**SOLUTION MANUAL**

**for**

**WATER AND WASTEWATER ENGINEERING**

**Water Supply and Wastewater Removal**

**By**

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**Chapter 1**

**Introduction to Water Systems**

**Problem 1.1**

What is the stream flow in MGD for a catchment area of 80 mile2 where rainfall rate is 45 in. per year and evaporation rate is 20 in. per year?

**Solution:**

Runoff rate (R)

= rainfall rate – evaporation rate

= (45 – 20) in/year

= 25 in/year

Conversion factors:

1 in/year = 1 in.-mile2/(year-mile2)

= 47,600 gpd/mile2

= 0.0476 MGD/mile2

= 17.378 MG/year/mile2

Stream flow with a runoff rate of 25 in/year

= (25) (17.378 MG/year/mile2) (80 mile2)

= 34800 MG/year

**= 95.3 MGD Stream flow**

Evaluation:

R = Q/A

Where

R = runoff rate

Q = stream flow or runoff flow in the watershed, MGD

A = watershed, catchment, or drainage area, mile2

Runoff rate, R = (95.3 MGD) / (80 mile2) = 1.19 MGD/mile2, which is **close to 1.0 MGD/mile2** for a typical

well-watered watershed in North America

**Problem 1.2**

A city is served by a raw water reservoir which has a water surface of 5.8 mile2 and an average effective depth of 18 ft. Determine the water storage volume.

**Solution:**

Conversion factor:

1 ft3 = 7.48 gal

1 mile2 = 27,878,400 ft2

**Water storage volume**

= (5.8 mile2) (27,878,400 ft2/mile2) (18 ft) (7.48 gal/ft3)

= 21.8 x 109 gal

= **21.8 BG**

**Problem 1.3**

The population of a city is 400,000, and the average daily per capita water demand is 150 gallons per capita per day (gpcd). Determine the city’s average daily water demand.

**Solution:**

Average daily water demand, Qave , MGD or gpd

= (population) (average daily per capita water demand)

= (400,000 persons) (150 gpd/person)

= 60,000,000 gpd

= **60 MGD**

**Problem 1.4**

How many days of draft can a raw water reservoir support for a city of 400,000 people? The reservoir has a water surface of 5.8 mile2 and an average effective depth of 18 ft.

**Solution:**

Water storage volume calculated from Problem 1.2

= 21.8 x 109 gal.

Average daily water demand calculated from Problem 1.3

= 60,000,000 gpd

Reservoir’s allowable days of draft

= (21.8 x 109 gal) / (60,000,000 gpd)

= **363 days of draft**.

**Problem 1.5**

What percent of mean annual runoff is to be consumed by a city of 400,000 people in an area with (a) rainfall rate = 45 in/year; (b) evaporation rate = 20 in/year; and (c) watershed catchment or drainage area = 80 mile2?

**Solution:**

Average daily water demand for a city of 400,000 people was calculated in Problem 1.3

= 60 MGD

Annual water consumption per square mile

= (average daily water demand) / (drainage area)

= (60 MGD) / (80 mile2)

= 0.75 MGD/mile2

= 750,000 gpd/mile2

Mean annual runoff calculated from Problem 1.1

= 25 in/year

= 435 MG/year/mile2

= 1,191,780 gpd/mile2

Percent of mean annual runoff consumed by the city

= (annual water consumption per square mile)/(mean annual runoff)

= (750,000 gpd/mile2) / (1,191,780 gpd/mile2)

= 0.63

= **63%**

**Problem 1.6**

Determine the net yield and water storage volume of a rain water system assuming that (a) the net yield of a rain collection facility approximates two-thirds its gross yield; (b) the mean annual rainfall is 25 in/year; (c) the mean annual evaporation rate is 8 in/year; (d) the rain collection roof area equals to 3,200 ft2; and (e) water storage volume equals to 50% of annual net yield.

**Solution:**

The net mean annual rainfall rate

= (25 in – 8 in)/year = 12 in/year

Gross yield per year

= (3,200 ft2) (17/12 ft) (7.48 gal/ft3)

= 33,900 gal/year.

Net yield per year

= (2/3) (33,900 gal/year)

= 22,600 gal/year

= **61.9 gpd**

Recommended water storage volume

= 0.5 (22,600 gal)

= **11,300 gal**

**Problem 1.7**

Determine the storage volume of a new raw water reservoir in accordance with the following given technical information: (a) city population = 400,000; (b) water consumption = 150 gpcd; (c) watershed or catchment area = 80 mile2; (d) rainfall rate = 45 in/year; (e) evaporation rate = 20 in/year; (f) minimum reservoir volume = 50 % annual net yield, or half of a year’s water supply, whichever is greater; (g) 75 % water resources development.

**Solution:**

Reservoir storage volume based on annual net yield

= (45 in/year - 20 in/year) [(0.0476 MGD /mile2) / (1 in/year)] x (0.75) (80 mile2) (0.5 x 365 d)

= (1.19 MGD/mile2) (0.75) (80 mile2) (0.5 x 365 d)

= 13,030 MG

= 13 billion gal

Reservoir storage volume based on water supply

= (400,000 persons) (150 gpd/person) (0.5) (365 d)

= 60,000,000 gpd (0.5) (365 d)

= 10.95 x 109 gal

= 11 billion gal

**Select the greater value of 13 billion gal to be the reservoir storage volume**.

**Problem 1.8**

Determine the number of people who can be sustainably supported by a watershed under the following conditions: (a) watershed area = 80 mile2; (b) annual rainfall rate = 45 in/year; (c) annual evaporation rate = 20 in/year; (d) water resource development = 75 %; (e) raw water reservoir volume to store 50% net annual yield or provide half of a year’s water supply, whichever is higher = 13 billion gal; and (f) water consumption rate = 150 gpcd.

