

Unit Operations and Processes in Environmental Engineering (2nd Edition)

Chapter 4, Problem 1P

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Problem

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It is desired to know the population of City X for 1996, 2006, 2011, 2016, and 2021. The economic background, climate, and so on are similar to those of the cities in the list that follows.

a. Estimate the 1996 population.

Note: The following statistics concerning utility connections, school enrollment, and telephone connections have been compiled.

	1990	1996
Utility connections	7,152	8,633
School enrollment	4,478	5,398
Telephone connections	5,589	6,748

b. Estimate the future populations by the curvilinear rate of growth.

Bureau of Census Records

YEAR	CITY X	CITY A	CITY B	CITY C	CITY D
1890	1,883	—	6,908	14,445	—
1900	2,029	—	8,069	20,686	—
1910	2,216	5,155	10,400	26,425	9,957
1920	3,291	5,713	12,085	38,500	15,494
1930	4,102	5,036	17,113	52,848	43,132
1940	6,390	13,766	28,256	55,982	51,497
1950	8,908	24,502	38,968	84,706	74,246
1960	12,622	40,050	51,230	97,808	137,969
1970	17,878	45,547	57,770	95,326	144,396
1980	23,583	62,762	70,508	101,261	149,230
1990	28,209	80,215	84,628	108,215	156,815

Step-by-step solution

Step 1 of 12

a)

Calculate the 1996 population by using the following equation.

$$P_{1996} = P_{1990} (\text{Growth Factor}) \dots\dots (1)$$

Calculate growth factor by using the equation,

$$\text{Growth Factor (of } X) = 1 + \frac{X_{\text{later}} - X_{\text{before}}}{X_{\text{later}}} \dots\dots (2)$$

Calculate growth factor for Utility connections,

Substitute 7152 for X_{later} and 8633 for X_{before} in equation.

$$\begin{aligned} \text{Growth Factor (of } X) &= 1 + \frac{8633 - 7152}{7152} \\ &= 1 + \frac{1481}{7152} \\ &= 1.207 \end{aligned}$$

Similarly, calculate for School enrollment and Telephone connections

Comment

Step 2 of 12

Tabulate the value of growth factors. Take the average of the three individual growth factors for the three given data sources to use to scale the population.

Data	1990 Value	1996 Value	Growth Factor
Utility connections	7152	8633	$1 + \frac{8633 - 7152}{7152} = 1.2071$
School enrollment	4478	5398	$1 + \frac{5398 - 4478}{4478} = 1.2054$
Telephone connections	5589	6748	$1 + \frac{6748 - 5589}{5589} = 1.2074$
Growth Factor (Average)	1.2066		

Comment

Step 3 of 12

Substitute 1.2066 for the growth factor in equation (1).

$$\begin{aligned} P_{1996} &= P_{1990} (\text{Growth Factor}) \\ &= (28209)(1.2066) \\ &= 34038 \text{ people} \end{aligned}$$

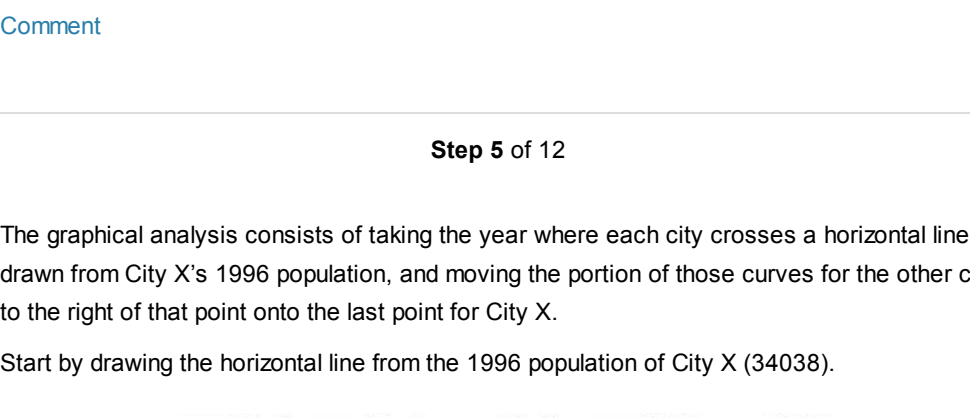
Hence, the 1996 population is estimated is **34038 people**.

