Hydromorphology of an Urbanizing Watershed Using Multivariate Elasticity

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Course:	CE291F
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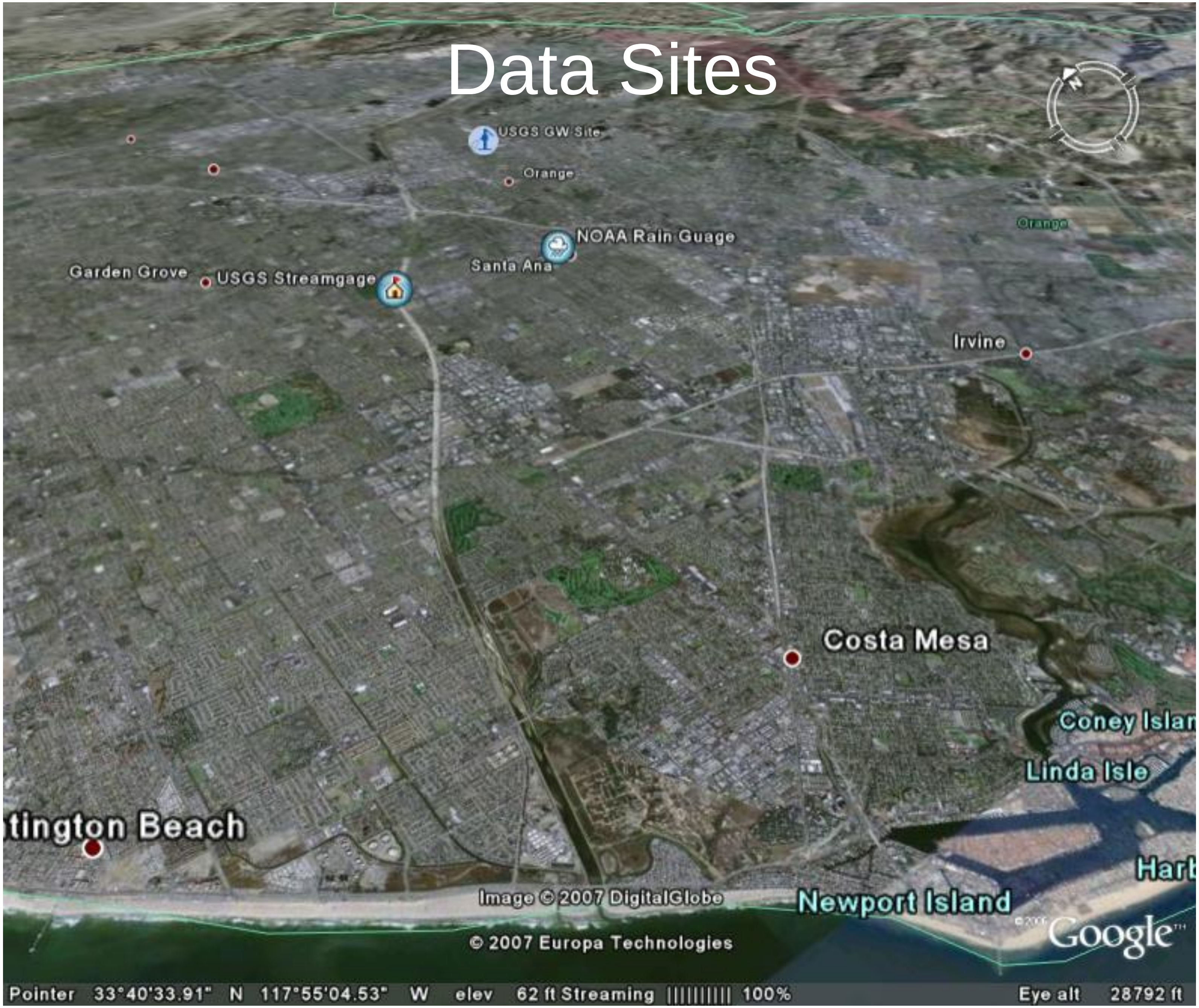
Definitions and Details

