DEVELOPMENT OF A STRATEGIC MONITORING PROGRAM DESIGN

Kick-off Meeting

Sarasota County Water Resources

12 December 2007

Janicki Environmental, Inc.

WORKSHOP TO DESIGN SARASOTA COUNTY'S STRATEGIC MONITORING PROGRAM

DECEMBER 10, 2007

9:00 a.m. – 12:00 p.m.

2817 Cattlemen Road, Sarasota, FL
Conference Room B

Invited Attendees:

COUNTY - Jon Perry, Jack Merriam, John Ryan, Kathy Meaux, Amanda Dominguez, Warren Davis, Theresa Connor, Rene Janneman, Laura Ammeson, Mike Jones, Mary Sassi, Eric Gustafson, Tricia Nihart, Jennifer Ryan, Jeff Banner, Cesar Rodriquez, Frank Desteno

JEA - Hans Zarbock

SWFWMD - Manny Lopez

NPDES MS4 Permit Co-Permitees - Nancy Woodley, Rick Winters, Rob Dwyer, James Linkogle, Elizabeth Wong

USF - Jim Griffin

FDEP - Tom Singleton, Charles Kovach

SBEP - Gary Raulerson, Mark Alderson

CHNEP - Catherine Corbett, Lisa Beever

Mote - Kellie Dixon

Janicki Environmental - Tony Janicki, Mike Wessel

Please submit by 12/7/07 to janickienv@aol.com : Monitoring questionnaire that was previously emailed.
Please bring: Copy of completed monitoring questionnaire.

9:00 a.m. – 9:10 a.m.	INTRODUCTION *Tony Janicki*
9:10 a.m. – 9:30 a.m.	WORKSHOP OBJECTIVES AND MONITORING DESIGN CONCEPTS *Tony Janicki*
9:30 a.m. – 10:00 a.m.	SUMMARY OF EXISTING PROGRAMS *Group Discussion* *Monitoring questionnaire that was emailed to attendees with existing monitoring programs will be reviewed.*
10:00 a.m. – 10:15 a.m.	BREAK
10:15 a.m. – 11:15 a.m.	CRITICAL QUESTIONS *Tony Janicki*
11:15 a.m. – 11:45 a.m.	MONITORING DESIGN CONSIDERATIONS *Tony Janicki*
11:45 a.m. – 1:00 p.m.	LUNCH DISCUSSION Next Steps

OBJECTIVES

- To review monitoring program design concepts
- To review existing monitoring programs
- To define critical questions that need to be addressed by a strategic monitoring program
- To discuss constraints
- To define next steps

Some Additional Topics for Discussion

- Spatial reporting units
- Temporal reporting units
- Meaningful levels of change
- Indicator selection

MONITORING PROGRAM DESIGN

Many have offered advice on how to best design a monitoring program

There is typically one common thread:

Define your objectives

Ambient monitoring information can be used in many ways

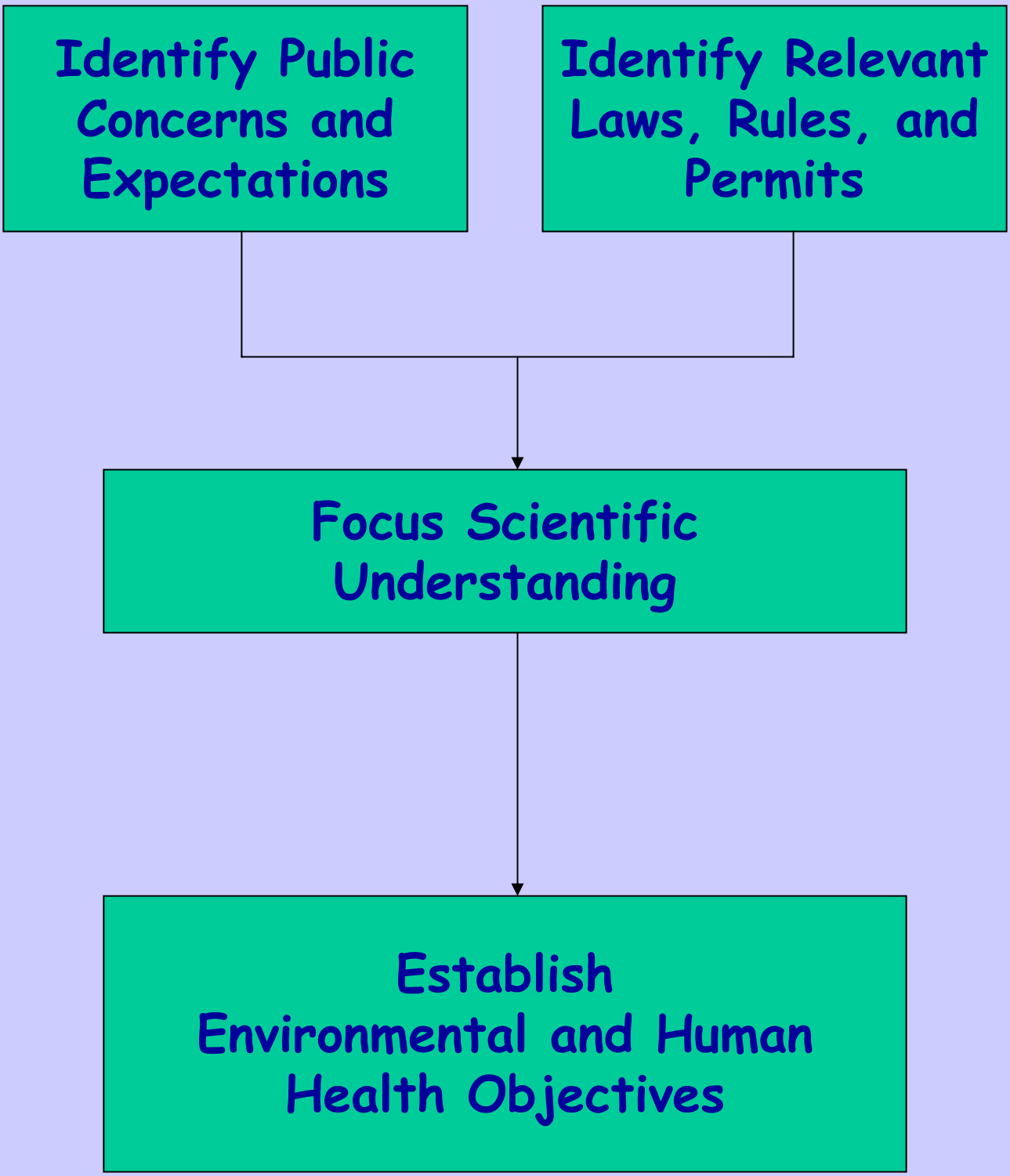
(NRC, 1990)

