Environmental Policy Analysis: How Much Uncertainty is Too Much and How Do We Know?

A Case Example of the Assessment of Ozone Monitor Network Options

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Problems with Uncertainty in Policy Analysis

- Consider uncertainty a flaw in otherwise good scientific analysis – ignore
- Failing to understand impact on policy alternatives – surprise
- Uncertainty exacerbates problems of limited time and resources at policy making organizations.

Decision Makers' Dilemma

- Would a different policy choice be made if the data are different than initially presented or assumed?
- How can this be determined?
  - First question: How much uncertainty can a decision tolerate? (Not, how uncertain is the data)

Multi-criteria Integrated Resource Assessment (MIRA)

- Examine how much uncertainty a particular decision can tolerate.
- Learn how uncertainty affects policy options
  - Test different data possibilities

MIRA Methodology

- Determine criteria (stakeholder participation) and define with a metric (data input)
- Index criteria (expert)
- Initialize with values (preference schemes)
- Obtain ranked list of options
- **Iterate**

- Details in: Stahl et al. (2002) BSTS 22(6): 443-459 and Stahl, C.H. (2003) University of Delaware Morris Library HN999 2004 .S781.

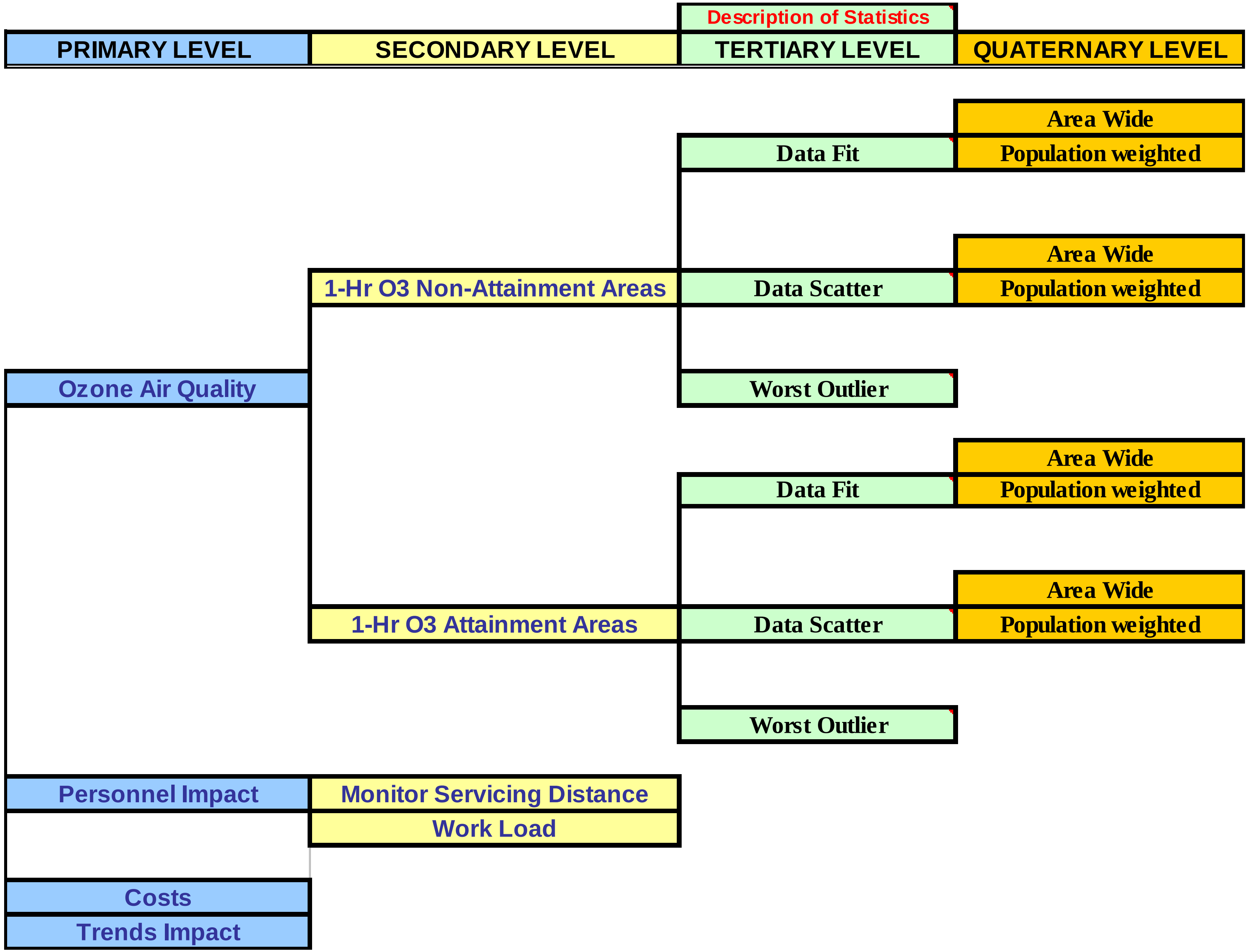
Monitoring Network Decision Question

- Is the current ozone monitoring network adequate?
  - Public health needs
  - Ecosystem needs
  - Considering costs, benefits (better air quality estimates)

Ozone Monitor Network Demonstration Study

- Monitoring data used for assessing human and ecological ozone exposure
- U.S. Mid-Atlantic region: currently 110 ozone monitors primarily in urban areas
- Assessment criteria (14 total):
  - Air Quality estimate (interpolation from monitoring sites and from modeled values)
  - Personnel resources (workload and distance from state agency office)
  - Costs (maintenance of existing and installation of new monitors)
  - Historical trends (value of historical data at the same site)

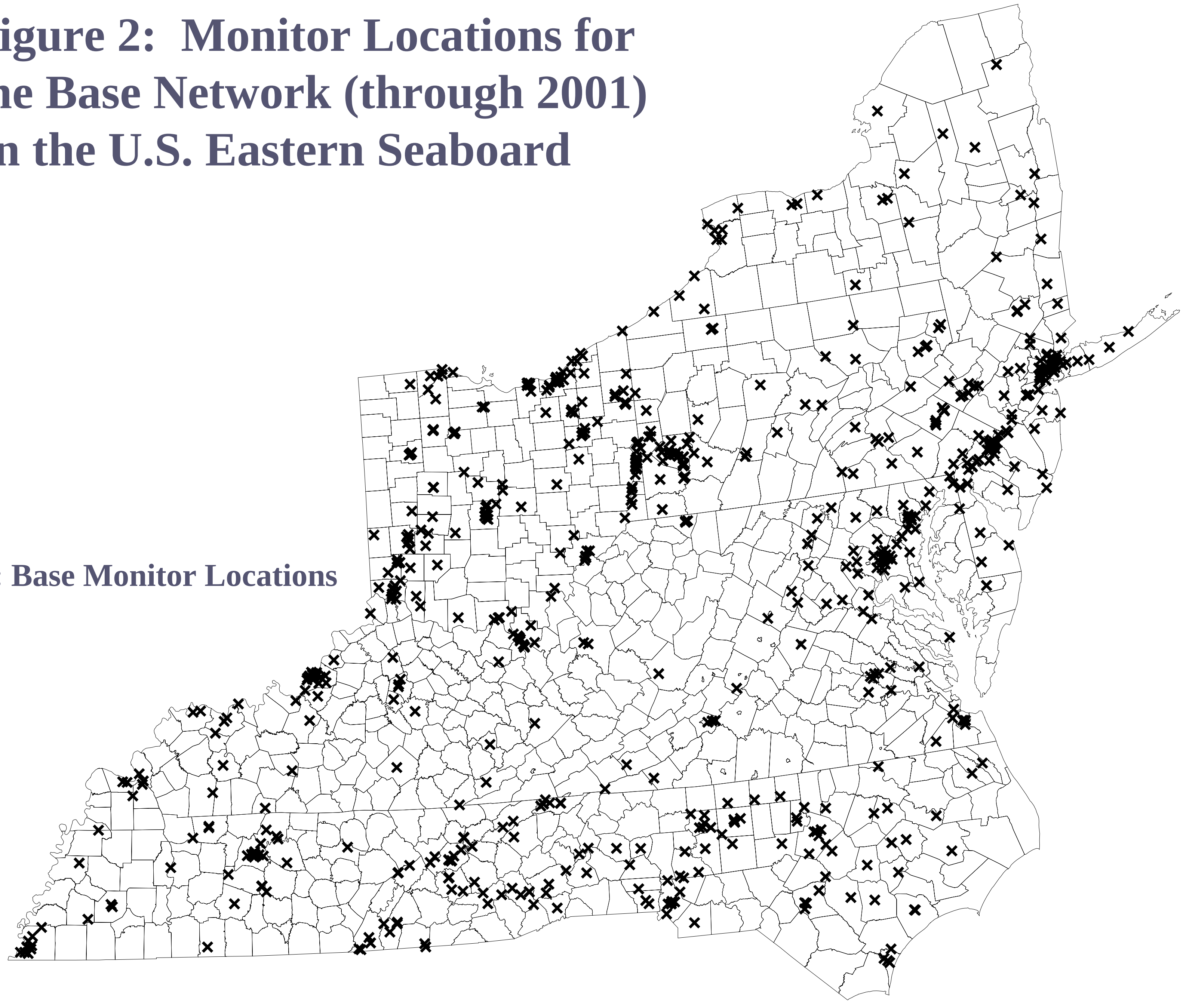
Figure 1: Ozone Monitoring Network Assessment Criteria



