Using Full Factorial Analysis to Enhance Water Quality Monitoring Programs

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SYMBIONT

ROCK ISLAND
ILLINOIS

CITY OF PEORIA

Outline

- Introduction
- n-Orthogonal Sampling Model
- Case Study – Illinois River; Peoria, Illinois

Full Factorial Regression Analysis (FFRA)

- Use when conclusions must be drawn from relatively small sample set.
- Full Factorial approach uses one data point multiple times to evaluate changes in water quality using paired comparisons
- Regression Analysis creates a regression model to overcome problems such as missing samples
- In FFRA, samples are collected in n-orthogonal **dimensions** (influencing factors) each with 2 or more ***levels***.

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Orthogonal Design

- Orthogonal **Dimension** (aka. Influencing Factor)
  - Depth of Sample
  - Location of Sample
- Dimension ***Level***
  - Depth of Sample = Shallow, Deep, Mid-depth
  - Location of Sample = Near Shore, Navigation Channel, Far Shore
- Dimensions are independent of each other
  - Time and Plume Travel – NOT INDEPENDENT
- Dimensions can be Categorical or Continuous

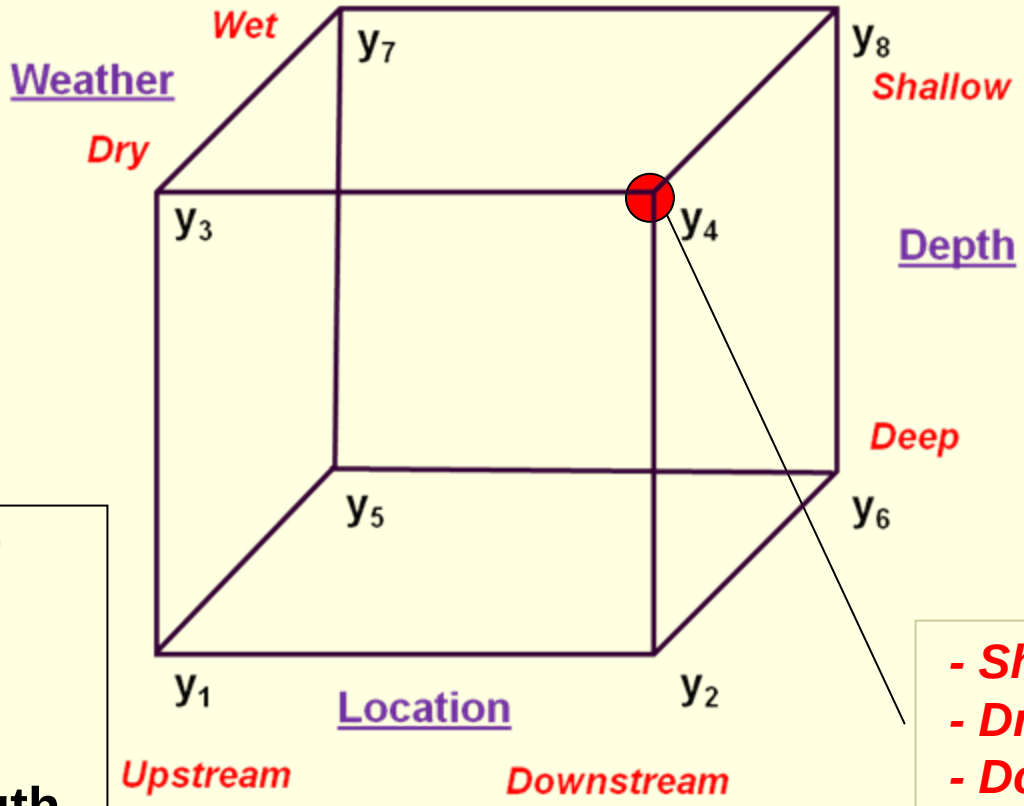
Example Orthogonal Design

3 Dimensions (ie. Influencing Factors) each with 2 *Levels*

- **Weather**
  - *Wet*
  - *Dry*
- **Location from Source**
  - *Upstream*
  - *Downstream*
- **Sample Depth**
  - *Shallow*
  - *Deep*

