ANSWER KEY

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? 36 WEEKS
2. How long must a pump with a capacity of 12 gal/min pump to fill a tank with a capacity of 37 m^3? 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 m^3
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 m^3/sec = 475 GAL/min
5. A small urban watershed has an area of 16.34 mi^2. 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? 4.92×10^{10} in^3
   B. In cubic feet? 2.85×10^7 ft^3
   C. In cubic meters? 8.07×10^5 m^3

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. 1315.2 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 (m^3/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.
RATE = 6.94 m^3/sec; 3-DAY VOLUME = 18,000 ha-cm = 180 ha-m; EQUIVALENT DEPTH FOR 3 DAYS = 72 cm

1.3. Water is to be supplied from a reservoir fed by a stream with a discharge of 2 m^3/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 m^3/s for a period of 15 days. Determine the reservoir size in km^3 and the rate of outflow when the reservoir is full. ✓ MINIMUM RESERVOIR SIZE = 351,000 m^3 = 0.000351 km^3; AT FULL, RATE OF OUTFLOW = 172,800 m^3/DAY

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 m^3/s. 3.31 DAYS = 79.3 HOURS

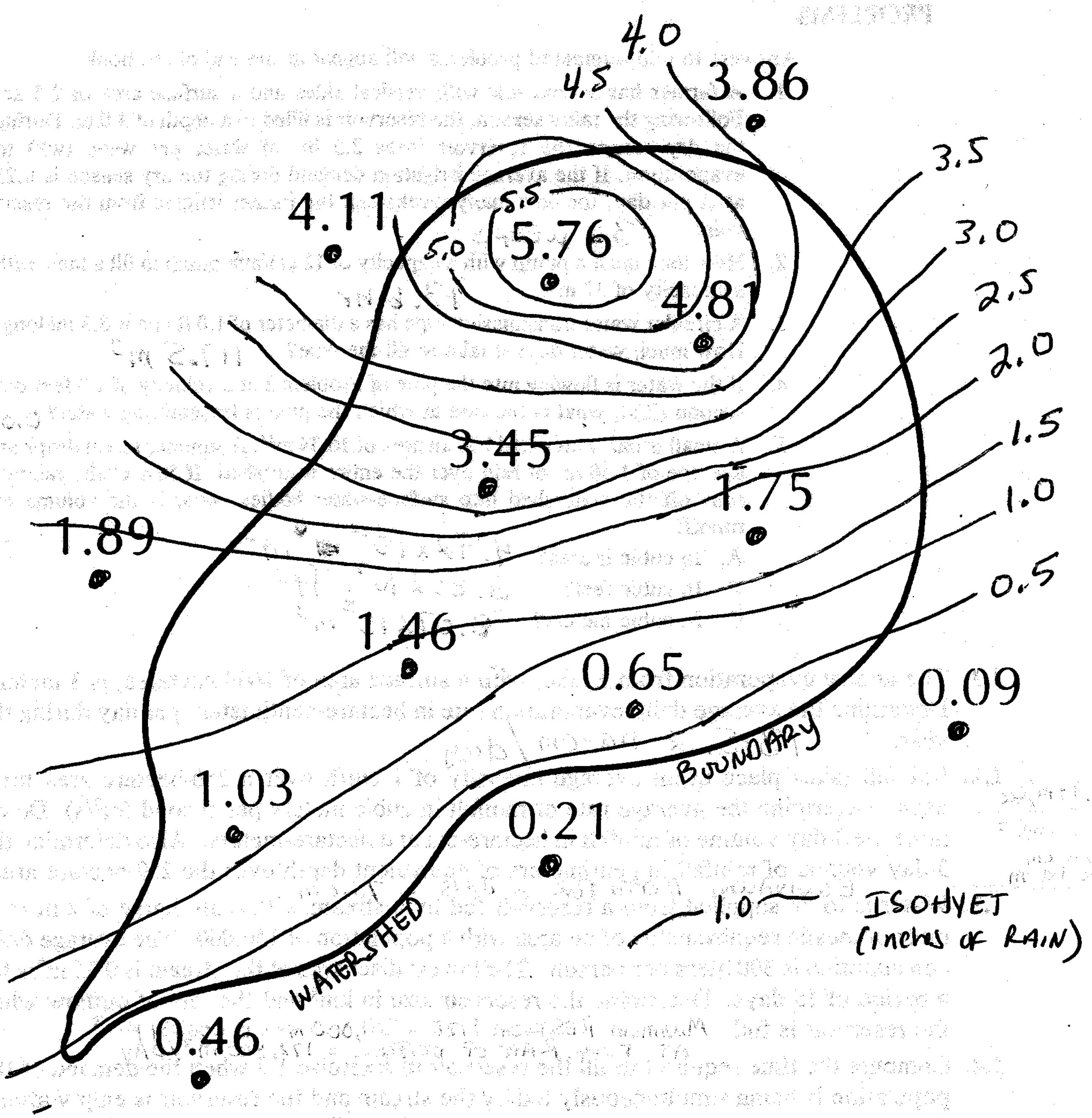
1.5. An area is being irrigated by a stream with a drainage area of 300 km^2. The drainage area contribution is 0.1 $m^3/s/km^2$. Determine the discharge of the channel and the area irrigated if 0.37 m^3/s are required per 1000 hectares. CHANNEL Q = 30 m^3/sec; AREA IRRIGATION = 81,081 ha