Monitor Network Options

- Status quo
  - Base
- Least Cost
  - (Base – 62 monitors) = 48 monitors
- Best Kriging Estimate
  - (Least Cost + 4 monitors) = 52 monitors

Figure 2: Monitor Locations for the Base Network (through 2001) on the U.S. Eastern Seaboard



X: Base Monitor Locations

Figure 3: Least Cost Network Option – Monitor Locations in U.S. Mid-Atlantic Region

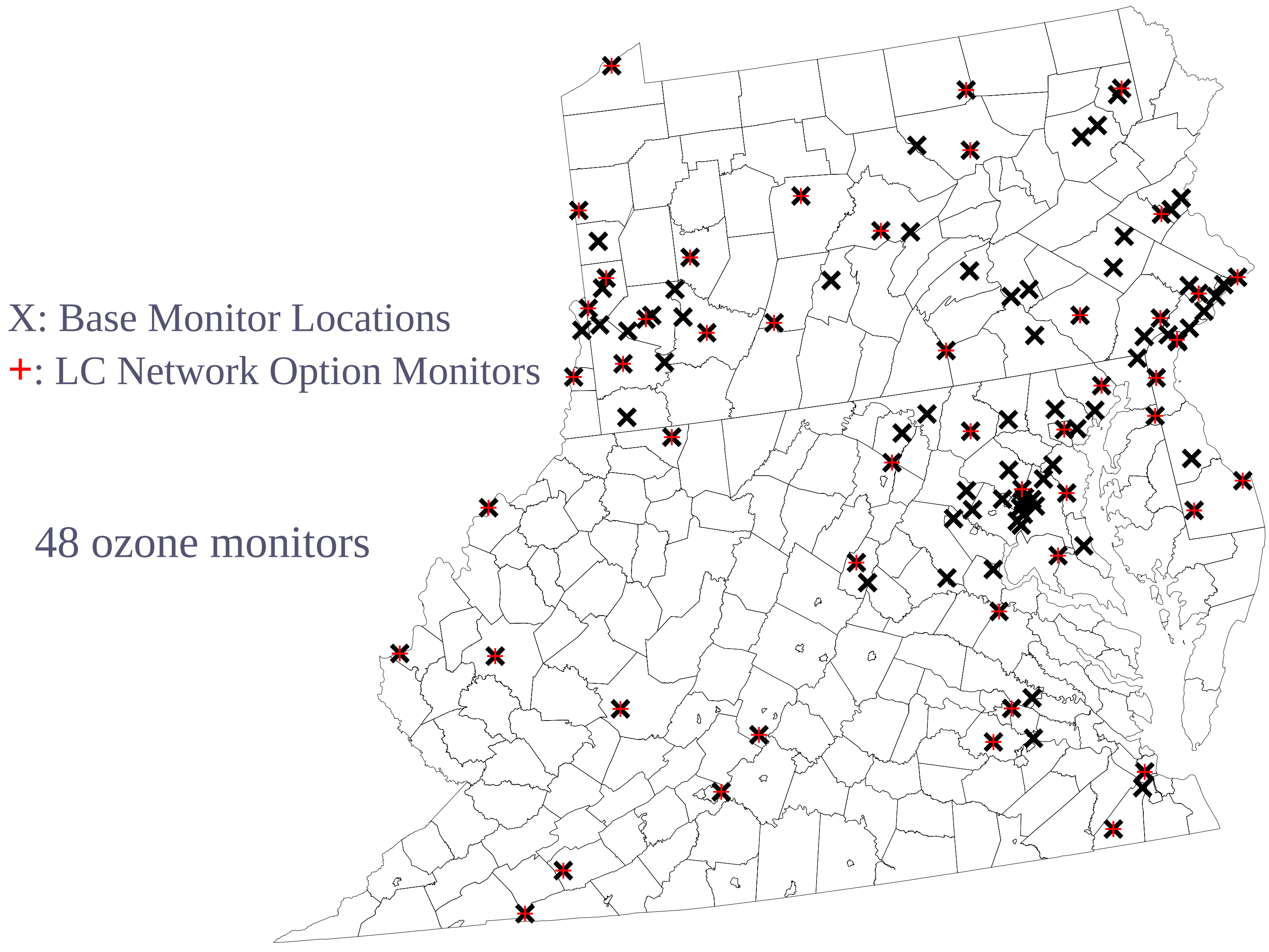
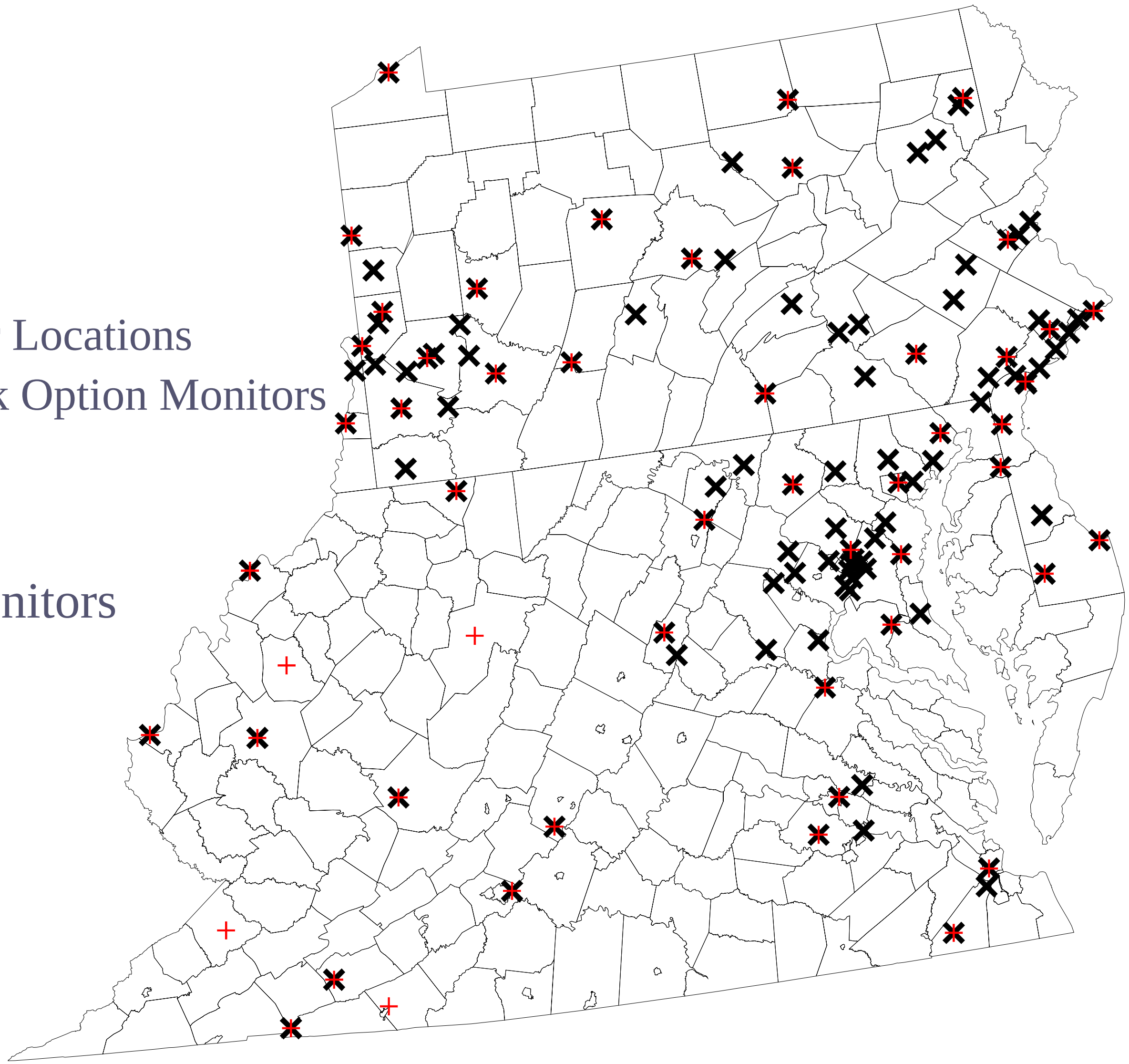