Orthogonal Design

Orthogonal Design with 3 Dimensions (factors), each with 2 *Levels*

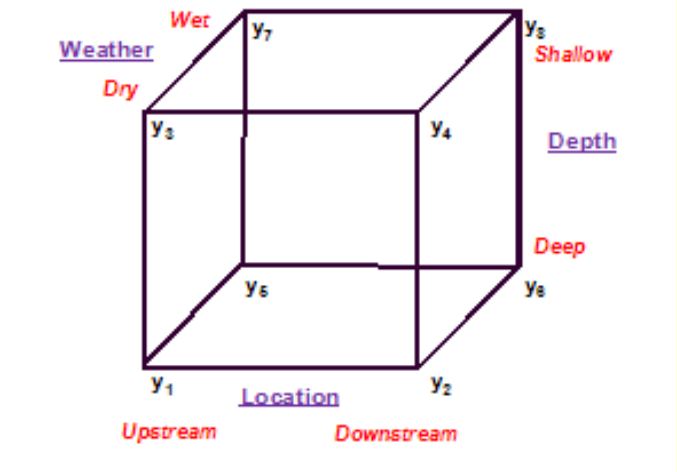


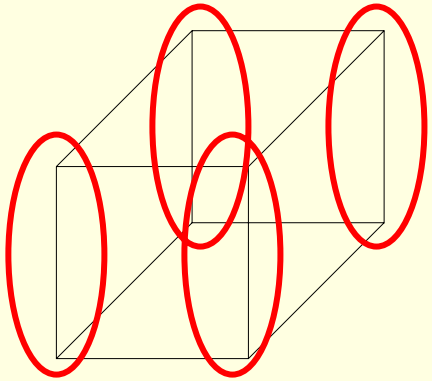
- *Shallow*
- *Dry weather*
- *Downstream*

Utilizing each water quality sample in multiple paired comparisons gives technique its strength.

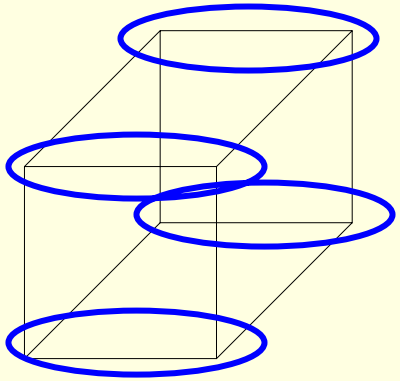
How Does Full Factorial Analysis Work with Orthogonal Design?

- Change in water quality is computed by averaging the change in pairs of samples

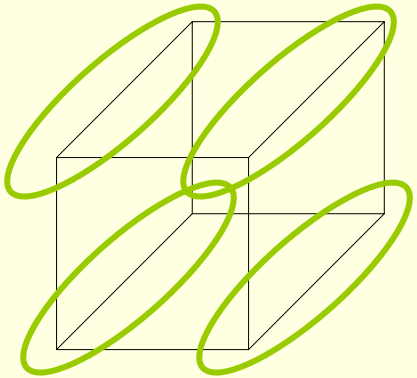




Depth
(Shallow – Deep)

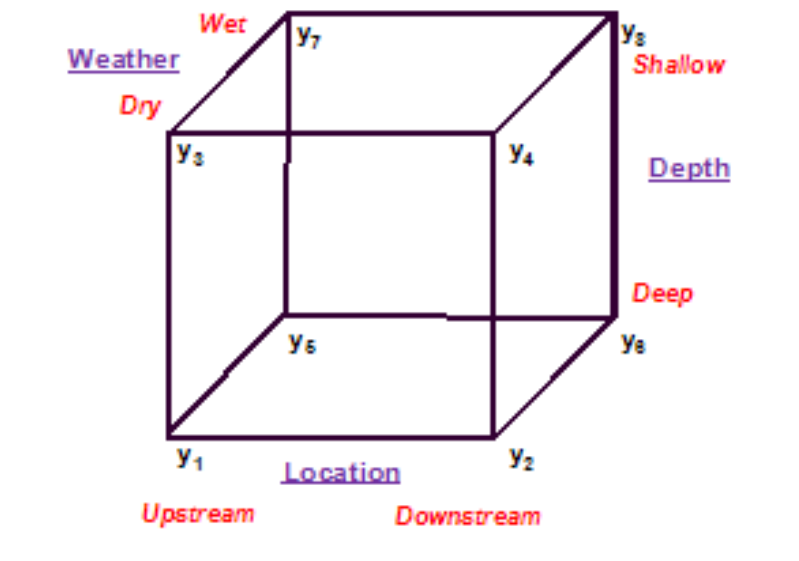


Location
(Upstream - Downstream



Weather
(Wet-Dry)