1.6. The average monthly precipitation in a watershed of 4500 km^2 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.
Q = 640 m^3/sec; AREA = 1.73×10^6 ha

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. STORAGE CAPACITY = 1×10^8 m^3

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 $m^3/s/1000$ 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 m^3/s.

TOTAL PUMPS NEEDED = 27 (19 ACTIVE, 8 STAND-BY); MINIMUM RIVER Q = 1.93 m^3/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:

Maximum 24-hour Rainfall Recorded	5.76 in
Minimum 24-hour Rainfall Recorded	0.09 in
Average 24-hour Rainfall Recorded	2.27
Standard Deviation of 24-hour Rainfall Rec'd	1.90
Median of 24-hour Rainfall Recorded	1.75
Total Number of Gage Stations	13

Environmental Geology Lab 1 - Watershed Rainfall Data

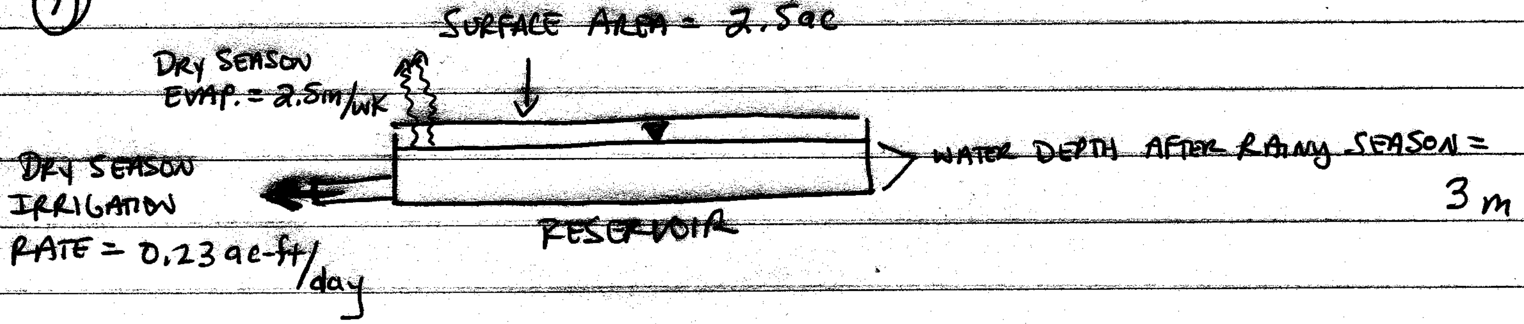
24-hr Rainfall (in)	
0.09	**Minimum Value**
0.21	
0.46	
0.65	
1.03	
1.46	
1.75	**Median Value**
1.89	
3.45	
3.86	
4.11	
4.81	
5.76	**Maximum Value**