- Hydromorphology: The structure and evolution of hydrologic systems.
- Question: How do hydrologic systems evolve in response to a variety of anthropogenic (human) and natural (climatic) influences?
- Goal: Better understand interactions between streamflow and trends in climate, land use, and water use.
- Case: Santa Ana River Watershed within Orange County

Santa Ana Watershed

2,500 mi.² total, 153.2 mi.² in Orange County

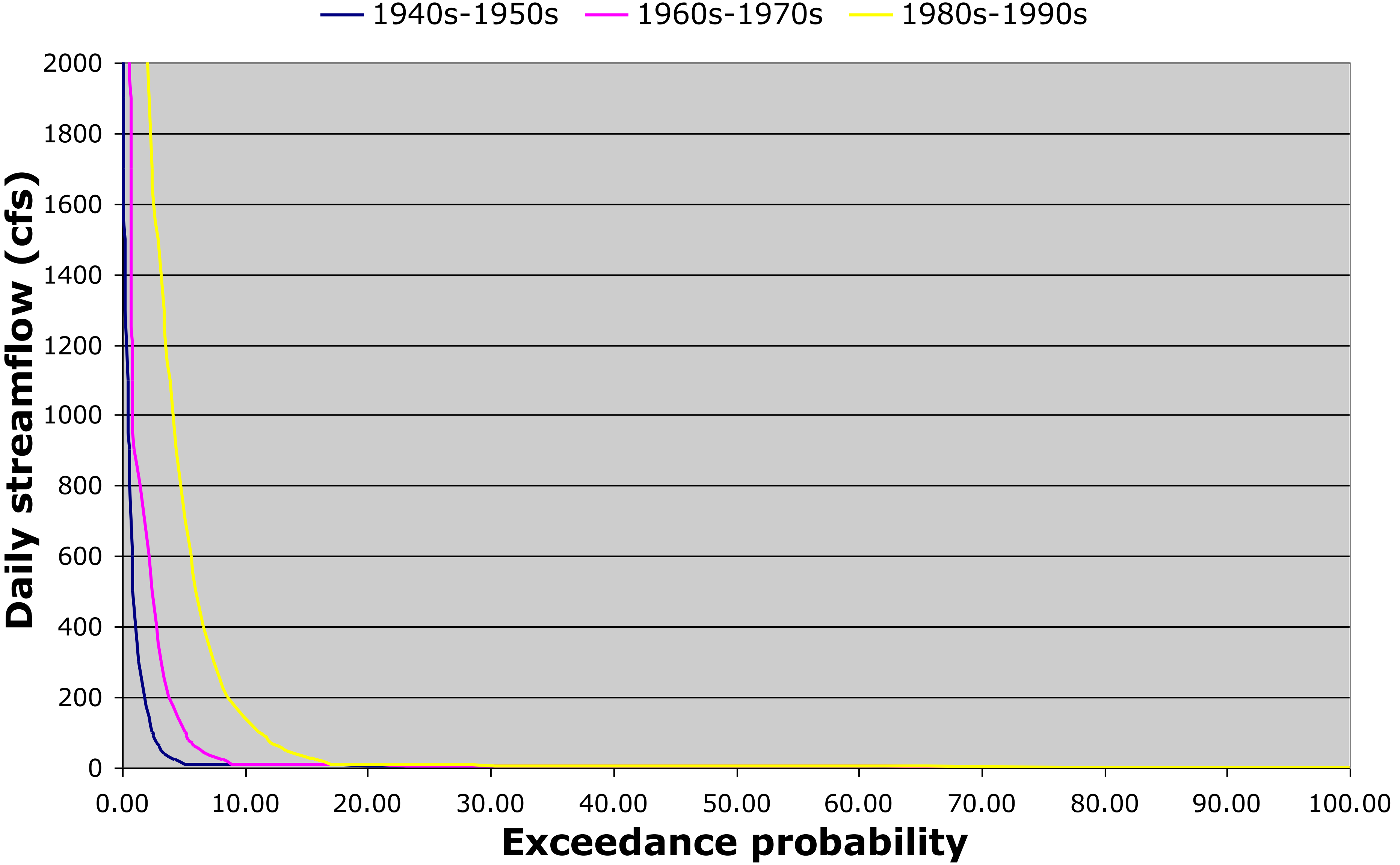
Data Sites


USGS GW Site
Orange
NOAA Rain Guage
Santa Ana
Garden Grove
USGS Streamgage
Orange
Irvine
Costa Mesa
Coney Islan
Linda Isle
tington Beach
Harb
Image © 2007 DigitalGlobe
Newport Island
© 2007 Europa Technologies
Google
Pointer 33°40'33.91" N 117°55'04.53" W elev 62 ft Streaming |||||||||| 100%
Eye alt 28792 ft

