Assessment of BMP impacts

Lecture based on assigned readings -

Mostaghimi et al., 2001 - BMPs for NPS pollution control
Meals et al., 2010 – Lag time

Other articles –
Inamdar et al., 2001
Inamdar et al., 2002
Assessment of BMP impacts

Ward et al identified specific steps for BMP impact assessment:

1. Define the monitoring objectives
2. Select statistical design and analysis procedures
3. Design monitoring network
4. Develop operating plans and procedures
5. Develop reporting procedures
Step 1: Define monitoring objectives –

• Impact of a suite of BMPs on water quality
• Do water quality parameters meet standards?
• Specific BMPs can also be targeted
• What are you evaluating – specific pollutants or derived indices?
• What are the expected goals?
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Step 2: Statistical Design –

Three types of designs exist –

• Paired Watershed studies

• Upstream/downstream design

• Sequential (before and after design)
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Paired Watershed studies

Two watersheds – control and treatment
Two periods of study – calibration and treatment
Watershed should have similar physical, chemical and biological characteristics

One watershed is treated with BMPs, other remains as is.
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Paired Watershed studies

Difficult to get similar watersheds.

If there are significant differences, the design fails.

Costs for monitoring can be more than other designs.
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Upstream / downstream design

- Design more appropriate to indicate the severity of problem than assessing BMP effectiveness
- Assumption that watershed characteristics do not change dramatically
- Not suitable for very small watersheds

![Diagram of upstream and downstream design](image)
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Sequential (before and after) design

- Single station - pre-BMP and post-BMP phases
- Costs are less
- Changes in climate, hydrology during pre or post BMP periods can create problems
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**Statistical analysis of data** –

To determine if indeed the BMPs are having an impact.

**Null hypotheses** – BMP have no impacts on water quality

Two activities –

Descriptive statistics – mean, median, standard deviation, variance, etc.

Statistical inference – tests to determine if the data sets are indeed different – parametric or non-parametric tests can be implemented
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Descriptive statistics – mean, median, standard deviation, variance, etc.

Allow for –

1. Initial overview of the results
2. Visual interpretation
3. Selection of variable for further analyses
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Parametric tests –

Assumption - data is normally distributed
Ch-square, t tests, regression, analysis of variance (ANOVA)

Parametric tests are robust when assumptions are met.

Non-parametric tests –

Do not require the assumption of normality
More robust when assumption are not met, or when outliers exist in data

Examples – Mann Whitney, Wilcoxon Rank, Kruskal Wallis test
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When tests that focus on two independent groups may not work –

**Monotonic trend tests** –

That reveal slow trends in water quality over time

Example – Mann Kendall test

When water quality data exhibit seasonality – Seasonal Kendall tests.
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Step 3: Design of the Monitoring Network

Where, what and when to sample?

- Identification of sampling locations
  - characterize response, BMP; number of samples required; cost, variance, use GIS

- Selection of water quality variables

- Scheduling of sampling
  - Too frequent – redundant data; infrequent – miss critical information; need to capture the variability in the system
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**Sampling locations with sampling scheme:**
FE – field edge. These have one surface runoff collector and soil water collector at each location.
GB- grass buffer. GB1 has surface runoff and soil water collector. GB2 has surface runoff collector.
RB – riparian buffer. These have one surface runoff collector and one soil water collector at each location.
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Examples of BMP assessment – case studies
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Example study – Nomini Creek, VA (Inamdar et al. 2001).

1463 ha cropland watershed (corn & soybeans)
Pre-BMP versus post BMP study
Sediment and nutrients (N & P)

Study period - 1985 - 1997

Pre BMP: Jan 86 – June 89 (3+ yrs)
Post BMP: Apr 90 – Jun 97 (7+ yrs)