Figure 4: Best Kriging Estimate Network Option – Monitor Locations in the U.S. Mid-Atlantic Region

X: Base Monitor Locations

+: BKE Network Option Monitors

52 ozone monitors



Data

- Ozone monitoring data
  - Ozone design value (3 year averages)
  - Historical trends of design values
  - Interpolation where no monitors
- Capital costs
  - New monitoring station
  - New ozone analyzer
- Operation and Maintenance costs
  - Monitoring station
  - Ozone analyzer
- Distance from monitoring station to state office
- Ratio of state staff to ozone monitors

Demonstration Focus

- Example is simplified for demonstration
- O/M cost for monitoring station
- O/M cost for ozone analyzer
- Examine how data uncertainty in these two variables affects 3 network options.

Cost Data

- Best current estimate; Obtained in 1993 dollars
  - O/M costs for an ozone monitoring station = $16,000
  - O/M costs for an ozone analyzer = $3,400

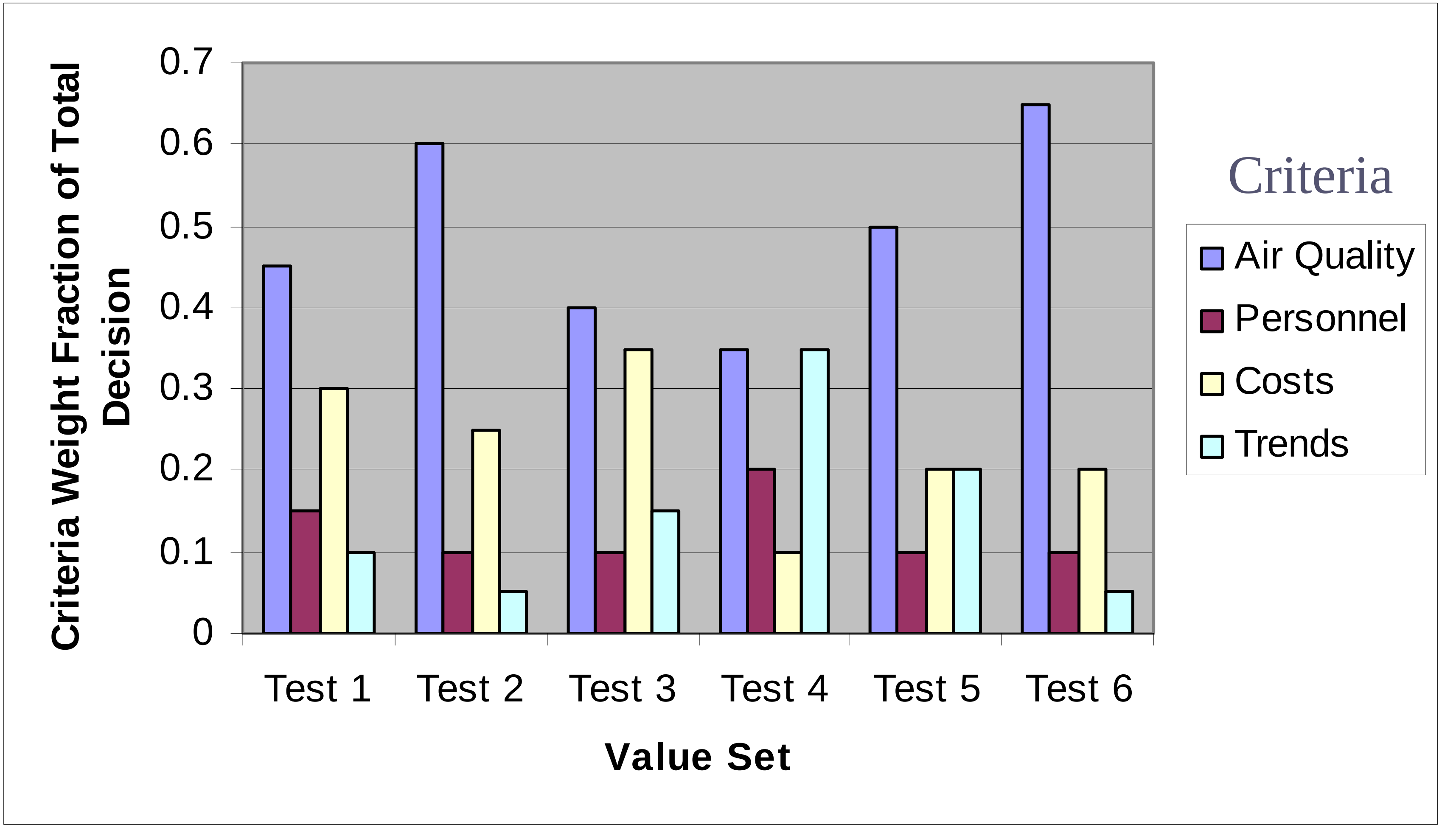
Data is Certain

- Previous MIRA analysis produced certain cardinal ranking: Best Kriging Estimate (BKE), Least Cost (LC), and Base (B)
- Keep same cardinal ranking for now
  - Air quality always greatest weight BUT actual weight can vary considerably.
- Values = Preference schemes
  - Many different sets produce BKE-LC-B cardinal ranking
  - 6 value sets tested

Cardinal Ranking Sidebar

- Understanding uncertainty = does the cardinal rank change with data uncertainty? If so, how/when/under what circumstances?
  - When are we “surprised”? (Cardinal ranking changes)
- Demonstration starts with seeing how original ranking is preserved and then examines how/when this changes with data uncertainty.