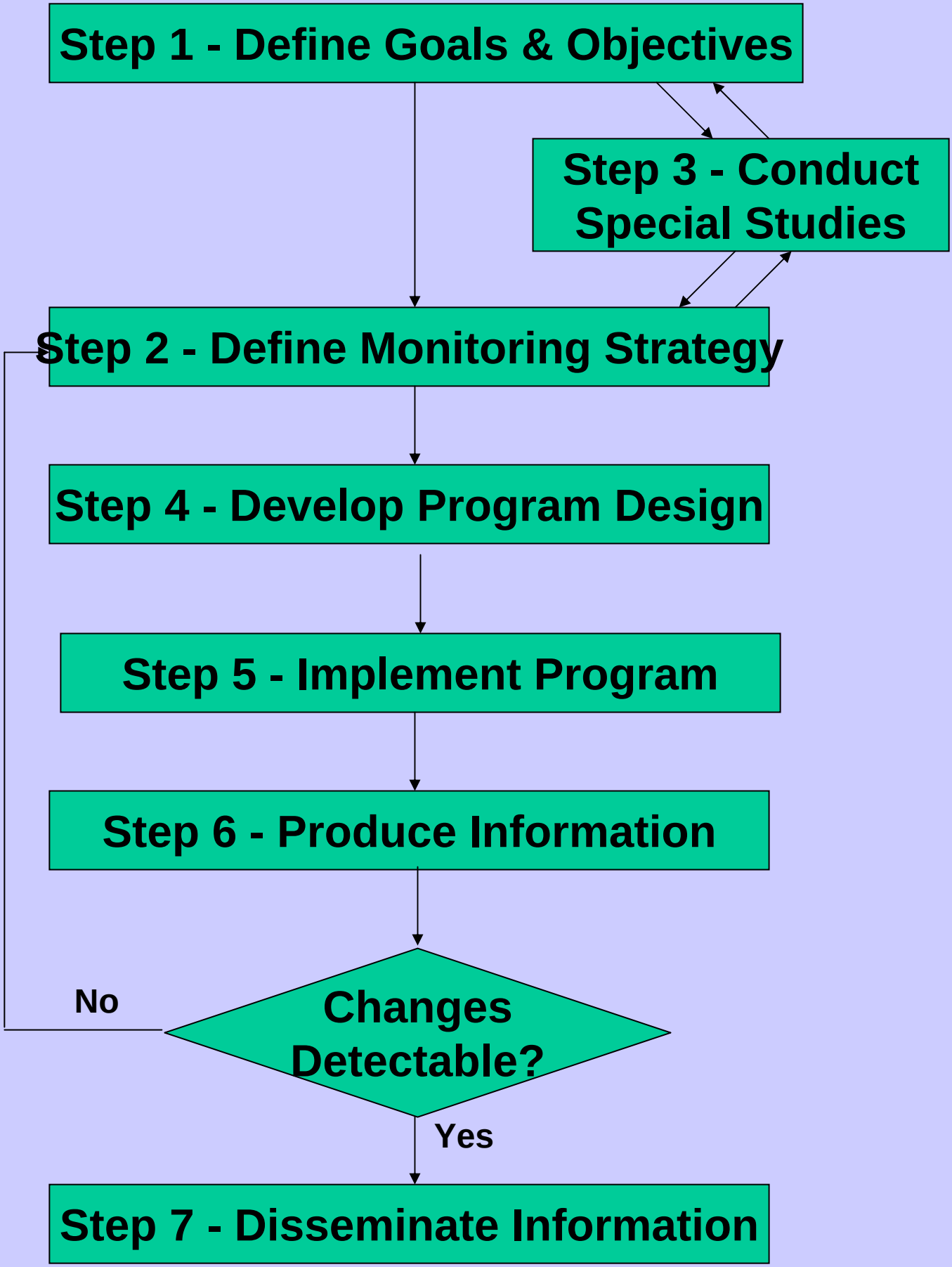
- ⇒Evaluate pollution abatement actions
- ⇒Early-warning system - lower-cost solutions
- ⇒Is it safe to swim or eat fish/shellfish?
- ⇒Model construction, adjustment, verification
- ⇒Scientific rationale for WQ standards
- ⇒Permit compliance
- ⇒Knowledge of how environment responds to human activity

Sound Program Design

- ⇒Goals & objectives - meaningful to the public
- ⇒Data management, synthesis, interpretation, and analysis
- ⇒Quality assurance - peer review
- ⇒Support for the long-term
- ⇒Flexible
- ⇒Make the information available

SETTING THRESHOLDS




Step 1 - Define Goals & Objectives
Step 3 - Conduct Special Studies
Step 2 - Define Monitoring Strategy
Step 4 - Develop Program Design
Step 5 - Implement Program
Step 6 - Produce Information
Changes Detectable?
No
Yes
Step 7 - Disseminate Information

Monitoring Program Elements

- Objectives
- Spatial reporting units
- Temporal reporting units
- Indicator selection
- Statistical model
- Methodology
- Data quality objectives
- Data management
- Data analysis
- Reporting

REVIEW OF EXISTING PROGRAMS

WHAT ARE THE CRITICAL QUESTIONS?

INDICATOR SELECTION CRITERIA

- Critical Criteria
  - Regionally responsive
  - Unambiguously interpretable
  - Low measurement error
  - Simple quantification
  - Environmental impact
  - Low year-to-year variation

INDICATOR SELECTION CRITERIA

- Desirable Criteria
  - Sampling unit stable
  - Available methods
  - Historical record
  - Retrospective
  - Anticipatory
  - Cost effective
  - New information

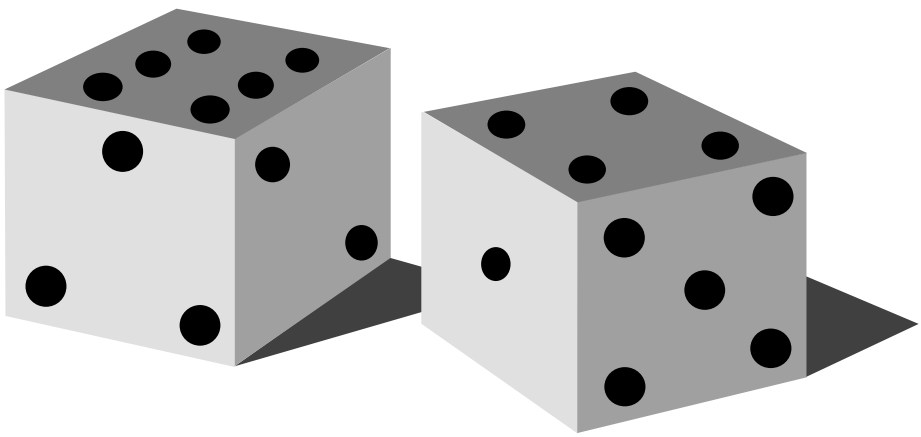
Some Statistical Considerations

TARGET POPULATION

The set of N population units about which inferences will be made

SAMPLED POPULATION

The set of population units directly available for measurement



Some Statistical Considerations

UNBIASED POPULATION ESTIMATES

Metrics whose average value, taken over all possible samples, is equal to the population value of the metric.

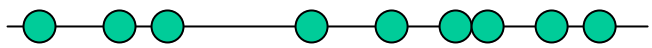
SUBPOPULATION

A specific portion of the target population, defined in either space or time.

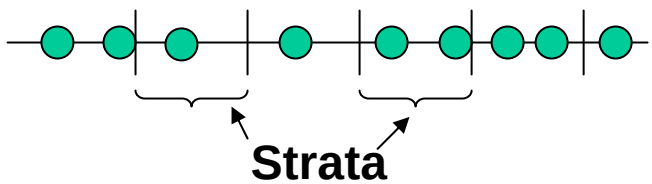
PROBABILITY SAMPLING

This approach requires a definition of the set of distinct samples which the sampling program is capable of sampling. The samples are selected by a random process in which each sample receives its appropriate probability of being sampled.