Step tests implemented

**BMPs:** strip cropping, conservation tillage, nutrient management, and integrated pest management (IPM), vegetative filter strips, grade stabilization structures, and drop structures
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Loads (kg/ha)</th>
<th>Concentration (mg/L)</th>
<th>% change</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-BMP</td>
<td>Post-BMP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation (mm)^[a]</td>
<td>967</td>
<td>1094</td>
<td>13</td>
<td>—</td>
</tr>
<tr>
<td>Streamflow (mm)^[a]</td>
<td>184</td>
<td>231</td>
<td>26</td>
<td>—</td>
</tr>
<tr>
<td>Solids</td>
<td>355</td>
<td>426</td>
<td>20</td>
<td>193.16</td>
</tr>
<tr>
<td>Dissolved ammonium–N</td>
<td>0.50</td>
<td>0.13</td>
<td>−74</td>
<td>0.27</td>
</tr>
<tr>
<td>Nitrate–N</td>
<td>1.49</td>
<td>2.02</td>
<td>36</td>
<td>0.81</td>
</tr>
<tr>
<td>Dissolved–organic–N</td>
<td>2.60</td>
<td>1.21</td>
<td>−53</td>
<td>1.41</td>
</tr>
<tr>
<td>Particulate–N</td>
<td>4.97</td>
<td>3.68</td>
<td>−26</td>
<td>2.70</td>
</tr>
<tr>
<td>Total–N</td>
<td>9.57</td>
<td>7.05</td>
<td>−26</td>
<td>5.20</td>
</tr>
<tr>
<td>Dissolved ortho–P</td>
<td>0.03</td>
<td>0.06</td>
<td>92</td>
<td>0.02</td>
</tr>
<tr>
<td>Dissolved organic –P</td>
<td>0.26</td>
<td>0.48</td>
<td>83</td>
<td>0.14</td>
</tr>
<tr>
<td>Particulate–P</td>
<td>1.01</td>
<td>0.70</td>
<td>−30</td>
<td>0.55</td>
</tr>
<tr>
<td>Total–P</td>
<td>1.31</td>
<td>1.26</td>
<td>−4</td>
<td>0.71</td>
</tr>
</tbody>
</table>

% changes in loads and flow-weighted concentrations
### Assessment of BMP impacts

<table>
<thead>
<tr>
<th>Parameter</th>
<th>&quot;t&quot; test</th>
<th>Wilcoxon Rank Sum (WRS) test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>0.3144</td>
<td>0.3076</td>
</tr>
<tr>
<td>Streamflow</td>
<td>0.0001</td>
<td>0.0011</td>
</tr>
<tr>
<td>Solids</td>
<td>0.1798</td>
<td>0.1054</td>
</tr>
<tr>
<td>Ammonium–N</td>
<td>0.0000</td>
<td>0.0001</td>
</tr>
<tr>
<td>Nitrate–N</td>
<td>0.1327</td>
<td>0.0541</td>
</tr>
<tr>
<td>Dissolved–organic–N</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>Particulate–N</td>
<td>0.0204</td>
<td>0.0032</td>
</tr>
<tr>
<td>Total–N</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>Ortho–P</td>
<td>0.8313</td>
<td>0.7832</td>
</tr>
<tr>
<td>Dissolved organic–P</td>
<td>0.3023</td>
<td>0.3774</td>
</tr>
<tr>
<td>Particulate–P</td>
<td>0.0879</td>
<td>0.1953</td>
</tr>
<tr>
<td>Total–P</td>
<td>0.2087</td>
<td>0.3228</td>
</tr>
</tbody>
</table>

p values from statistical tests
Assessment of BMP impacts

Overall, the findings of this study indicate that the BMPs were effective in reducing the losses of some forms of nutrients, such as ammonium–N and particulate–P, from the Nomini Creek watershed, but additional BMPs are necessary to achieve significant reductions in all forms of N and P.
Assessment of BMP impacts

Another example – Owl Run Creek watershed – Inamdar et al., 2002
1163 ha watershed
BMP impacts on Bacterial pollution - exports of fecal coliform from watershed
Pre- versus post-BMP design

Pre BMP: Aug 86- Jun 89 (3 yrs)
Post BMP: Jul 89 – Jun 96 (7 yrs)

BMPs: manure storage facilities, fencing, stream crossings, and watering troughs, conservation tillage, grassed waterways, and manure management.