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)



RESERVOIR SURFACE AREA = $2.5\ ac \left(\frac{4047\ m^2}{ac}\right) = 101{,}175\ m^2$

RESERVOIR WATER DEPTH = 3m

RESERVOIR WATER VOLUME = AREA × DEPTH = $(101{,}175\ m^2)(3m) =$

$303{,}525\ m^3$

DRY SEASON EVAPORATION RATE = $\left(2.5\ in/WK\right)\left(\frac{0.0254m}{in}\right) = 0.0635\ m/WK$

DRY SEASON EVAPORATION VOLUME LOSS = (EVAP. RATE) × (AREA) =

$\left(0.0635\ m/WK\right)101{,}175\ m^2 = 6425\ m^3/WK$

DRY SEASON IRRIGATION VOLUME USE = $\left(\frac{0.23\ ac\text{-}ft}{day}\right)\left(\frac{1233.5\ m^3}{ac\text{-}ft}\right)\left(\frac{7\ day}{WK}\right) =$

$1986\ m^3/WK$

TOTAL VOLUME REDUCTION PER WEEK = EVAPORATION VOL. + IRRIGATION VOL. =

$6425\ m^3/WK + 1986\ m^3/WK =$

$8411\ m^3/WK$

DRY SEASON LIFE OF RESERVOIR = $\frac{\text{INITIAL VOL.}}{\text{WEEKLY LOSS}} = \frac{303{,}525\ m^3}{8411\ m^3/WK} =$

36 WEEKS

(2) STEP 1 – CONVERT ALL UNITS TO METRIC!!

$$\text{PUMP RATE} = \frac{12\ \text{gal}}{\text{min}} \cdot \frac{3.78\times10^{-3}\ m^3}{\text{gal}} = 0.04536\ m^3/\text{min} = 2.72\ m^3/\text{hr}$$

TANK VOLUME = $37 m^3$

$$\text{TIME TO FILL TANK} = \frac{\text{TANK VOLUME}}{\text{PUMP RATE}} = \frac{37\ m^3}{0.04536\ m^3/\text{min}} = 816\ \text{min} =$$

$$816\ \text{min}\left(\frac{1\ \text{hr}}{60\ \text{min}}\right) = 13.6\ \text{hr}$$

(3) PIPE DIMENSIONS

$$\text{PIPE DIAMETER} = 1.0\ \text{ft}\left(\frac{0.3048\ m}{\text{ft}}\right) = 0.3048\ m$$

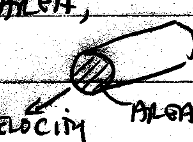
$$\text{PIPE LENGTH} = 1\ \text{mi}\left(\frac{1610\ m}{\text{mi}}\right) = 1610\ m$$

$$\text{VOLUME OF A CYLINDER} = (0.7854)(\text{LENGTH})(\text{DIAMETER})^2 =$$

$$(0.7854)(1610 m)(0.3048 m)^2 = 117.5\ m^3$$

(4) THIS IS ANALOGOUS TO CALCULATING WATER DISCHARGE IN A STREAM USING THE CONTINUITY EQUATION!