  - Bracket the analysis first with decision question’s uncertainty tolerance, then go to scientist/statistician.

Figure 5: Primary Criteria Level Value Sets



Criteria-Option Relationship

- Learn these relationships through experimentation and stakeholder discussions.
- In general,
  - Weighting Air quality criterion more heavily tends to favor BKE,
  - Weighting Trends criterion more heavily tends to favor Base, and
  - Weighting Personnel and Costs criteria more heavily tend to favor Least Cost

How much more preferred is the top ranked option?

- Compare separation between top ranked option and second ranked option with different value sets (via ratios).
  - Greater separation = first option more greatly preferred than next option
  - Actual criteria sums not important – relative ranking and degree of separation more important
  - Important to know for testing impact of data uncertainty on option ranking.

Table 2: Criteria Sums for selected Value sets

Value Set	Best Kriging Estimate	Least Cost	Base	BKE/LC (%)
Test 1	4.3904	4.2699	3.7098	2.81
Test 4	3.3083	3.2741	3.2044	1.04
Test 6	4.7658	4.3335	4.2502	9.97

Data is Uncertain

- Impact of Uncertainty on Top-ranked option?
  - Different combinations of data uncertainty produce differently ranked options.
  - Plot maximum criteria sum (i.e., first ranked network option) against varying data ranges.
    - When does the BKE option no longer look the most attractive when compared to the other options?

Figure 6: Impact on Top-ranked option due to O/M Cost Uncertainties (Test 4)