Comment

Step 4 of 12

b)

To estimate future population graphically, start by plotting the populations of the four cities in the same chart.

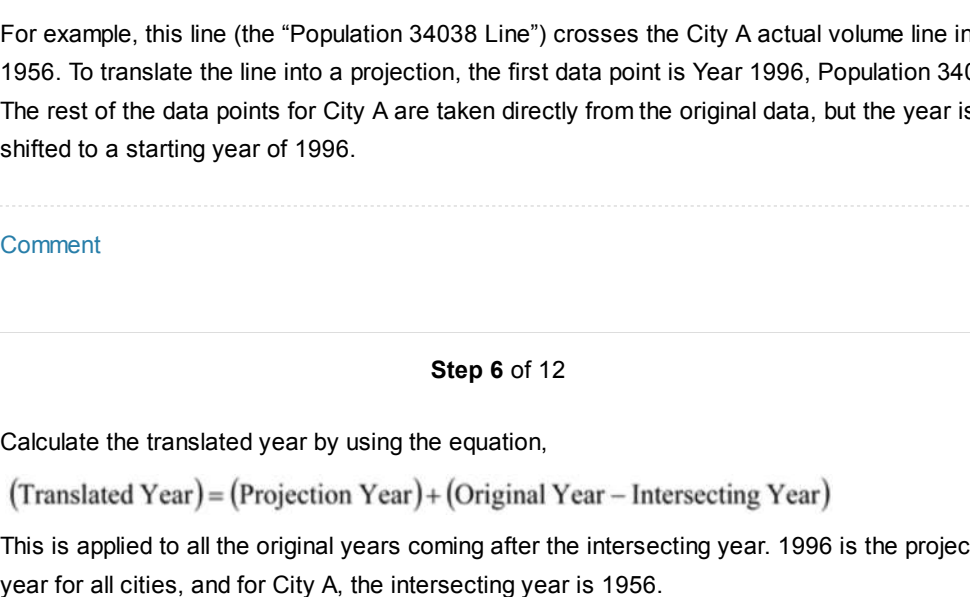


Comment

Step 5 of 12

The graphical analysis consists of taking the year where each city crosses a horizontal line drawn from City X's 1996 population, and moving the portion of those curves for the other cities to the right of that point onto the last point for City X.

Start by drawing the horizontal line from the 1996 population of City X (34038).



For example, this line (the "Population 34038 Line") crosses the City A actual volume line in 1956. To translate the line into a projection, the first data point is Year 1996, Population 34038. The rest of the data points for City A are taken directly from the original data, but the year is shifted to a starting year of 1996.

Comment

Step 6 of 12

Calculate the translated year by using the equation,

$$(\text{Translated Year}) = (\text{Projection Year}) + (\text{Original Year} - \text{Intersecting Year})$$

This is applied to all the original years coming after the intersecting year. 1996 is the projection year for all cities, and for City A, the intersecting year is 1956.

For example, the calculations for City A are given in the following table.

Original Year	Original Data	Translated Year	Translated Data
1956	34038 (estimated from graph)	1996	34038
1960	40050	$1996 + (1960 - 1956) = 2000$	40050
1970	45547	$1996 + (1970 - 1956) = 2010$	45547
1980	62762	$1996 + (1980 - 1956) = 2020$	62762
1990	80215	$1996 + (1990 - 1956) = 2030$	80215

Comment

Step 7 of 12

Repeat this procedure for the data from cities B, C, and D.

- City B's intersecting year is 1945.
- For example, 1950 data translates to $1996 + (1950 - 1945) = 2001$.
- City C's intersecting year is 1916.
- For example, 1920 data translates to $1996 + (1920 - 1916) = 2000$.
- City D's intersecting year is 1927.
- For example, 1930 data translates to $1996 + (1930 - 1927) = 1999$.