Step tests as well as trend tests
Assessment of BMP impacts

<table>
<thead>
<tr>
<th>Parameter</th>
<th>QOA Pre-BMP</th>
<th>QOA Post-BMP</th>
<th>QOB Pre-BMP</th>
<th>QOB Post-BMP</th>
<th>QOC Pre-BMP</th>
<th>QOC Post-BMP</th>
<th>QOD Pre-BMP</th>
<th>QOD Post-BMP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n*</td>
<td>51</td>
<td>117</td>
<td>47</td>
<td>108</td>
<td>40</td>
<td>108</td>
<td>41</td>
<td>110</td>
</tr>
<tr>
<td>Geometric Mean</td>
<td>1,189</td>
<td>669</td>
<td>1,244</td>
<td>2,196</td>
<td>103</td>
<td>185</td>
<td>1,077</td>
<td>1,367</td>
</tr>
<tr>
<td>Percent Change</td>
<td>-44</td>
<td>77</td>
<td>86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>3</td>
<td>20</td>
<td>15</td>
<td>200</td>
<td>2</td>
<td>20</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Maximum</td>
<td>60,000</td>
<td>16,000</td>
<td>103,250</td>
<td>160,000</td>
<td>1700</td>
<td>16,000</td>
<td>81,000</td>
<td>150,000</td>
</tr>
<tr>
<td><strong>FS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>50</td>
<td>133</td>
<td>52</td>
<td>124</td>
<td>43</td>
<td>125</td>
<td>41</td>
<td>126</td>
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<tr>
<td>Geometric Mean</td>
<td>2,384</td>
<td>556</td>
<td>2,015</td>
<td>836</td>
<td>531</td>
<td>211</td>
<td>1,302</td>
<td>702</td>
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<tr>
<td>Minimum</td>
<td>8</td>
<td>11</td>
<td>40</td>
<td>9</td>
<td>8</td>
<td>2</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>Maximum</td>
<td>540,000</td>
<td>620,000</td>
<td>142,000</td>
<td>350,000</td>
<td>227,000</td>
<td>140,000</td>
<td>163,000</td>
<td>266,500</td>
</tr>
<tr>
<td>FC:FS</td>
<td>0.5</td>
<td>1.2</td>
<td>0.6</td>
<td>2.6</td>
<td>0.2</td>
<td>0.9</td>
<td>0.8</td>
<td>1.9</td>
</tr>
</tbody>
</table>

*Number of samples.

Decrease at main outlet, but increases within watershed!
Assessment of BMP impacts

Statistically no significant difference between pre and post-BMP means!

<table>
<thead>
<tr>
<th>Watershed</th>
<th>“t”</th>
<th>FC</th>
<th>WRS</th>
<th>KS</th>
<th>“t”</th>
<th>FS</th>
<th>WRS</th>
<th>KS</th>
</tr>
</thead>
<tbody>
<tr>
<td>QOA</td>
<td>0.1748</td>
<td>0.1959</td>
<td>0.3826</td>
<td></td>
<td>0.0078</td>
<td>0.0162</td>
<td>0.0914</td>
<td></td>
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<tr>
<td>QOB</td>
<td>0.0985</td>
<td>0.1277</td>
<td>0.2788</td>
<td></td>
<td>0.0832</td>
<td>0.0531</td>
<td>0.1496</td>
<td></td>
</tr>
<tr>
<td>QOC</td>
<td>0.2768</td>
<td>0.2010</td>
<td>0.2125</td>
<td></td>
<td>0.0311</td>
<td>0.0852</td>
<td>0.1795</td>
<td></td>
</tr>
<tr>
<td>QOD</td>
<td>0.9755</td>
<td>0.8550</td>
<td>0.9748</td>
<td></td>
<td>0.1426</td>
<td>0.2019</td>
<td>0.5210</td>
<td></td>
</tr>
</tbody>
</table>
Assessment of BMP impacts

Figure 2. Seasonal Geometric Means for FC and FS for Watershed QOA.
Assessment of BMP impacts

A reduction in post-BMP FC concentrations was observed at the main watershed outlet (QOA), but all monitored subwatersheds recorded increases in FC concentrations.

The percent reduction at QOA was 44, whereas increases for QOC and QOD were 86 and 27 percent, respectively.

Despite these changes, the step tests did not yield significant differences.

In comparison, the seasonal Kendall test did register a significant difference between the overall trends for QOA pre-BMP and post-BMP periods.
Overall, although there were slight decreases in FC concentrations at the main watershed outlet and larger decreases in FS concentrations across all watersheds, definitive and consistent evidence of water quality improvement due to BMP implementation was not observed.