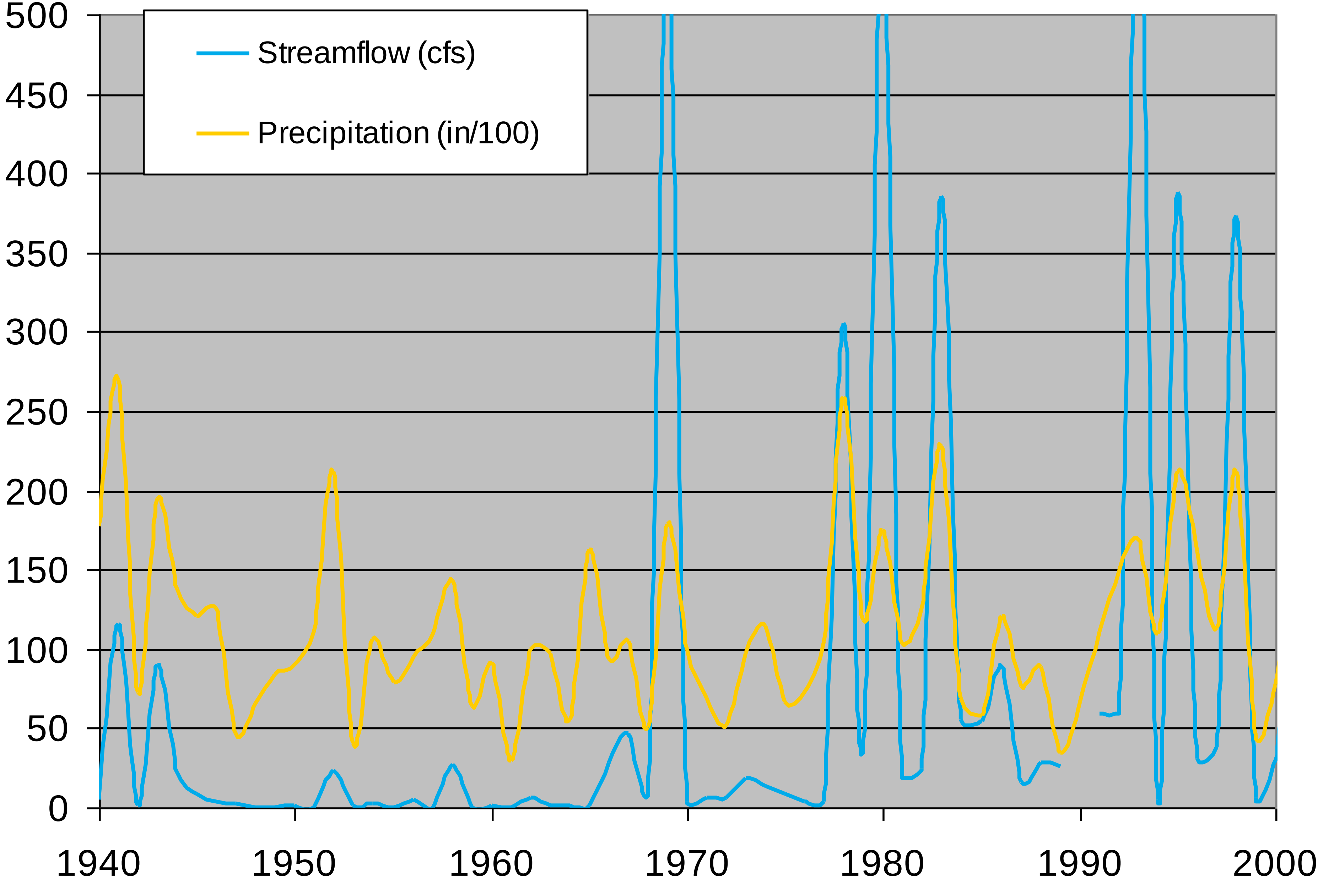
Data Collection: 1940 - 1999

Variable	Metric	Unit	Source	Resolution	Points
Streamflow	Discharge	cubic feet per second	USGS	daily average	21,900
Climate	Precipitation	1/100 inch	NOAA	monthly average	720
Water Use	Groundwater Levels	feet below ground surface	USGS	sporadic measurements	419
Land Use	Population	individuals	CDF	10-year census	7