$Q = AV$ where Q = DISCHARGE, A = CROSS-SECTIONAL AREA, V = VELOCITY OF WATER FLOW



$$\text{VELOCITY} = 1.3\ \frac{\text{ft}}{\text{sec}}\left(\frac{0.3048\ m}{\text{ft}}\right) = 0.39\ m/\text{sec}$$

$$\text{AREA OF PIPE} = \text{AREA OF CIRCLE} = (0.7854)(\text{diameter})^2 = (0.7854)(0.3048\ m)^2 = 0.073\ m^2$$

$$Q = AV = (0.073\ m^2)(0.39\ m/\text{sec}) = 0.03\ m^3/\text{SEC} = 475\ \text{GAL}/\text{MIN}$$

(5) WATERSHED AREA $= 16.34\ mi^2 \left(\frac{2.79\times10^7\ ft^2}{mi^2}\right) = 4.56\times10^8\ ft^2$

AVG. RAIN $= 1.5\ in \left(\frac{1\ ft}{12\ in}\right) = 0.125\ ft$

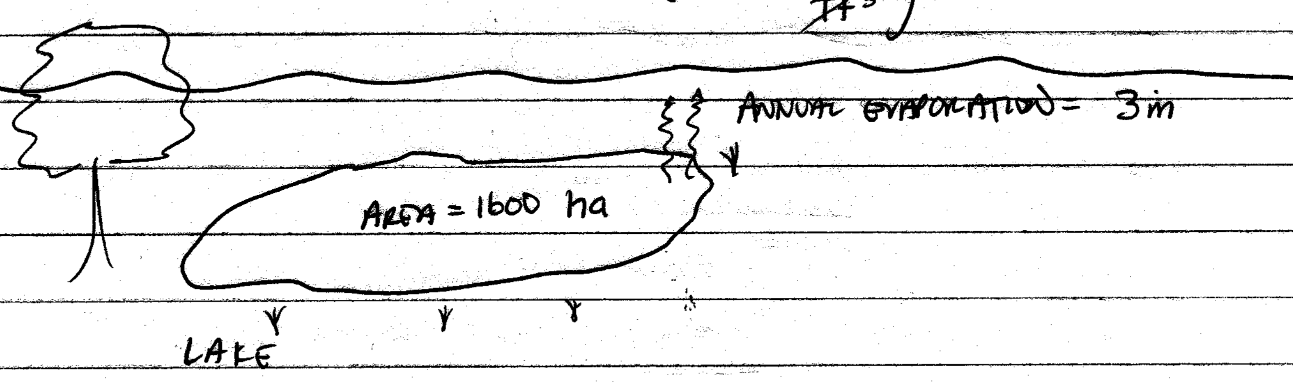
TOTAL RAIN VOLUME = (AVG. PRECIP) (WATERSHED AREA) =
$(0.125\ ft)(4.56\times10^8\ ft^2) = 5.7\times10^7\ ft^3$

RUNOFF = 50% OF TOTAL $= (0.5)(5.7\times10^7\ ft^3) = 2.85\times10^7\ ft^3$

Runoff $= (2.85\times10^7\ ft^3)\left(\frac{1728\ in^3}{ft^3}\right) = 4.92\times10^{10}\ in^3$

Runoff $= (2.85\times10^7\ ft^3)\left(\frac{0.02832\ m^3}{ft^3}\right) = 8.07\times10^5\ m^3$

(1.1)



AREA of LAKE = 1600 ha

ANNUAL EVAPORATION RATE $= 3\ m \left(\frac{100\ cm}{m}\right) = 300\ cm/yr$

DAILY EVAPORATION RATE $= \frac{300\ cm}{yr}\left(\frac{1\ yr}{365\ days}\right) = 0.822\ cm/day$

DAILY EVAPORATION VOLUME = (AREA)(EVAP. RATE) $= (1600\ ha)\left(0.822\ \frac{cm}{day}\right) =$

$$1315.2\ \frac{ha\text{-}cm}{day}$$

(1.2)

(R.I.) RAINFALL INTENSITY $= \dfrac{1\,cm}{hr}\left(\dfrac{1\,m}{100\,cm}\right) = 0.01\,\dfrac{m}{hr}$

AREA $= 250\,ha\left(\dfrac{1\times10^{4}\,m^{2}}{ha}\right) = 2.5\times10^{6}\,m^{2}$

TOTAL TIME $= (3\,DAYS)\left(\dfrac{24\,hr}{day}\right) = 72\,hr$

HOURLY RATE OF RAINFALL $= (R.I.)(AREA) = 0.01\,\dfrac{m}{hr}\; 2.5\times10^{6}\,m^{2} =$