Simple Random



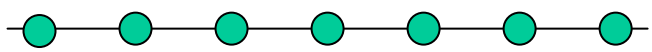
Stratified Random

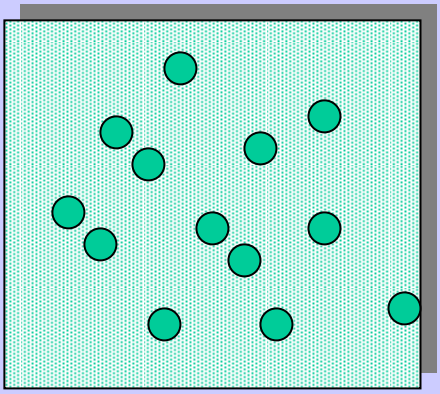


Multistage

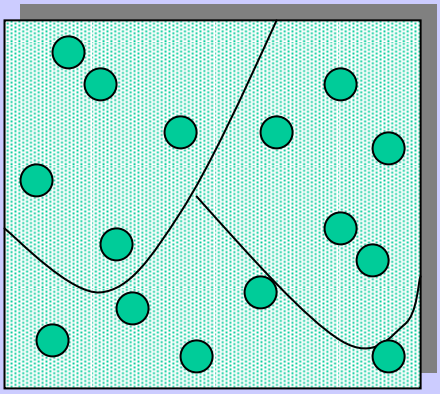
Cluster

Systematic





Simple Random



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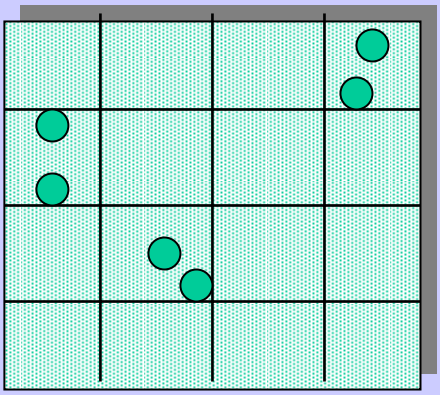
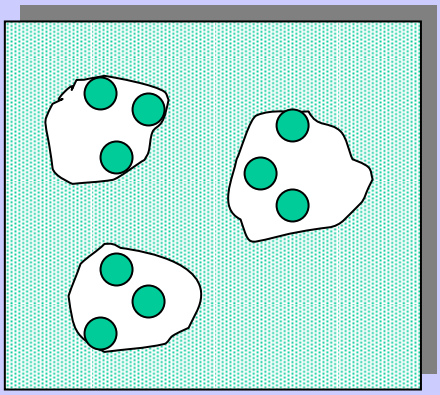
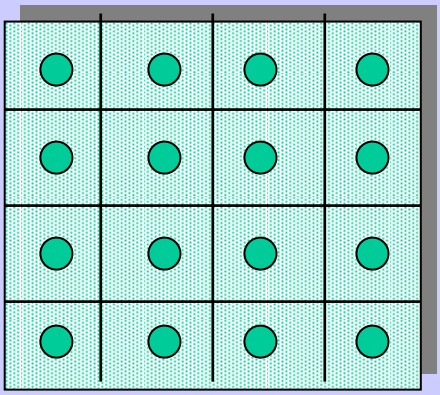


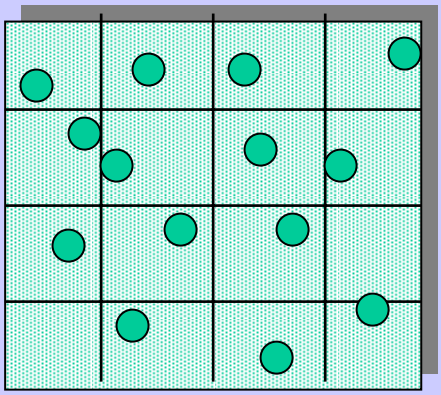
Two-Stage



Cluster



Systematic Grid



Random w/in Blocks

NONPROBABILITY SAMPLING

☞ **Haphazard sampling**: selection without conscious planning; "any sampling location will do"; can lead to biased estimates by sampling at convenient times and locations;

OK if population is completely homogeneous.

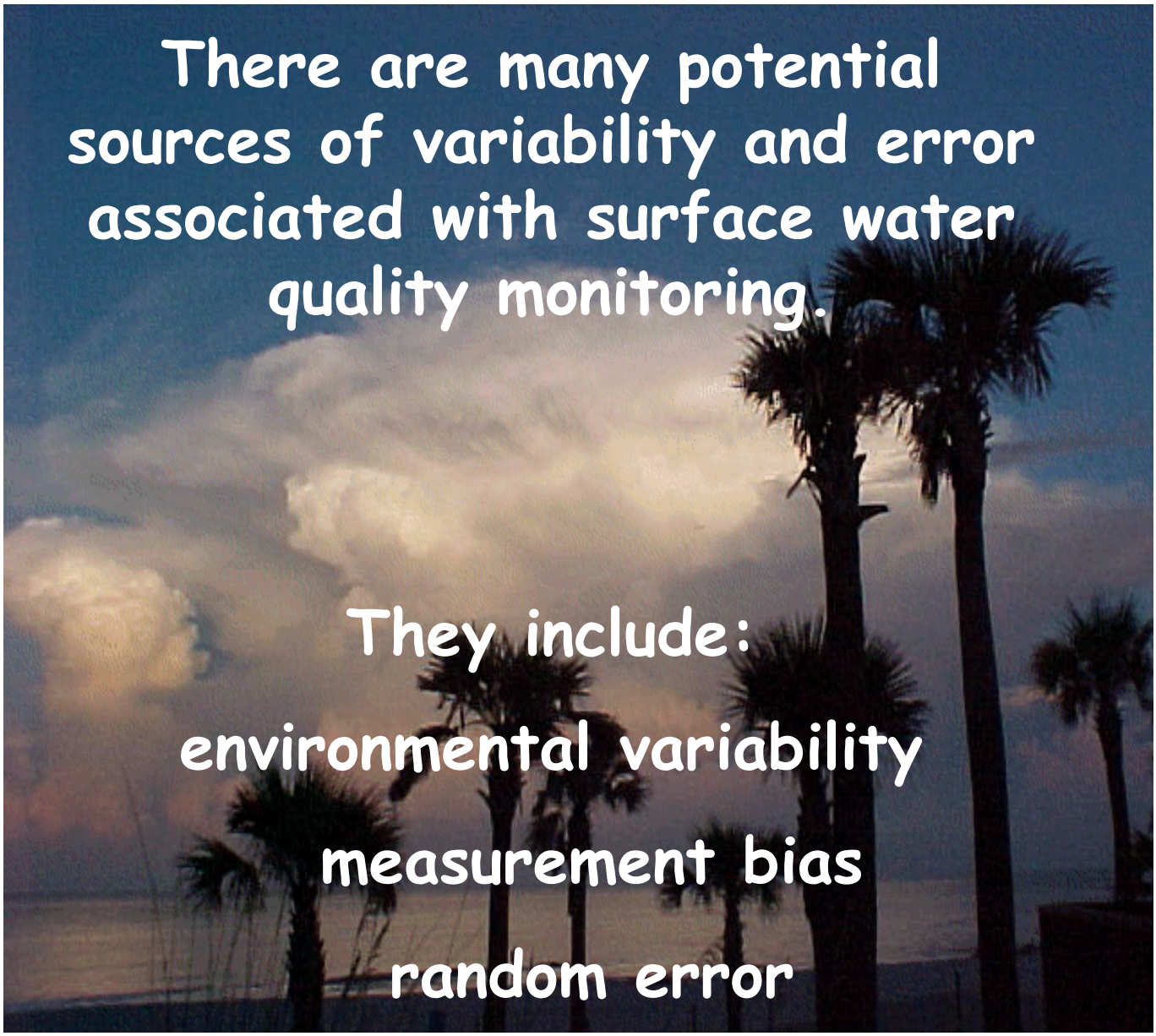
☞ **Judgment sampling**: subjective selection of "typical" or "representative" samples that are close to the sampler's impression of the average of the target population

JUDGMENT SAMPLING

Example: The sampler can see the all of the population units in the target population; selects those that appear to be "representative of average conditions; may choose those that are systematically too large or small.

Judgment sampling can result in accurate estimates of population means and totals. It is difficult to assess the accuracy of the parameter estimates.

SAMPLING VARIABILITY AND ERROR



There are many potential sources of variability and error associated with surface water quality monitoring.