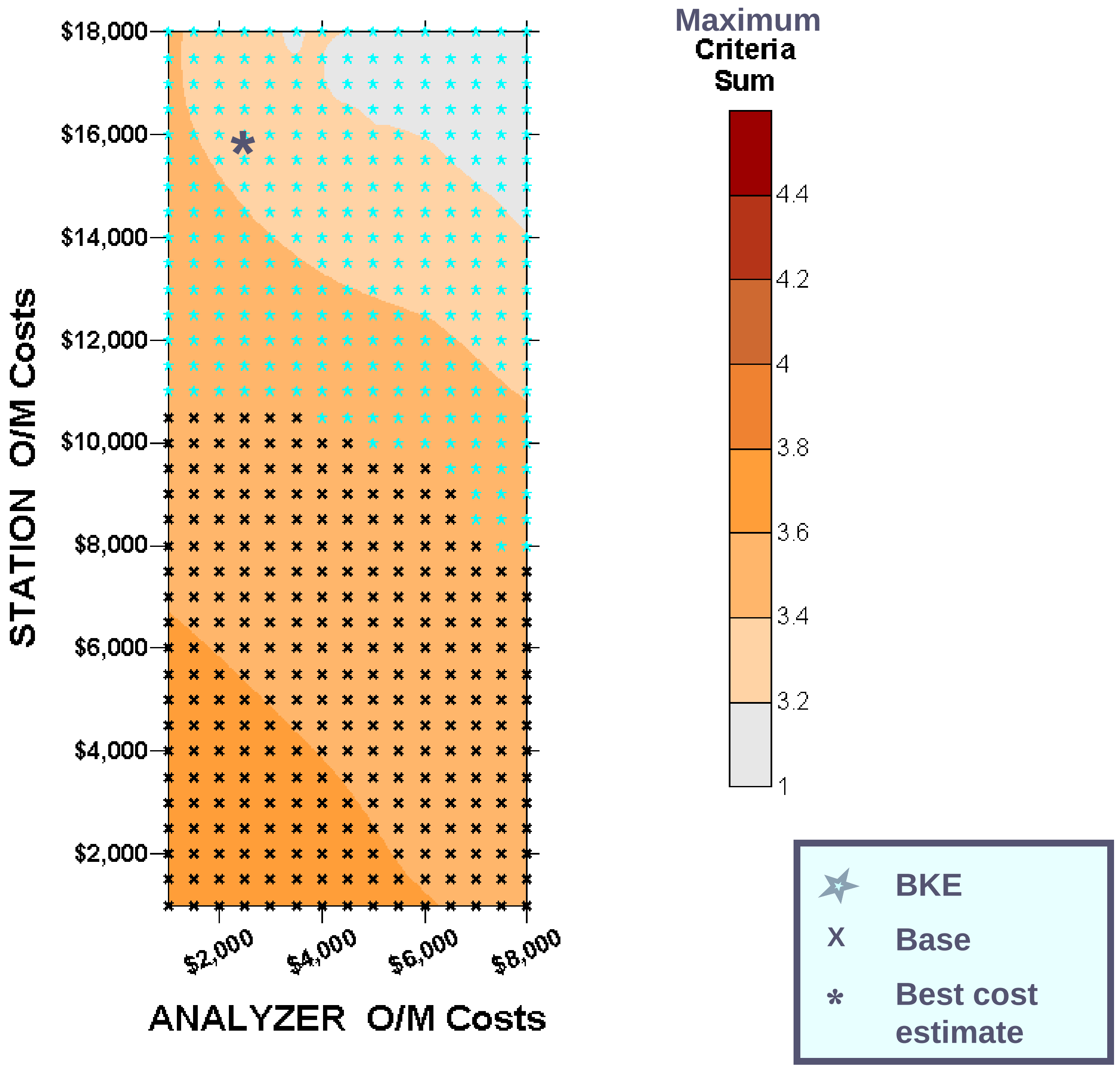


Figure 6 – Different Network Option Dominates in Certain Data Ranges

- BKE dominates in the mid-range of costs
- Base option is more favored initially at lower costs because of capital investment (constant in this demo) required for BKE option, even though BKE saves O/M costs.

Impact on Top-ranked option with Other Value Sets

- All other Test value sets retain BKE as top-ranked option as both O/M analyzer and station costs vary.
- What does this mean?

Comparing Impact of Uncertainty with Different Value Sets

- Different value sets respond differently to uncertainty – more or less “resilient”
- Whether uncertainty is too much depends on the value set (and indexing*)

* Indexing remains constant in this demonstration.

How much Uncertainty is Too Much?

- Data uncertainty is more acceptable in some contexts than others.
- MIRA allows decision makers to determine how much uncertainty is too much.

Implications for the policy maker

- Policy makers who understand the impacts of uncertainty on potential options are less likely to be surprised (flipping cardinal ranks).
- Target limited resources.
  - Test whether uncertainty is acceptable in the specific policy/decision context.
  - **Know when it is necessary to reduce uncertainty.**
- Approach statisticians/scientists with question of whether data uncertainty is within certain range (tested via MIRA) rather than asking what the data uncertainty is.

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