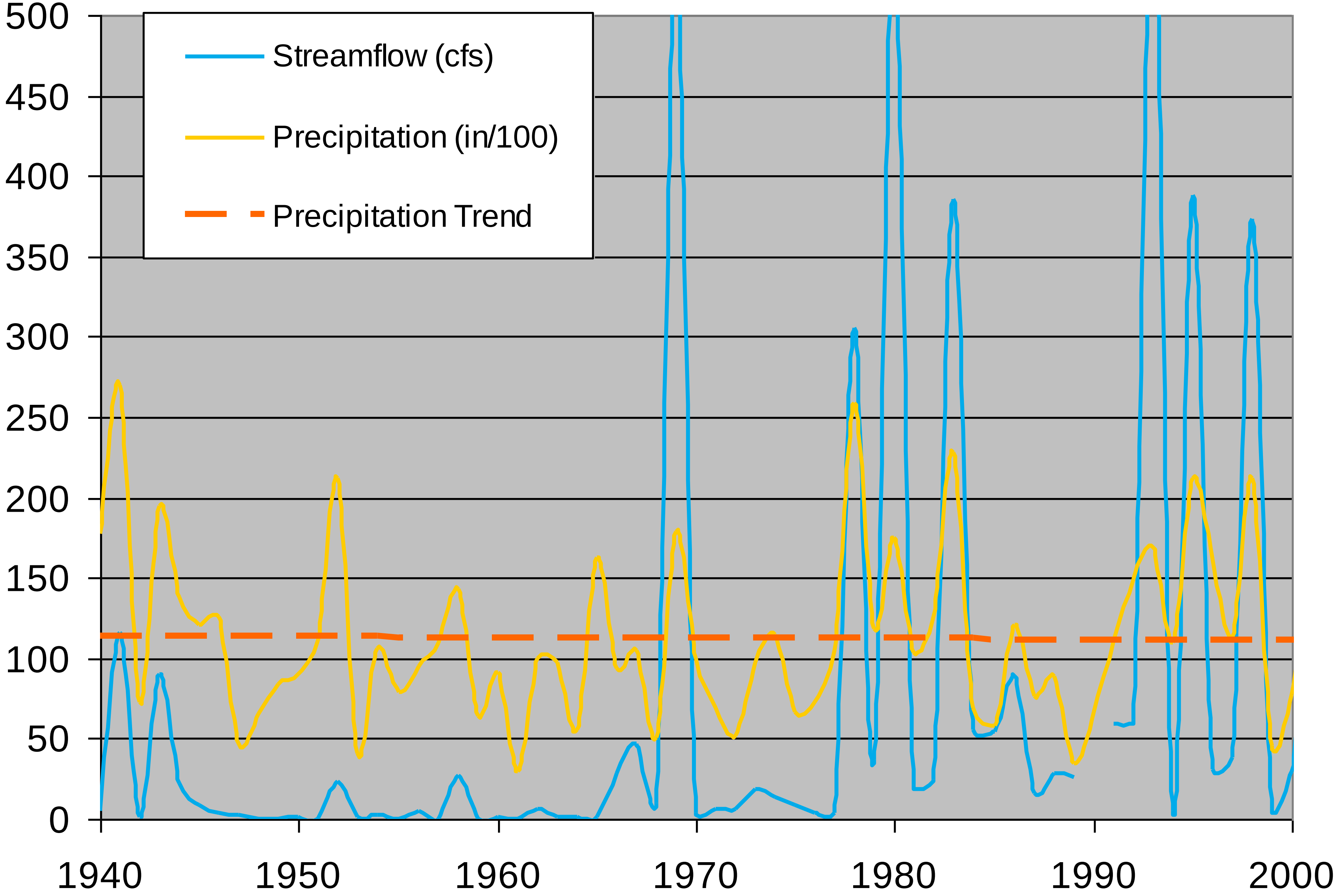
Flow duration curve



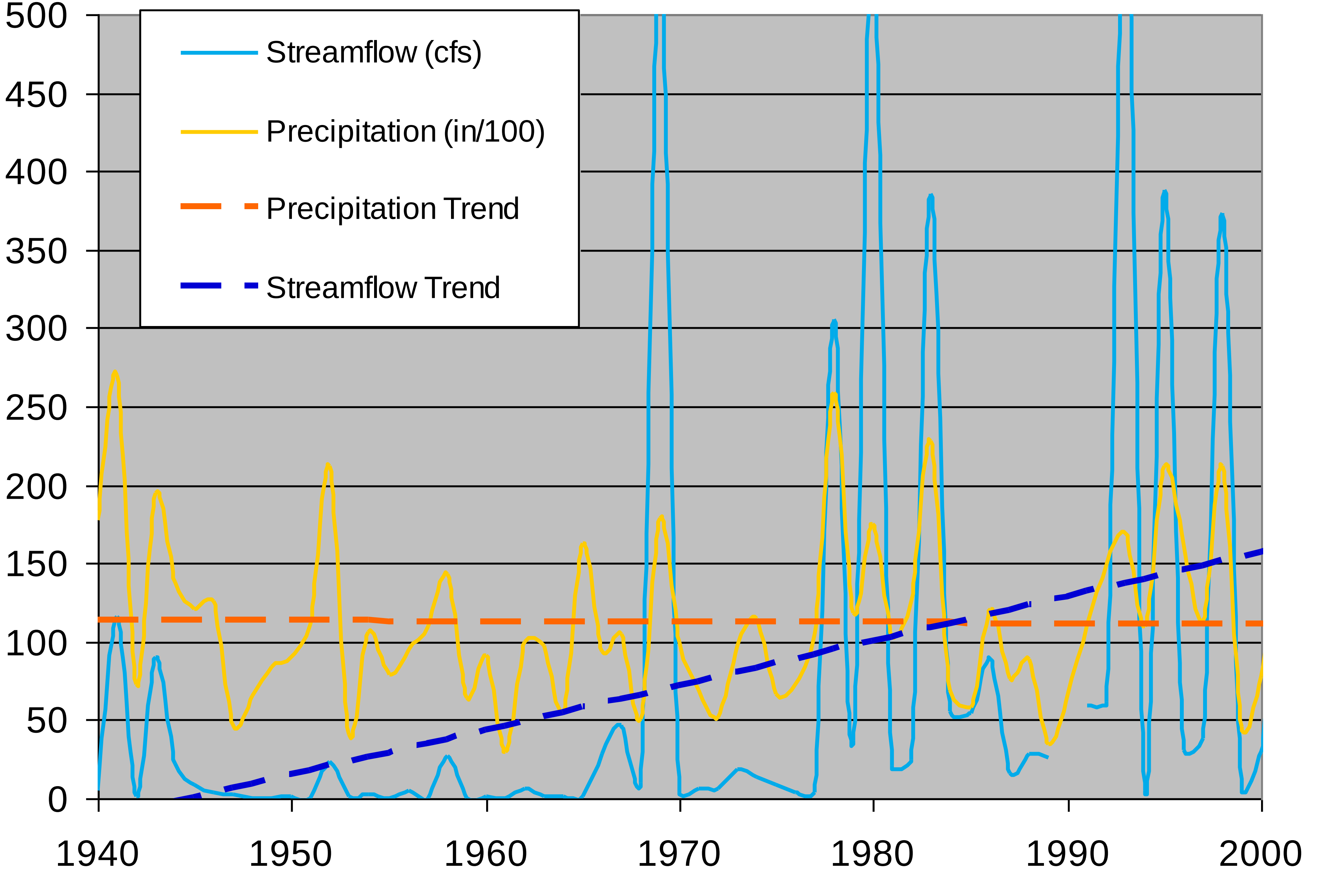
Natural Influences