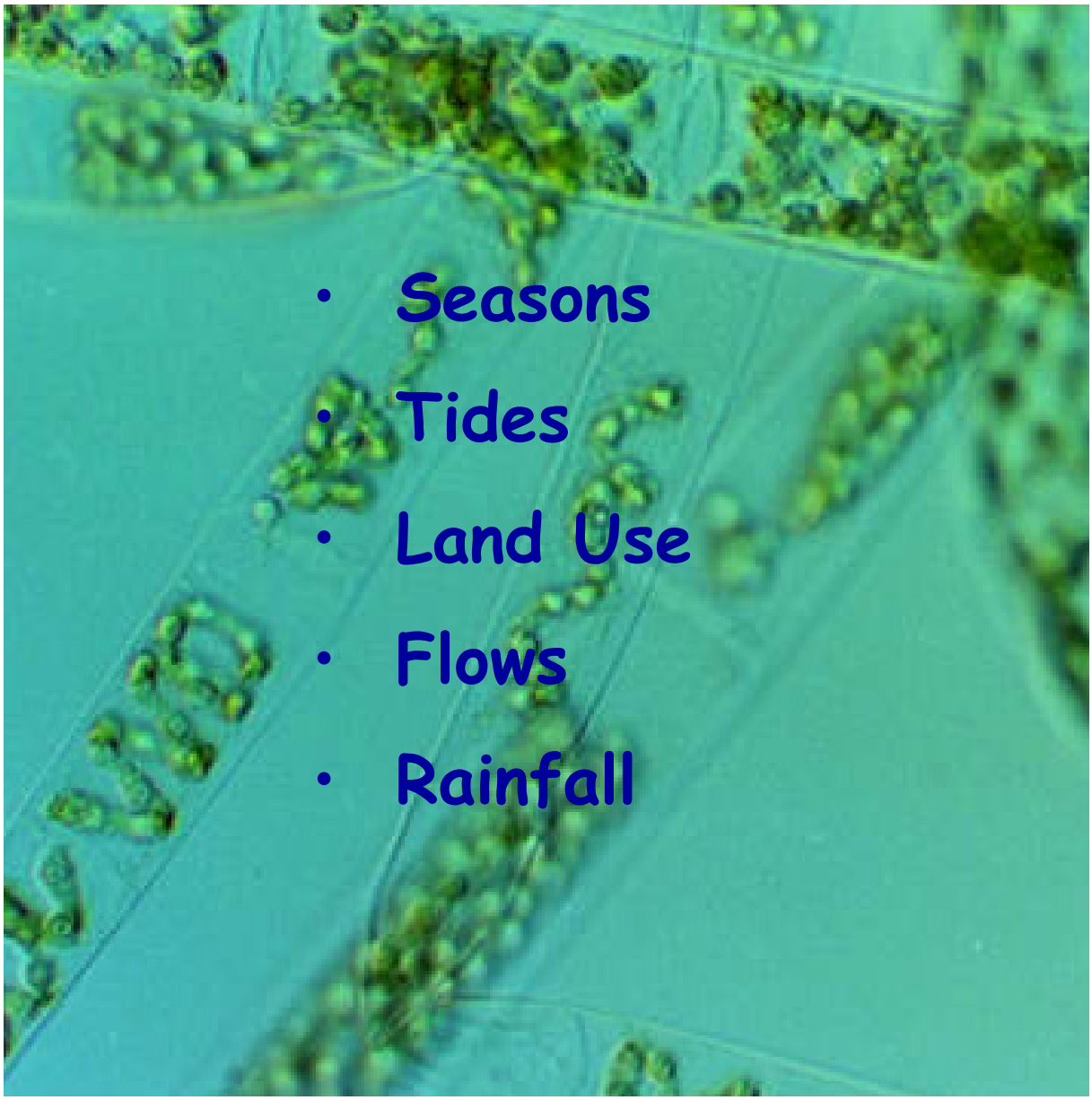
They include:

environmental variability

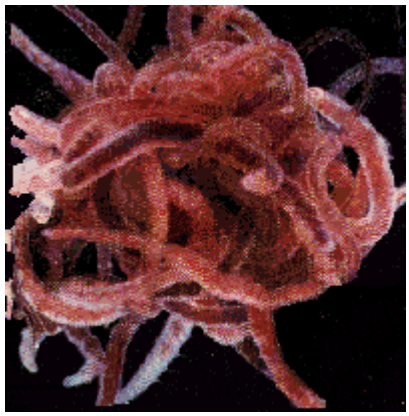
measurement bias

random error

ENVIRONMENTAL VARIABILITY



- Seasons
- Tides
- Land Use
- Flows
- Rainfall



MEASUREMENT BIAS

Consistent under- or over-estimation of the true values in the population units.

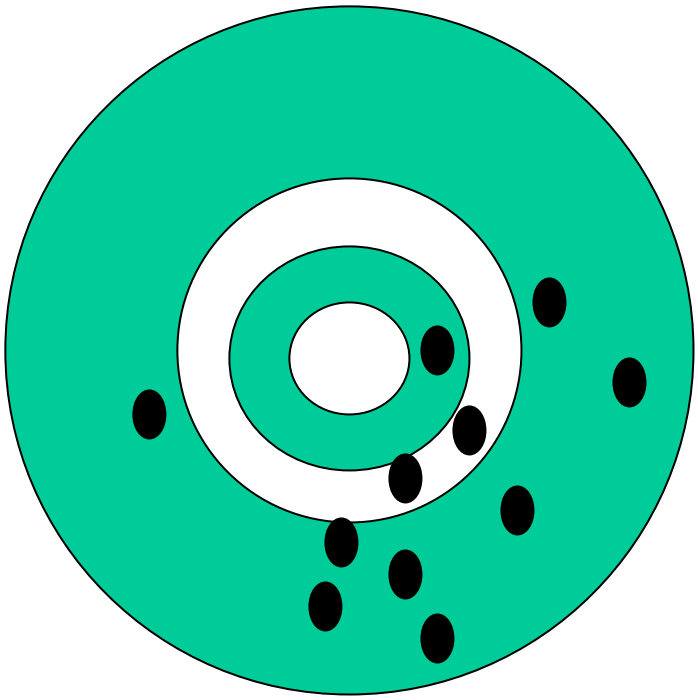
PRECISION

A measure of the size of the closeness of agreement among individual measurements

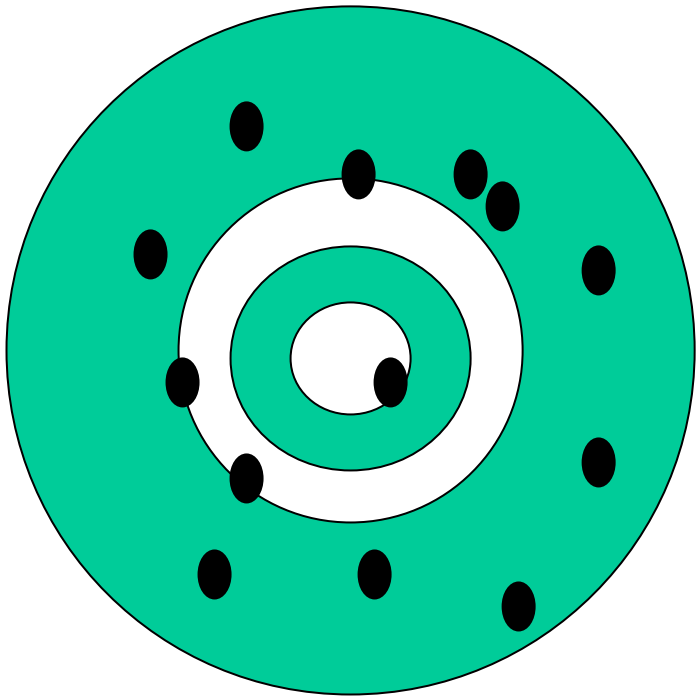
ACCURACY

A measure of the closeness of measurements to the true value.