Orthogonal Design and FFRA



$$\text{Average Location Effect} = \frac{(y_2 - y_1) + (y_4 - y_3) + (y_6 - y_5) + (y_8 - y_7)}{4}$$

$$\text{Average Weather Effect} = \frac{(y_5 - y_1) + (y_6 - y_2) + (y_7 - y_3) + (y_8 - y_4)}{4}$$

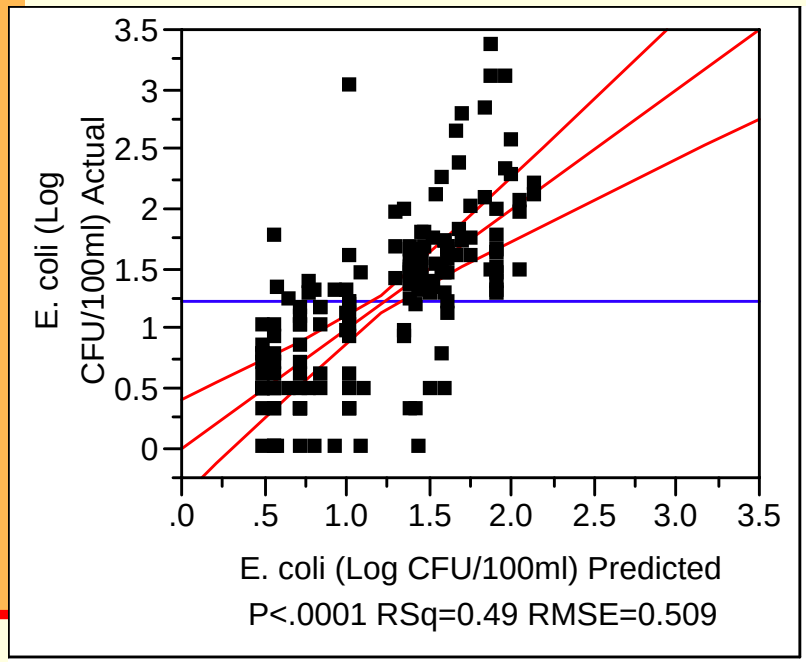
$$\text{Average Depth Effect} = \frac{(y_3 - y_1) + (y_4 - y_2) + (y_7 - y_5) + (y_8 - y_6)}{4}$$

- 2 Sampling Rounds = 8 samples
- 8 Samples = 12 paired comparisons
- W/o FFRA, it would take 24 samples to make the same comparisons

Full Factorial Analysis can assess factor Interactions as well!

How Does the Analysis Work?

JMP 6.0 from SAS Institute, Cary, NC



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	38.854781	4.85685	18.7473
Error	154	39.896562	0.25907	Prob > F
C. Total	162	78.751342		<.0001

- **Dimension** test using ANOVA
- ***Level*** tests using several ad-hoc pair wise comparisons (ex. Tukey-HSD)

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Illinois River; Peoria, Illinois