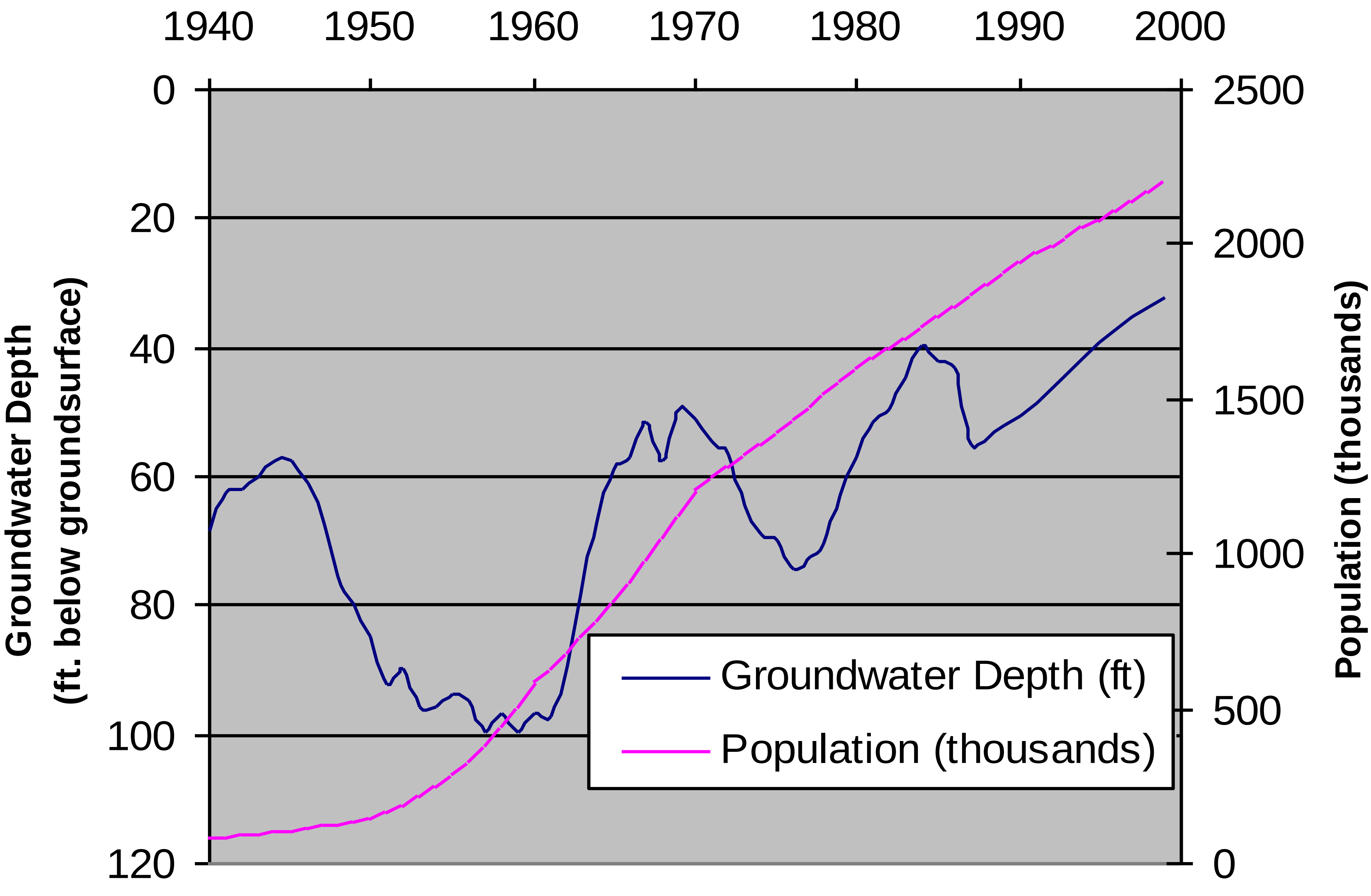
Natural Influences



Natural Influences



Human Influences



Elasticity

- Econometric concept applied to hydrology to describe sensitivity of streamflow to changes in other phenomena, for example precipitation:

  The precipitation elasticity of streamflow, defined as

$$\varepsilon_{\mathrm{P}} = \frac{dQ/\overline{Q}}{dP/\overline{P}} = \frac{dQ}{dP}\frac{\overline{P}}{\overline{Q}} \qquad (1)$$

  relates the proportional change in streamflow (at mean) to proportional change in precipitation. If $\varepsilon_{\mathrm{P}} = 2$ for annual streamflows, then a 1% change in precipitation leads to a 2% change in streamflow.

Multivariate Elasticity

- Consider the total differential (Chapter 1) of streamflow resulting from simultaneous changes in precipitation (P), land use (L) and water use (W):

$$dQ = \frac{\partial Q}{\partial P} dP + \frac{\partial Q}{\partial L} dL + \frac{\partial Q}{\partial W} dW \qquad (2)$$

- It is useful to estimate the differentials as a percentage of change from the mean for each variable in (2):

$$\left(\frac{Q - \overline{Q}}{\overline{Q}}\right) = \frac{\partial Q}{\partial P}\frac{\overline{P}}{\overline{Q}}\left(\frac{P - \overline{P}}{\overline{P}}\right) + \frac{\partial Q}{\partial L}\frac{\overline{L}}{\overline{Q}}\left(\frac{L - \overline{L}}{\overline{L}}\right) + \frac{\partial Q}{\partial W}\frac{\overline{W}}{\overline{Q}}\left(\frac{W - \overline{W}}{\overline{W}}\right) \qquad (3)$$

or

$$q = \varepsilon_P \cdot p + \varepsilon_L \cdot l + \varepsilon_W \cdot w \qquad (4)$$

Regression Analysis

- To find coefficients $\varepsilon_P, \varepsilon_L, \varepsilon_W$ use Ordinary Least Squares, which "fits" observed data, and returns standard errors and accuracy measurements. To do this, use datapoints (x_i, y_i) with $i = 1, 2, ..., n$ to find f such that $y_i \approx f(x_i)$