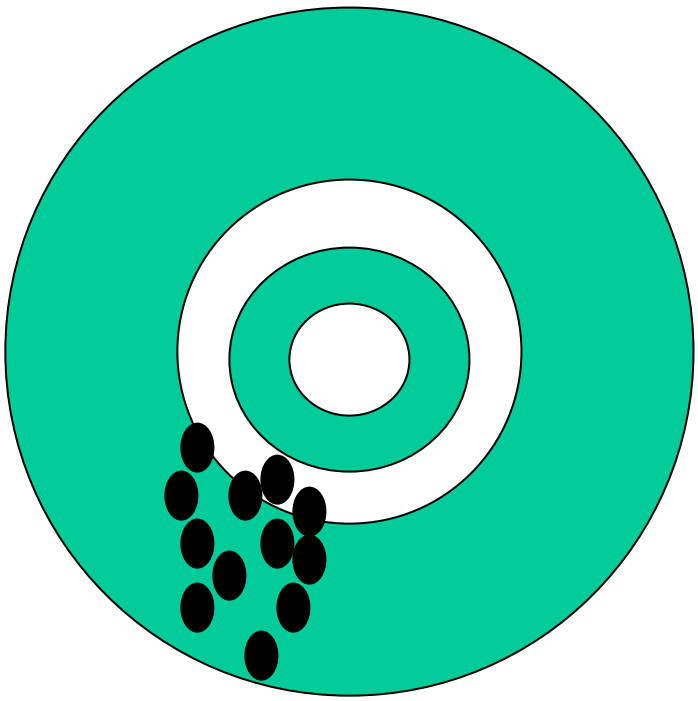
High Bias +
Low Precision



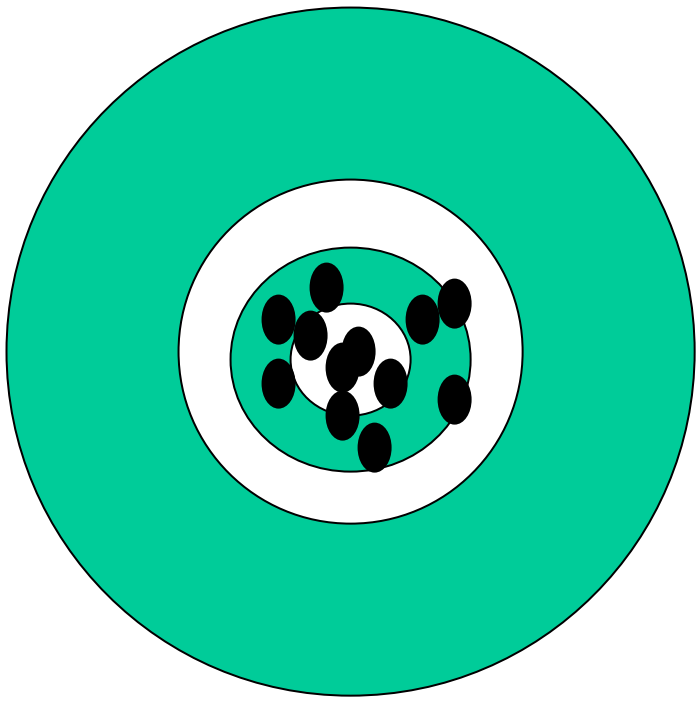
Low Bias +
Low Precision



High Bias +
High Precision

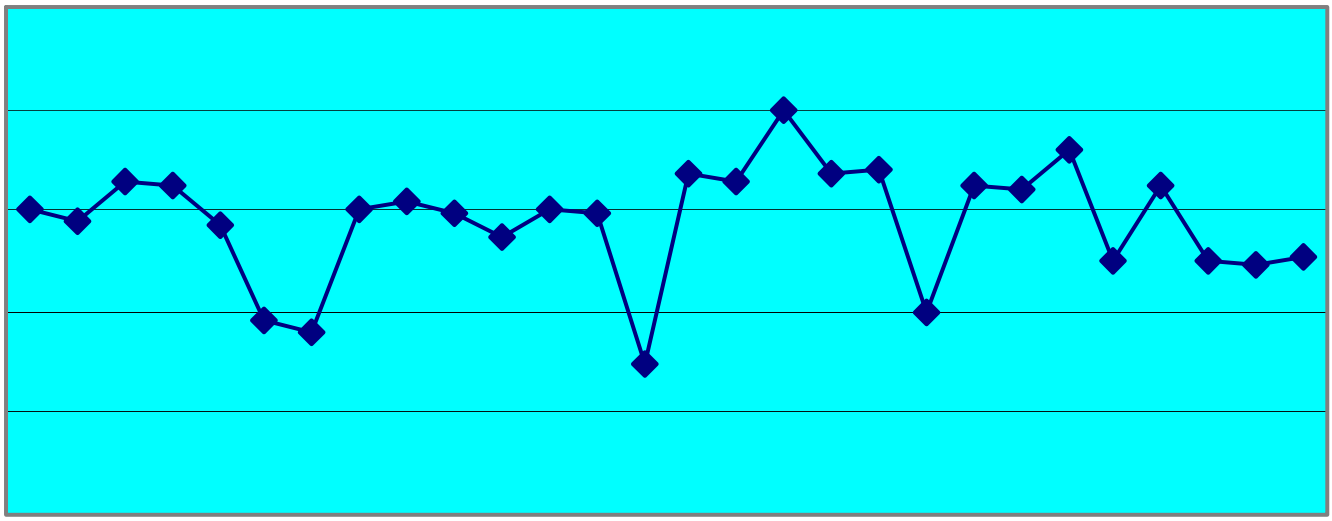


Low Bias +
High Precision

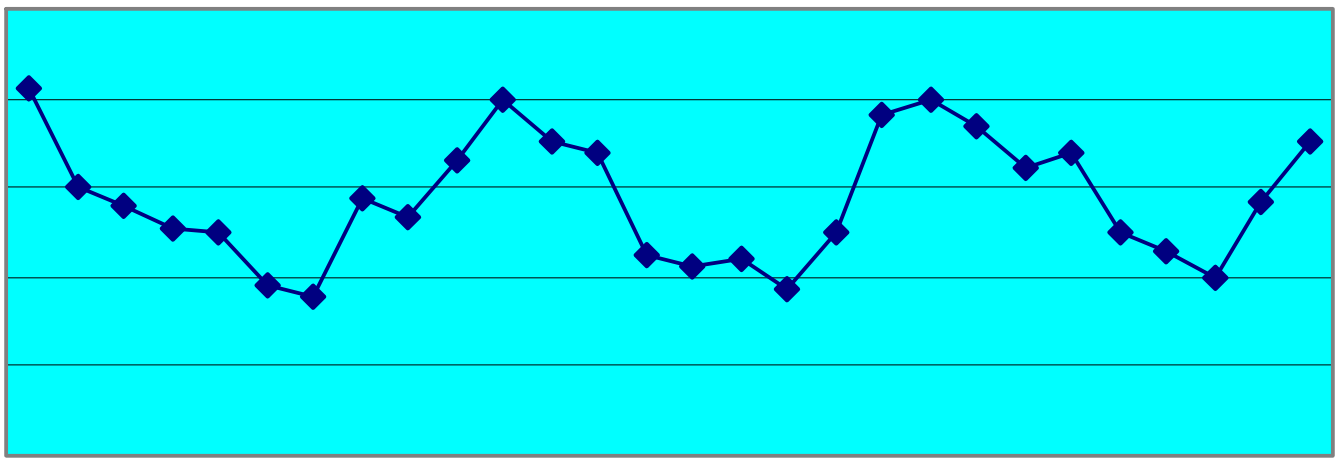


INFORMATION TYPE	METHOD TYPE		
	Graphical	**Estimation**	**Testing**
Average Conditions	Box and Whisker Plots Time Series Plots	Sample Mean, Median Confidence Limits Standard Deviation, Error	T-test ANOVA Mann-Whitney Test Wilcoxon Signed Rank Test Kruskal-Wallis Test
Trends or Changing Conditions	Annual Box and Whisker Plots Time Series Plots	Linear Regression Seasonal Kendall Slope Estimator	T-test for Significance of Slope BACI