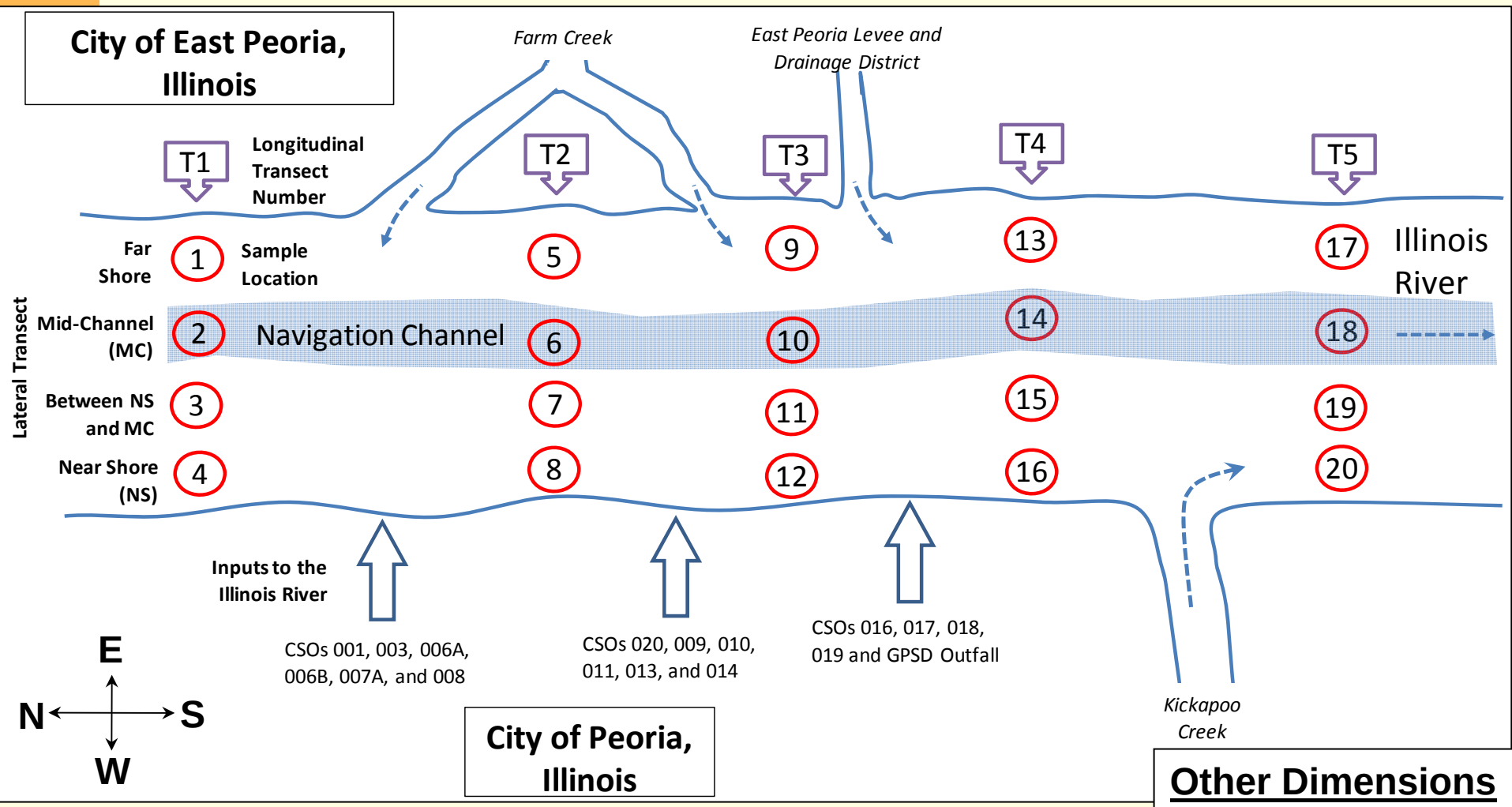
Peoria, Illinois

- City is served by combined and separate storm sewers.
- City discharges at 16 permitted CSO outfalls
- Water levels in Illinois River maintained for navigation.
- Symbiont and other members of the MACTEC team conducted water quality study in the Illinois River to evaluate CSO impacts.

Water Quality Study

- Developed specific set of questions
- Identified **Dimensions** and ***Levels***
- Monitoring network of 20 sampling locations
- Samples collected nearly random and analyzed for selected constituents of concern