Comment

Step 8 of 12

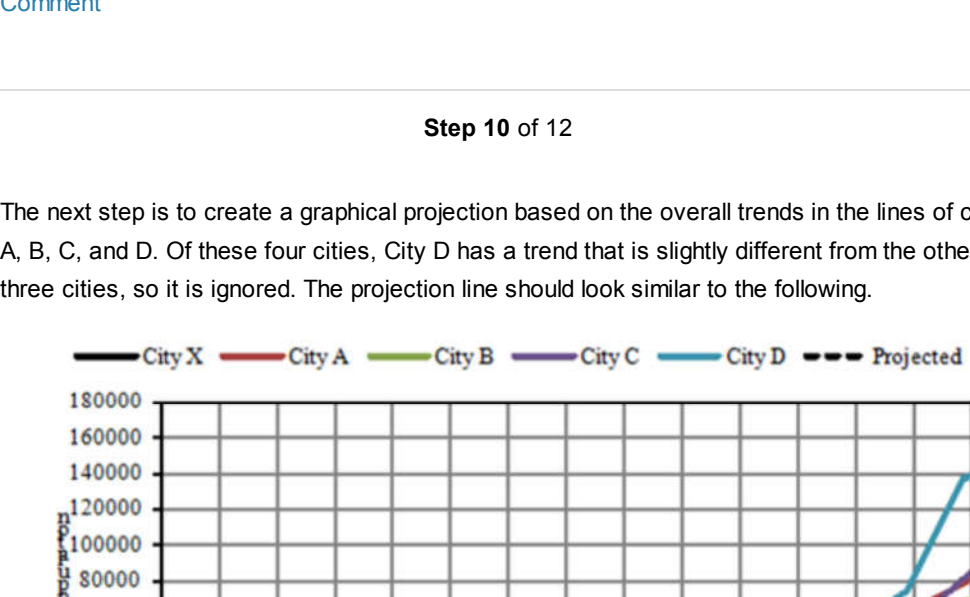
The translated data for the four cities are given in the following table. Recall that the starting point is the same for all four cities (Year 1996, with population 34038).

Year	City A Population	Year	City B Population	Year	City C Population	Year	City D Population
1996	34038	1996	34038	1996	34038	1996	34038
2000		2001	38968	1920	38500	1999	43132
2010		2011	51230	1930	52848	2008	51497
2020		2021	57770	1940	55982	2019	74246
2030		2031	70508	1950	84706	2029	137969
		2041	84628	1960	97808	2039	144396
				1970	95326	2049	149230
				1980	101261	2059	156815
				1990	108215		

Comment

Step 9 of 12

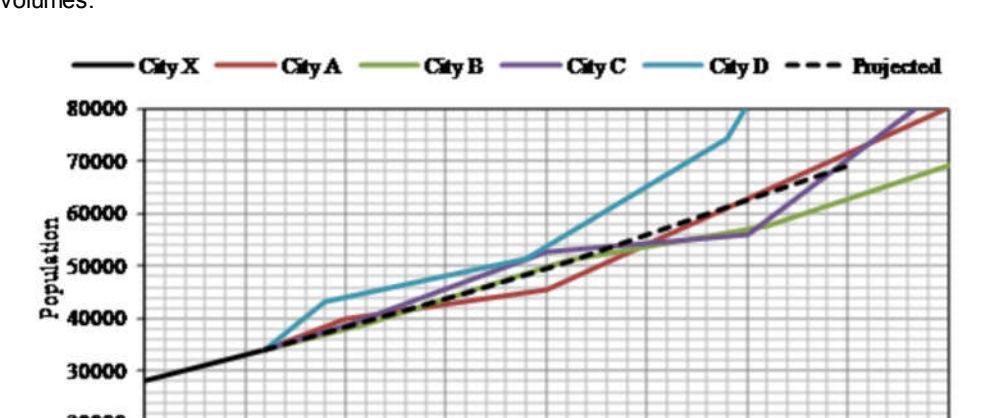
Plot all of this data on a new plot to show possible projections based on the historical growth of cities A, B, C, and D.