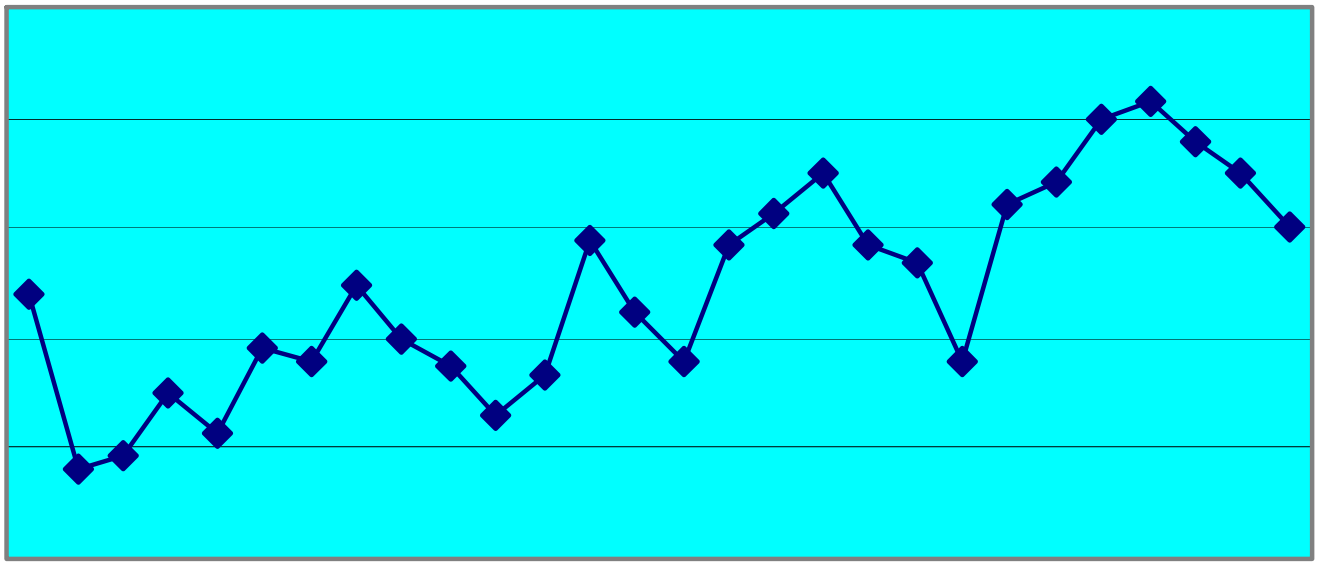
Random



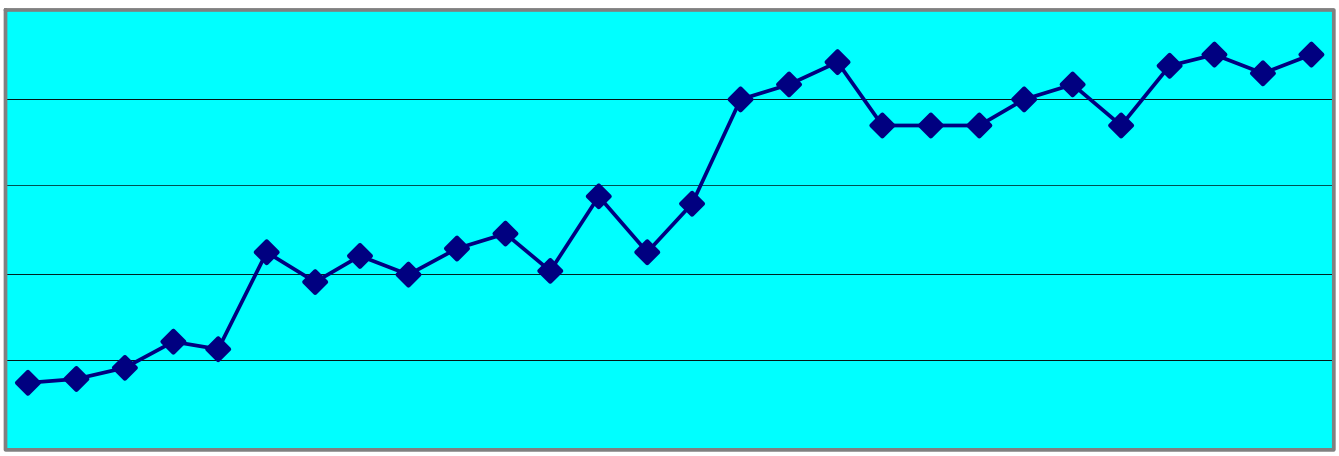
Cycle + Random



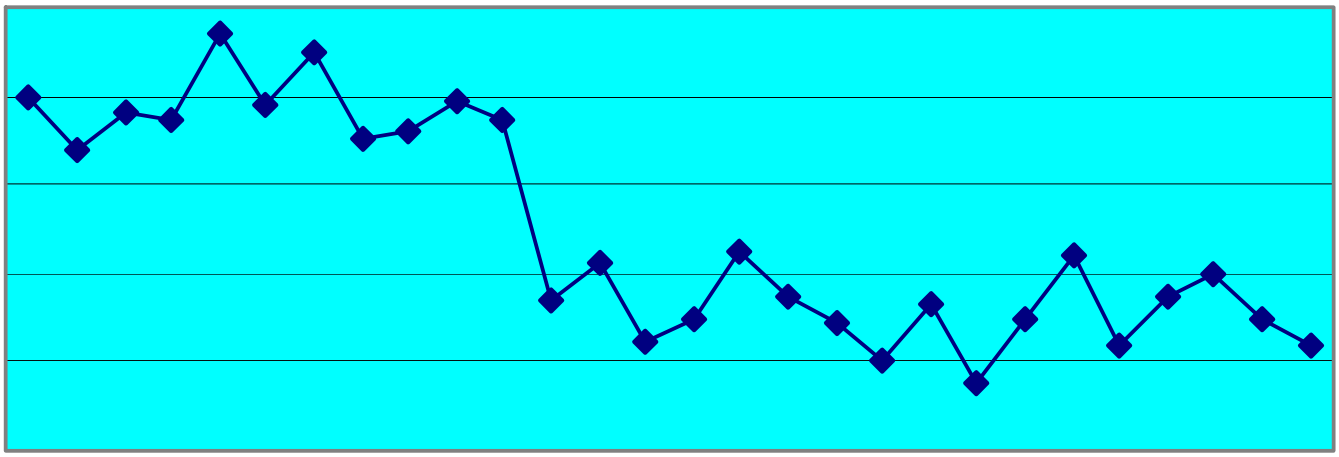
Trend + Random



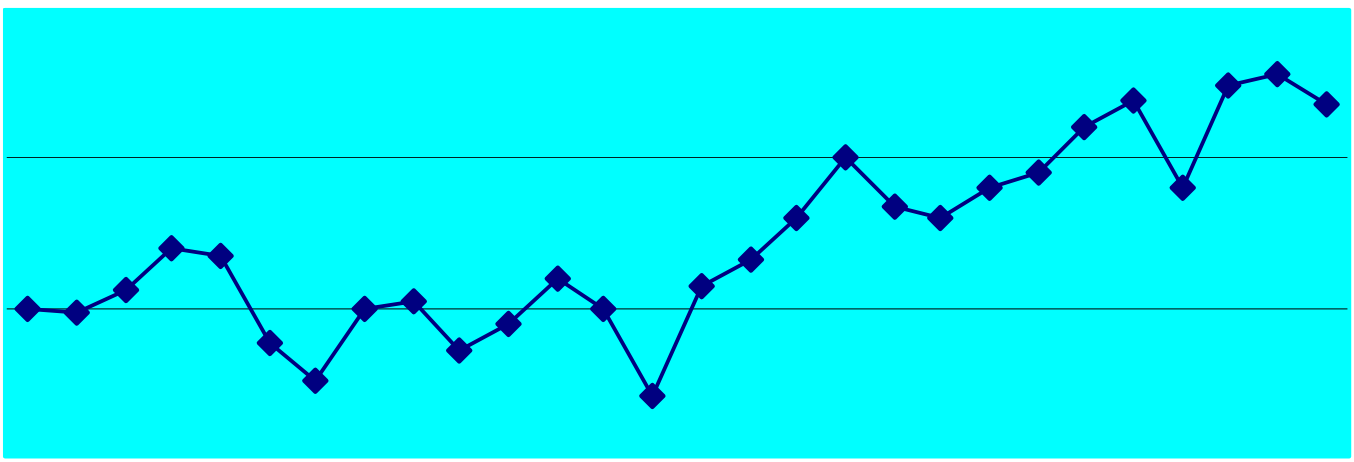
Trend + Non-random



Step-change + Random



Random followed by Trend



Year	**Season**						
	1	2	3	...	j	…	m
1	y_{11}	y_{21}	y_{31}	…	y_{1j}	…	y_{1m}
2	y_{12}	y_{22}	y_{32}	…	y_{2j}	…	y_{2m}
3	y_{13}	y_{23}	y_{33}	…	y_{3j}	…	y_{3m}
…	…	…	…	...	…	…	…
i	y_{1i}	y_{2i}	y_{3i}	…	y_{ij}	…	y_{im}
...	...	...	...	...	...	…	...
n	y_{1n}	y_{2n}	y_{3n}	...	y_{nj}	…	y_{nm}
N	n_1	n_2	n_3	...	n_i	...	n_m

m = # samples/year

n = # years

y_{ij} = j^{th} sampling time in year i

i = 1, 2, 3, … n

j = 1, 2, 3, … m

Additive Model

$$y_{ij} = \alpha_i + \beta_j + \varepsilon_{ij}$$

Additive Model

$$y_{ij} = \alpha_i + \beta_j + \varepsilon_{ij}$$

α_i = between-year component

β_i = within-year component

ε_{ij} = residual variability

MANN-KENDALL TEST

Distribution-Free Trend Test

This nonparametric test for trend is appropriate when seasonal effects are not significant.

Particularly useful when data are not normally distributed and when some data are missing.