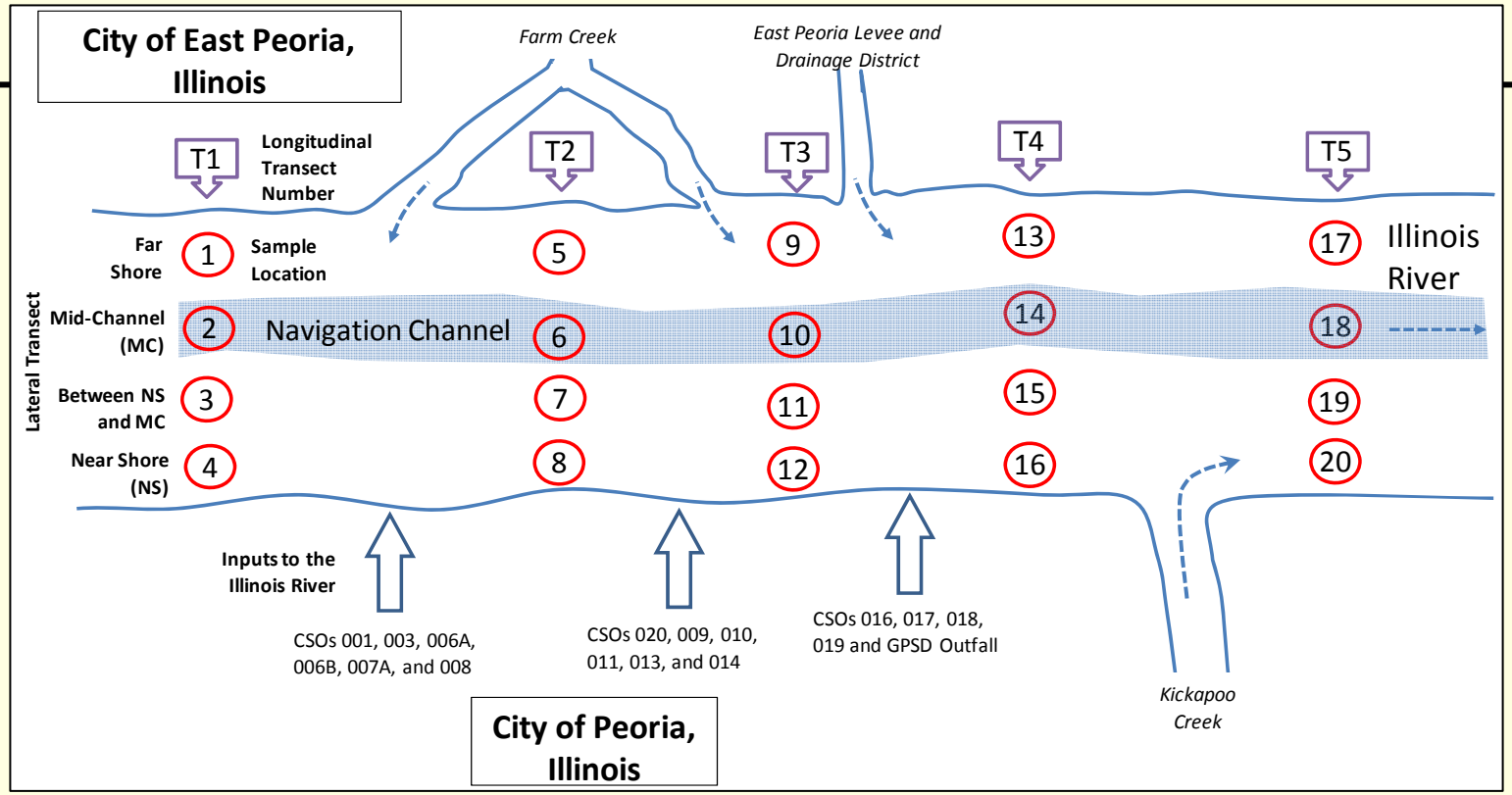
Monitoring Schematic



Other Dimensions

1. Weather
2. River Stage

Example Question and Model



Question	Model Dimensions	Dimension *Levels*
Does water quality in the Illinois River generally degrade during wet weather?	Longitudinal Transect Number	T1, T2, T3, T4, T5
	Lateral Transect	Near Shore, Between Near Shore and Mid Channel, Mid Channel, Far Shore
	Weather	Wet Weather, Dry Weather
	River Stage	Normal Pool, Above Normal Pool

Multiple Models

- Single model was not sufficient to answer all project questions
- Certain effect levels had to be combined

Question	Model Dimensions	Dimension *Levels*
Does water quality degrade in the Illinois River during a CSO event as it flows through the City of Peoria?	Time	Pre-CSO, During CSO, River Flushed
	General Longitudinal Location	Upstream, CSO Warning Area
	River Stage	Normal Pool, Above Normal Pool
	General Lateral Position	Near Shore, River

- Combining ***Levels*** allowed for other questions to be answered

FFRA Modeling Results

- Water quality degrades in the Illinois River during a CSO event, in both the downstream areas impacted by Peoria CSOs and the upstream area not impacted by Peoria CSOs.
- During dry and wet weather, water quality was worse in the CSO Warning Area (Transects 2 through 5 combined) as compared to upstream (Transect 1).
- Etc.

Lessons Learned

- Before starting water quality monitoring project, develop SPECIFIC questions to answer
- Design the monitoring network and analysis to answer these questions
- Some questions cannot be answered by a single model

Acknowledgements

- MACTEC Team Members
- Jane Gerdes, Gene Hewitt – City of Peoria
- Dale Howard, Bob Hawes – City of Rock Island

Questions?