This leads us to conclude that although BMP implementation can be expected to accomplish some improvement in water quality, BMP implementation alone does not ensure compliance with current water quality standards.
Assessment of BMP impacts

Why don’t we see impact of BMPs?
Lag time in effectiveness of BMPs – article by Meals et al., 2010

Lag time –

“..as the time elapsed between installation or adoption of management measures at the level projected to reduce NPS pollution and the first measurable improvement in water quality in the target water body.”
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Lag time can be influenced by –

1. Flow path and amount of flow
2. Hydrologic/watershed conditions
3. Pollutant involved
4. Type of BMP
5. Scale of system (watershed or waterbody)
6. Legacy/History of the watershed/system
7. Response variable
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Flow path and amount of flow

1. Surface runoff, ditches (fast)
2. Shallow subsurface flow (slow)
3. Deep groundwater flow (very slow); retardation effects - sorption
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Hydrologic/watershed conditions -

1. Wet conditions (quick response, smaller lag time)
2. Dry conditions (slower response, longer lag time)
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Pollutant form and type -

1. Particulate (transported with surface runoff)
2. Dissolved (surface or groundwater)
3. Type – e.g., P versus bacteria (short life)
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Type of BMP:

Manure storage may provide a quick response and short lag time, as opposed to riparian forest buffers which may require a longer period of growth.
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Scale of system/watershed/water body

Smaller watersheds or waterbody will have smaller lag times for response

Larger watersheds or water bodies will likely require longer lag times.

Residence time will be factor -
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Scale of system/watershed/water body

<table>
<thead>
<tr>
<th>Waterbody</th>
<th>Location</th>
<th>Surface area</th>
<th>Residence time</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake St. Clair</td>
<td>MI/ONT</td>
<td>1114</td>
<td>0.04</td>
<td>Quinn, 1992</td>
</tr>
<tr>
<td>Narragansett Bay</td>
<td>RI</td>
<td>328</td>
<td>0.1</td>
<td>Dettmann, 2001</td>
</tr>
<tr>
<td>Delaware Estuary</td>
<td>DE</td>
<td>1989</td>
<td>0.3</td>
<td>Dettmann, 2001</td>
</tr>
<tr>
<td>Chesapeake Bay</td>
<td>VA/MD</td>
<td>11,542</td>
<td>0.6</td>
<td>Dettmann, 2001</td>
</tr>
<tr>
<td>Lake Erie</td>
<td>NY/PA/OH/ONT</td>
<td>25,700</td>
<td>3</td>
<td>Quinn, 1992</td>
</tr>
<tr>
<td>Lake Champlain</td>
<td>VT/NY/QUE</td>
<td>1127</td>
<td>3.3</td>
<td>LakeNet, 2009</td>
</tr>
<tr>
<td>Lake Mendota</td>
<td>WI</td>
<td>4</td>
<td>4.5</td>
<td>UW CFL, 2009</td>
</tr>
<tr>
<td>Lake Huron</td>
<td>MI/ONT</td>
<td>59,600</td>
<td>21</td>
<td>Quinn, 1992</td>
</tr>
<tr>
<td>Lake Michigan</td>
<td>MI/IN/IL/WI/ONT</td>
<td>57,800</td>
<td>100</td>
<td>Quinn, 1992</td>
</tr>
<tr>
<td>Lake Superior</td>
<td>MI/MN/ONT</td>
<td>82,100</td>
<td>191</td>
<td>Quinn, 1992</td>
</tr>
<tr>
<td>Lake Tahoe</td>
<td>CA/NV</td>
<td>501</td>
<td>650–700</td>
<td>UCD TERL, 2009</td>
</tr>
</tbody>
</table>
Assessment of BMP impacts

Legacy/History system/watershed/water body

If the water body has a large storage of nutrients, e.g., P – it will have a large lag time, since stored P will continue to be released even if there is no new inputs!

Positive feedbacks – eutrophication – algal growth – decay – anoxic conditions - enhance nutrient release because of anoxic conditions – more eutrophication

Negative feedbacks – restored oyster reefs – water filtering – reduced plankton biomass – increased water clarity – growth of benthic plants
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Response Variable – 

Type of response variable will also influence the lag time:
- Hydrology
- Water quality
- Eutrophication / algal growth / plankton biomass
- Benthic invertebrates
- Fish and higher aquatic species