  …by minimizing $S = \sum_{i=1}^{n} (y_i - f(x_i))^2$

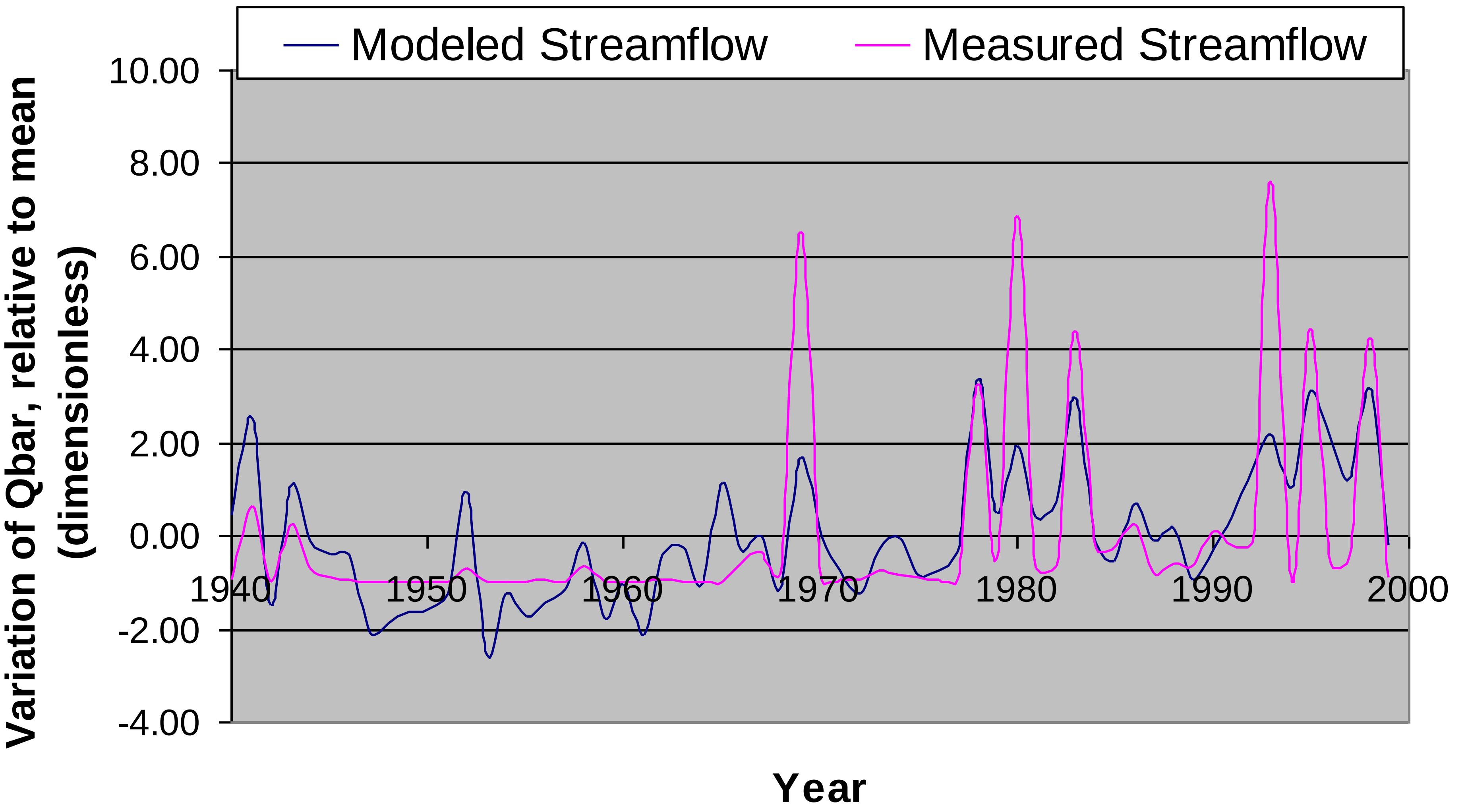
- Analysis performed on three streamflow conditions:
  – Average Streamflow $\overline{Q}$
  – Flood Condition $Q_{\max}$
  – Low Flow Condition Q_{90}

Results

Streamflow Variable (in cfs)		Explanatory Variables		
		Climate, ε_p	Land Use, ε_L	Water Use, ε_W
		Annual Precipitation, P (in inches)	Watershed Population, L (thousands)	Well Levels, W (in ft. bellow groundsurface)
Flood - Q_{max}	ε	1.749	0.664	-1.504
	S_ε	0.227	0.219	0.993
	p	0.000	0.004	0.135
Average - $\overline{Q}$	ε	2.312	0.674	-2.116
	S_ε	0.413	0.397	1.803
	p	0.000	0.095	0.245
Drought - Q_{90}	ε	2.857	0.694	-2.377
	S_ε	0.606	0.584	2.650
	p	0.000	0.240	0.373

The variables ε, S_ε, and p are the elasticity estimate, its standard deviation, and p-value (confidence interval), respectively.

Goodness of Fit



Conclusions

About Data

- Real data can be problematic
- Climate has larger effect on average and low flows
- Land use has small effect but most on low flows
- Consistent with findings by others who have used this method

About Model

- Larger coefficients have greater accuracy (lower p-value)
- Any number of independent variables could be added to model
- Could be used to predict changes in development patterns or climate

Streamflow Prediction

- Population is expected to double over the next 50 years
  - Holding precipitation and water use constant…

➢ Daily Average Streamflow $\overline{Q}$ goes from 71 cfs to 110 cfs

- If precipitation increases with climate change (e.g. 20%)
  - Holding population and water use constant…

➢ Daily Average Streamflow $\overline{Q}$ goes from 71 cfs to 95 cfs