The test statistic is

$$S = \Sigma \, sgn \, (y_k - y_i)$$

where:

$$sgn \; x = \begin{cases} 1 & \text{if} \quad x > 0 \\ 0 & \text{if} \quad x = 0 \\ -1 & \text{if} \quad x < 0 \end{cases}$$

SEASONAL KENDALL TEST

Distribution-Free Trend Test

Effect of season eliminated by calculating the test statistic separately for each season and summing for overall test

The test statistic for season j is

$$S_j = \Sigma \, sgn \, (y_{kj} - y_{ij})$$

where:

$$sgn \; x = \begin{cases} 1 & \text{if} \quad x > 0 \\ 0 & \text{if} \quad x = 0 \\ -1 & \text{if} \quad x < 0 \end{cases}$$

The seasonal Kendall test statistic is:

$$S = \Sigma \, S_j$$

SEN OR SEASONAL KENDALL SLOPE ESTIMATOR

(Gilbert, 1987)

The nonparametric slope estimate is the median of all possible slope estimates based on pairs of observations in the same season.

B is the slope estimator and is the median of:

$$(y_{kj} - y_{ij})/(k - i)$$

for $i<k$ and j fixed, taken over $j=1,2,\ldots m$.

Nonparametric Estimation of a Step Change in a Water Quality Variable

(Hirsch, 1988)

Suppose a step change occurred after year d; what was the magnitude of the change in level between the two periods:

$i=1,2,\ldots d \quad \Rightarrow \quad i=d+1,\ldots n$

For season j,
all possible differences (y_{kj} - y_{ij}) are calculated where

$i=1,2,\ldots d$ and $k=d+1,\ldots n$,

for $j=1,2,\ldots,m$.

LEAST SQUARES REGRESSION

Linear regression is a parametric trend testing tool.

Tests of significance of a change over time of a specified form and estimation of the change are part of the regression methodology.

A t-test may be used to test that the true slope is different from zero.

There are several assumptions and/or considerations that affect the robustness of the t-test:

- normality of the data and errors
- no serial correlation
- homogeneity of error variances
- seasonal cycles

It is critical to test the assumptions discussed above. Some of the problems can be alleviated by employing some form of transformation; most commonly application is the logarithmic.

LEAST SQUARES REGRESSION

Some Examples

Linear Trend

$$y_{ij} = \alpha_j + \beta_j i + \varepsilon_{ij}$$

Curvilinear Trend

$$y_{ij} = \alpha_j + \beta_{jt} i + \varepsilon_{ij}$$

Step-Change at Year k

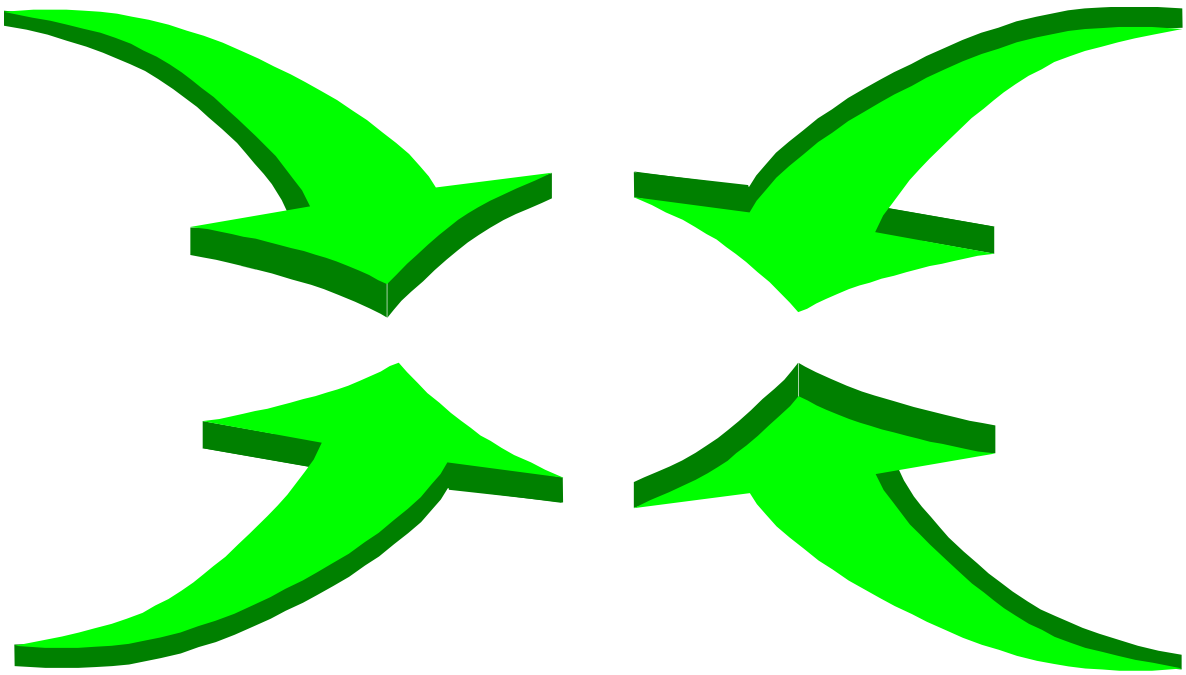
$$y_{ij} = \alpha_{j1} + \varepsilon_{ij}, \qquad i \le k$$

$$= \alpha_{j2} + \varepsilon_{ij}, \qquad i > k$$

Stable Annual Cycle and Linear Trend

$$y_{ij} = \mu + \beta_1 \cos(2\pi j/12) + \beta_1 \sin(2\pi j/12) + \omega(i + j/12) + \eta_{ij}$$

In some cases, the seasonal variation is poorly represented by sinusoidal terms and a general smoothing technique may be more appropriate.



LOESS - a **locally weighted regression smoother** may be more appropriate.

(Cleveland and Grosse, 1991)

Log - Log Multiple Regression Model

$$\ln \swarrow = \hat{a}_0 + \hat{a}_1 \ln(Q) + \hat{a}_2 \ln(Q)^2$$

$\swarrow$ = estimated concentration

Q = instantaneous discharge

$\hat{a}_0$, $\hat{a}_1$, and $\hat{a}_2$ = estimated by regression

FLOW ADJUSTMENT FOR WATER QUALITY DATA

(Smith and Alexander, 1983)

$$\swarrow = \hat{a}_0 + \hat{a}_1 * f(Q)$$

$\swarrow$ = estimated concentration

Q = instantaneous discharge

$\hat{a}_0$ & $\hat{a}_1$ = intercept and slope, respectively

f(Q) = Q (linear)

f(Q) = ln Q (log)

f(Q) = 1/(1+BQ) (hyperbolic)

f(Q) = 1/Q (inverse)

TREND ANALYSIS AS AN ENVIRONMENTAL IMPACT ASSESSMENT TOOL

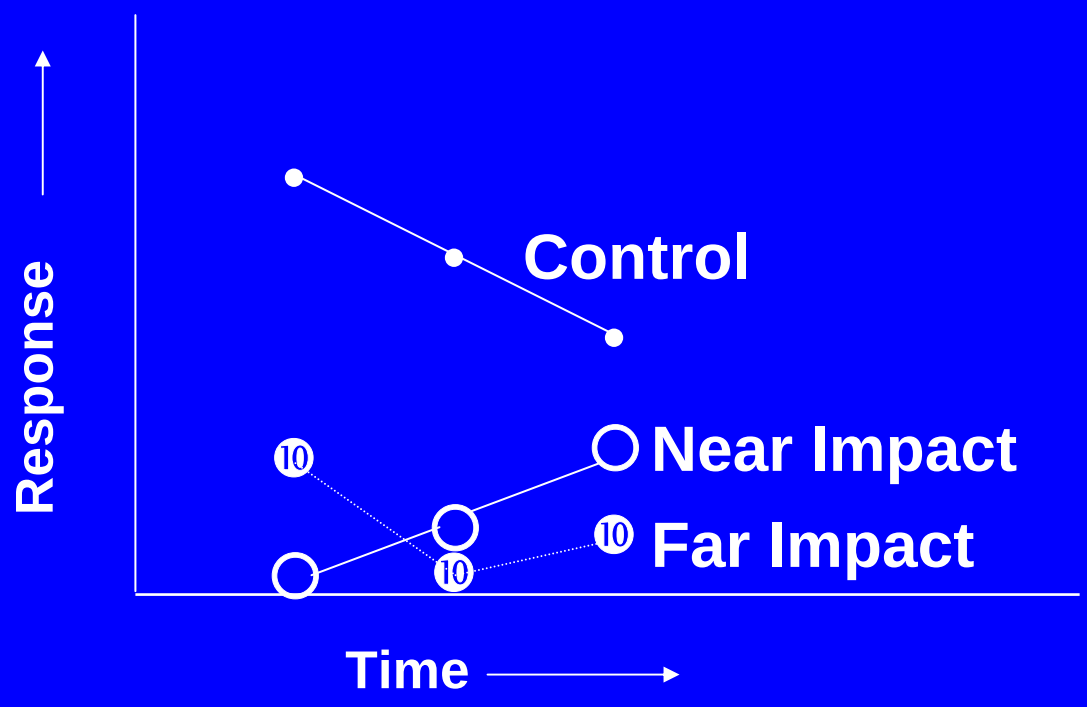
Frequently, answering questions regarding potential environmental impact assessment relies upon conducting an experiment with replicates each randomly applied to one of several treatments, and subsequent statistical analysis.