**Solution:**

P = population of a city, which is to be determined.

It is expected that the reservoir will only provide half of a year’s water supply = 0.5 x 365 days

P (150 gpcd) (0.5) (365 d) = 13,000,000,000 gal

Population of a city, which can be adequately supported by the watershed, P

= (13,000,000,000 gal) / [(150 gpcd) (0.5) (365 d)]

= **475,000**

**Problem 1.9**

Determine the number of people that can be adequately supported by a watershed under the following conditions: (a) watershed area = 80 mile2; (b) water supply system with no reservoir for water storage; (c) low-water flow = 0.1 ft3/s or 64,600 gpd per mile2; and (d) water consumption rate = 150 gpcd.

**Solution:**

Population that can be sustained

= (80 mile2) (64,600 gpd/mile2) / (150 gpcd)

= **34,500 people**

**Problem 1.10**

Make a rough estimate of the ground water movement velocity (ft/day) if (a) all the groundwater laterally within 400 ft of the well comes fully within its influence; and (b) the yield of the aquifer is 258 gpm (gallon per minute); and the aquifer through which ground water moves is 25 ft deep.

**Solution:**

Q = (A) (V) (7.48 gal/ft3)

Where

Q = groundwater flow, gpd

A= aquifer cross-sectional area, ft2

V = groundwater moving velocity, ft/d

Groundwater flow = 258 gpm = 371,520 gpd

371,520 gpd = (25 x 2 x 400 ft2) (Vg) (7.48 gal/ft3)

**V** = (371,520) / [(25 x 2 x 400) (7.48)] = **2.48 ft/d**

**Problem 1.11**

Estimate the surface area (ft2) of a slow sand filter that is to deliver water to a village of 1000 people assuming that (a) the average daily water demand = 100 gpcd; (b) the slow sand filter’s filtration rate is 3 million gallons per acre per day (MGAD); and (c) two slow sand filters are required, each filter is able to treat the full water flow and one of the two filters is a standby unit.

**Solution:**

Q = A R

Where

Qs = water flow treated by a slow sand filter, MGD

A = surface area of a slow sand filter, acre

R = filtration rate of a slow sand filter, MGAD

Water flow from a village of 1000 people at 100 gpcd, Q

= (1000 persons) (100 gpcd)

= 100,000 gpd

= 0.1 MGD

Conversion factor: 1 acre = 43,560 ft2

Surface area of slow sand filter, A

= Q / R

= (0.1 MGD) / (3 MGAD)

= 0.0333 acre

= 0.0333 x 43,560 ft2

= 1450 ft2

**Select two slow sand filters, each has a surface area of 1450 ft2. One of the two filters is a standby unit.**

**Problem 1.12**

Estimate roughly the size of a water supply pipe leading to a water distributing reservoir serving a small village of 2000 people assuming that (a) the water consumption rate is 100 gpcd; and (b) water velocity in pipe = 3 ft/s.

**Solution:**

Average daily water demand, Qave

= (2000 persons) (100 gpcd)

= 200,000 gpd = = 0.2 MGD

Conversion factor: 1 MGD = 1.547 ft3/s

Maximum daily water demand, Qmax

= 1.5 Qave

= 1.5 x 0.2 MGD

= 0.3 MGD = 0.464 ft3/s

Q = A V

Where

Q = selected design flow, ft3/s

A = cross-sectional area of pipe, ft2

V = water velocity in the pipe, ft/s

Here, Q = Qmax = 1.5 x Qave = 0.464 ft3/s for designing a conduit leading to a distributing reservoir; V = 3 ft/s

Area of a circular conduit, A = Q/V

= (0.464 ft3/s) / (3 ft/s)

= 0.1547 ft2

A = πD2/4 where D = diameter of a pipe, ft

0.1547 ft2 = (D2) (0.785)

D = 0.444 ft = 5.32 in

**Select the nominal size of 6 in. for a circular conduit leading to the distributing reservoir.**

**Problem 1.13**

Determine the diameter of a water main to serve a residential area, assuming (a) an average water demand of 150 gpcd; (b) population = 30,000; (c) fire flow requirement = 500 gpm; and (d) recommended water velocity = 3.5 ft/s.

**Solution:**

Residential average daily water demand

= (36,000) (150)

= 5,360,000 gpd

= 3,720 gpm

Total water demand = 3,720 + 500 = 4,220 gpm = 3,700/(60 x 7.48) = 9.4 ft3/s

Q = A V

Where

Q = water flow selected for design, ft3/s

A = cross-sectional area of a pipe, ft2

V = water velocity in the pipe, ft/s

Here Q = 9.40 ft3/s and V = 3.5 fps, then

A = Q/V

= 9.40/3.5

=2.69 ft2.

A = 2.69 = πD2/4

D = 1.85 ft = 22.2 in.

**Select the next nominal size of 24 in for the water distribution pipe**

**Problem 1.14**

Roughly, what is the replacement cost of the waterworks of a city of 10,000 people?

**Solution:**

Assuming a per capita cost of $1,800, the total first cost is 1,800 x10,000 = $18,000,000

Assuming that 30% of this amount is invested in the collection works, 10% in the purification works, and 60% in the distribution works, the breakdown is as follows:

(a) Collection works, 0.3 x 18,000,000 = $5,400,000

(b) Purification works, 0.10 x 18,000,000 = $1,800,000

(c) Distribution works, 0.60 x 18,000,000 = $10,800,000.