$25{,}000\,m^{3}/hr$

DAILY RATE OF RAINFALL $= 25{,}000\,\dfrac{m^{3}}{hr}\left(\dfrac{24\,hr}{day}\right) = 600{,}000\,\dfrac{m^{3}}{day}$

RATE OF RAINFALL PER SECOND $\left(25{,}000\,\dfrac{m^{3}}{hr}\right)\left(\dfrac{1\,hr}{3600\,sec}\right) = 6.94\,\dfrac{m^{3}}{sec}$

3-DAY VOLUME

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

$\left(\dfrac{0.01\,m}{hr}\right)\left(\dfrac{72\,hr}{3\,DAYS}\right) 250\,ha = 180\,\dfrac{ha\text{-}m}{3\,DAYS}$

EQUIVALENT DEPTH FOR 3 DAYS $= \dfrac{\text{TOTAL 3-DAY VOLUME}}{\text{AREA}}$

TOTAL 3-DAY VOLUME = 18,000 ha-cm

AREA = 250 ha

EQUIVALENT DEPTH $= \dfrac{18{,}000\,ha\text{-}cm}{250\,ha} = 72\,cm$

(1.3) NORMAL RESERVOIR INFLOW [redacted] $= \frac{2\,m^3}{sec} \cdot \frac{60\,sec}{min} \cdot \frac{60\,min}{hr} \cdot \frac{24\,hr}{day} = 172{,}800\ \frac{m^3}{DAY}$

AVERAGE DAILY CONSUMPTION RATE $= \frac{300\,L}{person/DAY} \cdot \frac{0.001\,m^3}{1\,L} = \frac{0.3\,m^3}{PERSON/DAY}$

TOTAL DAILY VOLUME CONSUMPTION = (AVG. CONSUMPTION RATE)(TOTAL POPULATION) =

$\left(0.3\,m^3/person/day\right)\left(150{,}000\ persons\right) = 45{,}000\ \frac{m^3}{DAY}$

★ MINIMUM RATE OF OUTFLOW NEEDED = RATE OF CONSUMPTION BY PEOPLE = $45{,}000\ m^3/DAY$

LOWEST RATE OF INFLOW $= \frac{0.25\,m^3}{sec}\left(8.64 \times 10^4\ \frac{sec}{DAY}\right) = 21{,}600\ \frac{m^3}{DAY}$

TOTAL VOLUME OF INFLOW, AT LOWEST RATE, OVER 15 DAYS =

(RATE)(TIME) $= \left(21{,}600\ \frac{m^3}{DAY}\right) 15\ DAY = 324{,}000\ m^3$

TOTAL VOLUME CONSUMED OVER 15 DAYS =

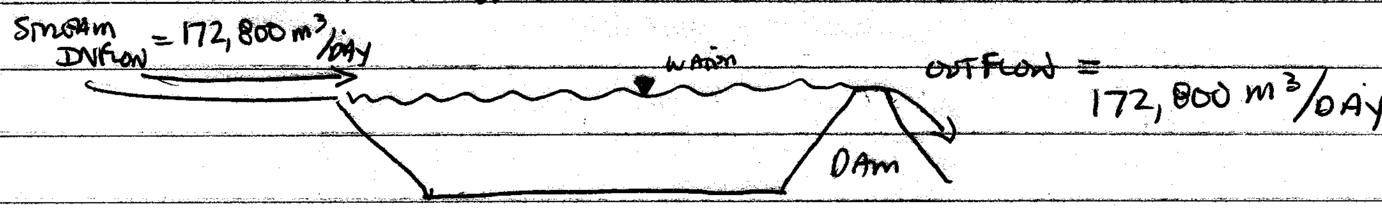
$\left(45{,}000\ \frac{m^3}{DAY}\right) 15\ DAY = 675{,}000\ m^3$