It is almost impossible to ensure random application of treatments with replication. In general, the goal of a study of an unreplicated perturbation is to determine whether the state of the perturbed system differs significantly from what it would have been in the absence of the perturbation.

(Stewart-Oaten et al., 1992)

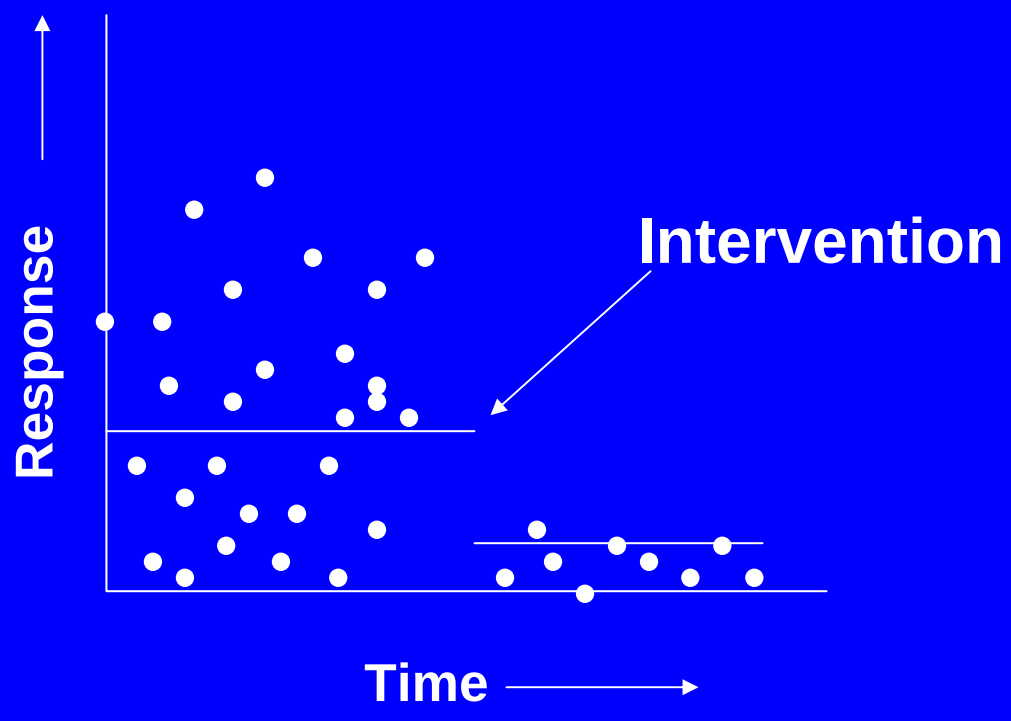
THREE COMMONLY USED IMPACT ASSESSMENT DESIGNS

CONTROL - IMPACT



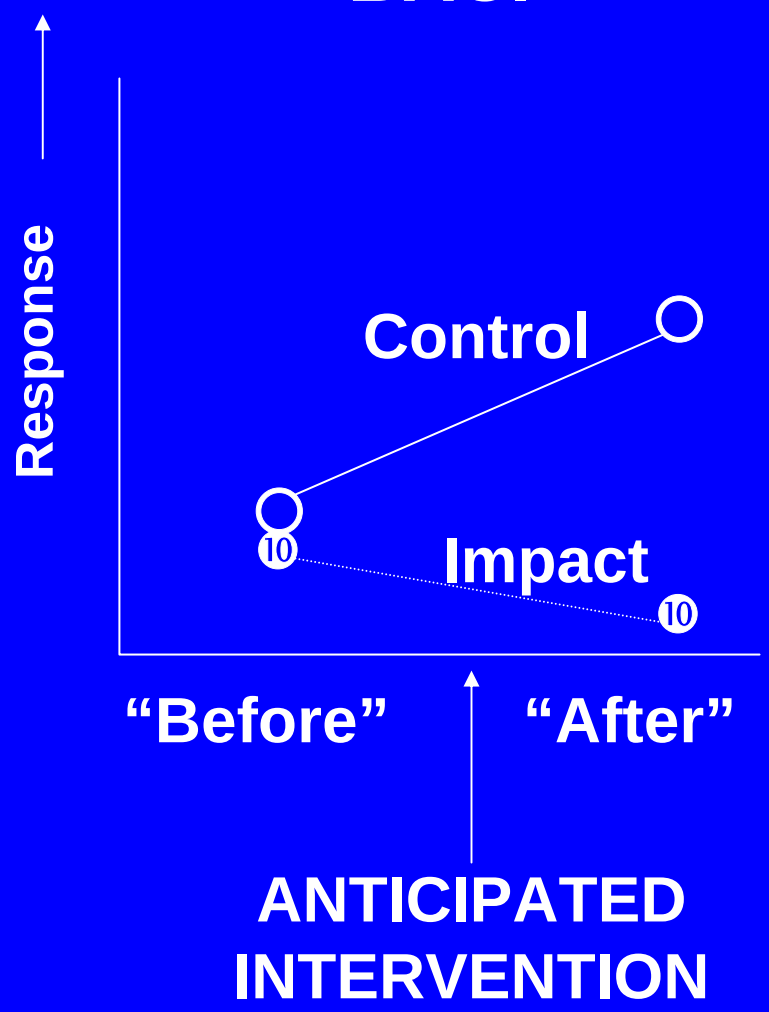
THREE COMMONLY USED IMPACT ASSESSMENT DESIGNS

BEFORE - AFTER



THREE COMMONLY USED IMPACT ASSESSMENT DESIGNS

BACI



BEFORE-AFTER-CONTROL-IMPACT DESIGN

BACI

The BACI design entails sample collection from two sites (impact and control), at least one time each before and after the anticipated intervention.

The before-after time treatment is of most interest; the control-impact location treatment is generally of secondary interest.

The test of an impact entails examination of the time-location interaction.

TREATMENT	TIME	CONTROL	IMPACT	DIFFERENCE
Before	1	y_{b1c}	y_{b1t}	d_{b1}
	2	y_{b2c}	y_{b2t}	d_{b2}
	.	.	.	.
	.	.	.	.
	.	.	.	.
	n	y_{bNc}	y_{bNt}	d_{bn}
After	n+1	y_{a1c}	y_{a1t}	d_{a1}
	n+2	y_{a2c}	y_{a2t}	d_{a2}
	.	.	.	.
	.	.	.	.
	.	.	.	.
	n+m	y_{amc}	y_{amt}	d_{am}

The observed differences between the Control and Impact sites during the Before period is taken as an estimate of the mean difference that would have existed in the After period before the perturbation.

The differences from the Before period are compared to those observed in the After period.

A change in the mean difference indicates that the system at the Impact site has undergone a change relative to the Control site.

These differences are tested using a two-sample t test.

There are three important assumptions associated with application of the t test.

1.) Additivity - time and location effects are additive, in the absence of a perturbation the Control-Impact differences are the same over all dates.

2.) Independence - observed differences from different dates are independent.

3.) Identical Normal Distributions - the distribution of the deviation (observed difference - mean difference) is a) the same for each date within a period, b) the same in the After period as in the Before period, c) normal.