m²

Average monthly precipitation = \(\frac{46 \text{ cm}}{1 \text{ m}}\) \(\frac{1 \text{ m}}{100 \text{ cm}}\) = 0.46 m

Total rainfall volume per month = (Area) (Precip.) =

\[ (4.5 \times 10^9 \text{ m}^2) \times (0.46 \text{ m}) = 2.07 \times 10^9 \text{ m}^3 \]

If 20% of precipitation is lost, then runoff = \(0.8 \times \) (Total monthly vol.)

= \(0.8 \times \frac{2.07 \times 10^9 \text{ m}^3}{\text{MD}}\) = 1.66 \times 10^9 \text{ m}^3/\text{MD}

Channel discharge = \(\left(\frac{1.66 \times 10^9 \text{ m}^3}{\text{MD}}\right)\left(\frac{1 \text{ m}}{30 \text{ days}}\right)\left(\frac{1 \text{ day}}{24 \text{ hr}}\right)\left(\frac{1 \text{ hr}}{60 \text{ min}}\right)\left(\frac{1 \text{ min}}{60 \text{ sec}}\right)\) = 640.4 m²/sec

(Cont.)
1.6 (cont)

Stream Discharge = \( 640.4 \text{ m}^3 \text{ sec} \)

Irrigation Rate Final (1.5) = \( 1000 \text{ ha} \)
\[ \frac{0.37 \text{ m}^3 \text{ sec}}{0.43\text{ m}^3 \text{ sec}} \]

Area irrigated = (Irrigation Rate) \times (Stream 0.15 sec)
\[ \left( \frac{1000 \text{ ha}}{0.37 \text{ m}^3 \text{ sec}} \right) \left( 640.4 \text{ m}^3 \text{ sec} \right) = 1.73 \times 10^6 \text{ ha} \]

1.7

Watershed Area (from 1.6) = \( 4500 \text{ km}^2 \) \( \left( \frac{10^6 \text{ m}^2}{\text{km}^2} \right) = 4.5 \times 10^9 \text{ m}^2 \)

20 Day Precipitation = \( \left( \frac{28 \text{ cm}}{1 \text{ m}} \right) \left( \frac{1 \text{ m}}{100 \text{ cm}} \right) = 0.28 \text{ m} \)

20 Day Total Rain Volume = \( (0.28 \text{ m}) (4.5 \times 10^9 \text{ m}^2) = 1.26 \times 10^9 \text{ m}^3 \)

Remember: of the total volume, only 80% is available as runoff (from 1.6 above)!!

Effective Volume \( = (0.8)(1.26 \times 10^9 \text{ m}^3) = 1.01 \times 10^9 \text{ m}^3 \)

Irrigation Rate = \( 0.37 \text{ m}^3 \text{ sec} \)
\[ \frac{1000 \text{ ha}}{} \]

Total Volume Required for 20 Days \( \frac{0.37 \text{ m}^3 \text{ sec}}{1 \text{ min} \text{ hr} \text{ day}} \)
\[ \frac{1000 \text{ ha}}{1000 \text{ ha}} \]

\( 639360 \text{ m}^3 \)
Area to be irrigated (from 1.6 above) = $1.73 \times 10^6 \text{ ha}$

Total volume to be needed for 20 days =

$$\left( \frac{6.3936 \text{ m}^3}{1000 \text{ ha}} \right) \times (1.73 \times 10^6 \text{ ha}) = 1.11 \times 10^9 \text{ m}^3$$

Total 20 day volume received = $1.01 \times 10^9 \text{ m}^3$

Total 20 day infiltration volume needed = $1.11 \times 10^9 \text{ m}^3$

Reservoir (storage) capacity needed =

$\frac{\text{Required} - \text{Received}}{1.11 \times 10^9 \text{ m}^3 - 1.01 \times 10^9 \text{ m}^3} = 1 \times 10^8 \text{ m}^3$
Population = 200,000
Agricultural Area = 3600 ha

Total Daily Consumption = \( \frac{320 L}{\text{person}} \times \frac{200,000 \text{ people}}{\text{person}} \times \frac{0.001 m^3}{L} \) = 64,000 m³/day

Total Daily Irrigation Volume = \( \frac{0.33 m^3/ sec}{1000 \text{ ha}} \times 3600 \text{ ha} \times 8.64 \times 10^4 \text{ sec/day} \) = 102,643 m³/day

Total Daily Water Required = People + Irrigation = 64,000 m³/day + 102,643 m³/day = 166,643 m³/day

Minimum River Discharge = \( \frac{166,643 \text{ m}^3/ \text{day}}{8.64 \times 10^4 \text{ sec}} \) = 1.93 m³/sec

Pumps Needed: 1 Pump = \( \frac{0.1 \text{ m}^3/ \text{sec}}{8.64 \times 10^4 \text{ sec/day}} \) = 8640 m³/day

\( \frac{166,643 \text{ m}^3/ \text{day}}{8640 \text{ m}^3/ \text{day}} \) = 19 Pumps (Active) / 70%

(0.7)x = 19
x = 27

Total Pumps = 27; Active Pumps = 19
Stand-By Pumps = 8 (30% of Total)