MINIMUM RESERVE CAPACITY (DURING DRY SPELL) $= 675{,}000\ m^3 - 324{,}000\ m^3 =$

$351{,}000\ m^3 \left(\frac{1\,Km^3}{10^9\,m^3}\right) = 0.000351\ Km^3$

(CONT.) →

WHEN RESERVOIR IS FULL - AND MAINTAINED AT ~~FULL~~, THE RATE OF OUTFLOW OVER SPILLWAY = RATE OF INFLOW FROM STREAM



TO MAINTAIN THE RESERVOIR AT FULL, THE MINIMUM RATE OF INFLOW MUST EQUAL THE RATE OF CONSUMPTION $= 45{,}000 \frac{m^3}{DAY}$

(1.4)

MINIMUM RESERVOIR VOLUME $= 351{,}000\ m^3$

DAILY CONSUMPTION RATE $= 45{,}000\ m^3/DAY$

RATE OF STREAM INFLOW $= 1.75 \frac{m^3}{sec}\left(8.64\times10^4 \frac{sec}{DAY}\right) = 151{,}200 \frac{m^3}{DAY}$

EFFECTIVE, NET INFLOW, = RATE OF STREAM INFLOW − DAILY CONSUMPTION RATE =

$$\left(151{,}200 \frac{m^3}{DAY} - 45{,}000 \frac{m^3}{DAY}\right) = 106{,}200 \frac{m^3}{DAY}$$

TIME TO FILL RESERVOIR $= \frac{\text{VOLUME}}{\text{EFFECTIVE RATE}} = \frac{351{,}000\ m^3}{106{,}200\ m^3/DAY} =$

3.31 DAYS =

79.3 hrs.

(1.5)

WATERSHED AREA = 300 Km^2

UNIT DISCHARGE = $0.1\ m^3/sec/Km^2$

CHANNEL DISCHARGE = (AREA)(UNIT DISCHARGE) =

$$(300\ Km^2)(0.1\ m^3/sec/Km^2) = 30\ m^3/sec$$

IRRIGATION RATE = $\frac{1000\ ha}{0.37\ m^3/sec}$

AREA IRRIGATED = (IRRIGATION RATE) × (CHANNEL DISCHARGE) =

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

(1.6)

TOTAL WATERSHED AREA = $4500\ Km^2 \left(\frac{10^6\ m^2}{Km^2}\right) = 4.5 \times 10^9\ m^2$

AVG. MONTHLY PRECIPITATION = $(46\ cm)\left(\frac{1\ m}{100\ cm}\right) = 0.46\ m$

TOTAL RAINFALL VOLUME PER MONTH = (AREA)(PRECIP.) =

$$(4.5 \times 10^9\ m^2)(0.46\ m) = 2.07 \times 10^9\ m^3$$

IF 20% OF PRECIPITATION IS LOSSED, THEN RUNOFF = (0.8)(TOTAL MONTH VOL.)

$$= (0.8)\left(\frac{2.07 \times 10^9\ m^3}{mo}\right) = 1.66 \times 10^9\ m^3/mo$$

CHANNEL DISCHARGE = $\left(1.66 \times 10^9\ m^3/mo\right)\left(\frac{1\ mo}{30\ days}\right)\left(\frac{1\ day}{24\ hr}\right)\left(\frac{1\ hr}{60\ min}\right)\left(\frac{1\ min}{60\ sec}\right) = 640.4\ m^3/sec$

(CONT.) →

1.6 (CONT)

STREAM DISCHARGE $= 640.4 \frac{m^3}{sec}$

IRRIGATION RATE FROM (1.5) $= \frac{1000\ ha}{0.37\ m^3/sec}$

AREA IRRIGATED = (IRRIGATION RATE) x (STREAM DISCHARGE) =

$$\left(\frac{1000\ ha}{0.37\ m^3/sec}\right)(640.4\ m^3/sec) = 1.73 \times 10^6\ ha$$