Comment

Step 10 of 12

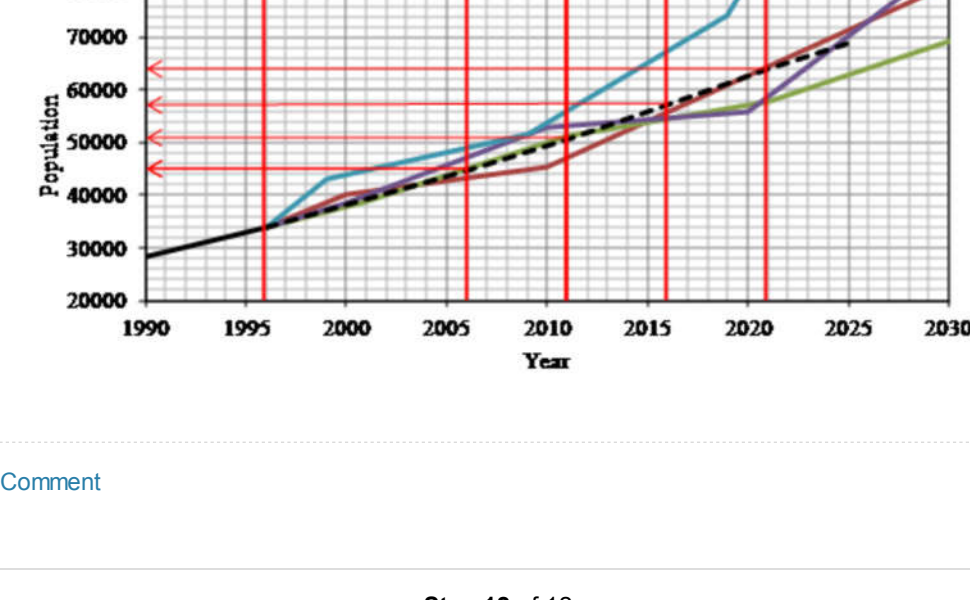
The next step is to create a graphical projection based on the overall trends in the lines of cities A, B, C, and D. Of these four cities, City D has a trend that is slightly different from the other three cities, so it is ignored. The projection line should look similar to the following.



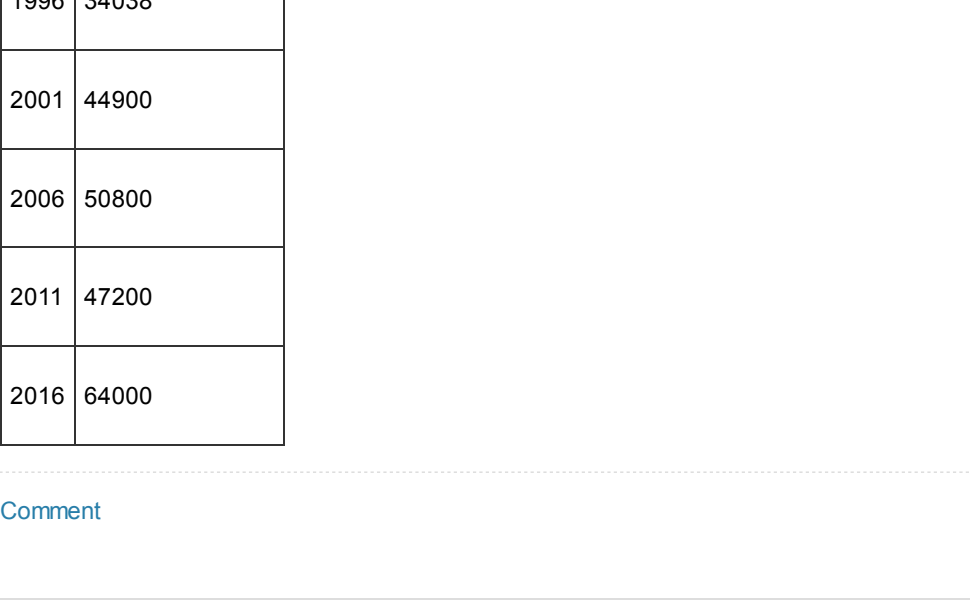
Comment

Step 11 of 12

The following plot shows a zoomed-in view that facilitates graphically estimating the projected volumes.



The final step is to graphically determine the future year projected volumes by finding the vertical displacement of each point where the desired year intersects the projection line. The years 2001, 2006, 2011, and 2016 are shown in the following graphic.



Comment

Step 12 of 12

From this procedure, obtain the estimated values for the future years. Combining these with the previously estimated 1996 volumes, the final volume projections can be obtained.

Year	Estimated Volume
1996	34038
2001	44900
2006	50800
2011	47200
2016	64000

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