(1.7) WATERSHED AREA (from 1.6) $= (4500\ km^2)\left(\frac{10^6\ m^2}{km^2}\right) = 4.5 \times 10^9\ m^2$

20 DAY PRECIPITATION $= (28\ cm)\left(\frac{1\ m}{100\ cm}\right) = 0.28\ m$

20 DAY TOTAL RAIN VOLUME $= (0.28\ m)(4.5 \times 10^9\ m^2) = 1.26 \times 10^9\ m^3$

REMEMBER: OF THE TOTAL VOLUME, ONLY 80% IS AVAILABLE AS RUN OFF (FROM 1.6 ABOVE)!!

EFFECTIVE VOLUME $= (0.8)(1.26 \times 10^9\ m^3) = 1.01 \times 10^9\ m^3 / 20\ DAY$

IRRIGATION RATE $= \frac{0.37\ m^3/sec}{1000\ ha}$

TOTAL VOLUME REQUIRED FOR 20 DAYS =

$$\frac{0.37\ m^3/sec \cdot \frac{60\ sec}{min} \cdot \frac{60\ min}{hr} \cdot \frac{24\ hr}{day} \cdot 20\ day}{1000\ ha} =$$

$$\frac{639360\ m^3}{1000\ ha}$$

(CONT →)

AREA TO BE IRRIGATED (FROM 1.6 ABOVE) = 1.73×10^6 ha

TOTAL VOLUME of H_2O NEEDED FOR 20 DAYS =

$$\left(\frac{639360 \text{ m}^3}{1000 \text{ ha}}\right)\left(1.73 \times 10^6 \text{ ha}\right) = 1.11 \times 10^9 \text{ m}^3$$

TOTAL 20 DAY VOLUME RECEIVED = 1.01×10^9 m^3

TOTAL 20 DAY IRRIGATION VOLUME NEEDED = 1.11×10^9 m^3

RESERVOIR (STORAGE) CAPACITY NEEDED =

REQUIRED − RECEIVED =

$1.11 \times 10^9 \text{ m}^3 - 1.01 \times 10^9 \text{ m}^3 = 1 \times 10^8 \text{ m}^3$

(1.8) POPULATION = 200,000 IRRIGATED AREA = 3600 ha

TOTAL DAILY CONSUMPTION VOLUME $= \left(\frac{320\ \ell}{\text{person}}\right)\left(200{,}000\ \text{people}\right)\left(\frac{0.001\ m^3}{\ell}\right) =$

$64{,}000\ m^3/\text{DAY}$

TOTAL DAILY IRRIGATION VOLUME $= \left(\frac{0.33\ m^3/\text{sec}}{1000\ ha}\right)\left(3600\ ha\right) 8.64\times10^4 \frac{\text{sec}}{\text{DAY}} =$

$102{,}643\ m^3/\text{DAY}$

TOTAL DAILY WATER REQUIRED = PEOPLE + IRRIGATION =

$64{,}000\ m^3/\text{DAY} + 102{,}643\ m^3/\text{DAY} =$

$166{,}643\ m^3/\text{DAY}$

MINIMUM RIVER DISCHARGE $= \left(166{,}643\ m^3/\text{DAY}\right)\left(\frac{1\ \text{DAY}}{8.64\times10^4\ \text{sec}}\right) =$

$1.93\ m^3/\text{SEC}$

PUMPS NEEDED: $1\ \text{Pump} = \left(0.1\ m^3/\text{sec}\right)\left(\frac{8.64\times10^4\ \text{sec}}{\text{day}}\right) = 8640\ m^3/\text{DAY}$

$\left(166{,}643\ m^3/\text{DAY}\right)\left(\frac{1\ \text{pump}}{8640\ m^3/\text{DAY}}\right) = 19\ \text{PUMPS}$ (70% ACTIVE)

$(0.7)x = 19$

$x = 27$

TOTAL PUMPS = 27; ACTIVE PUMPS = 19

STAND-BY PUMPS = 8 (30% of TOTAL)