Assessing Ecological Integrity for Impaired Waters Decisions in Chesapeake Bay, USA

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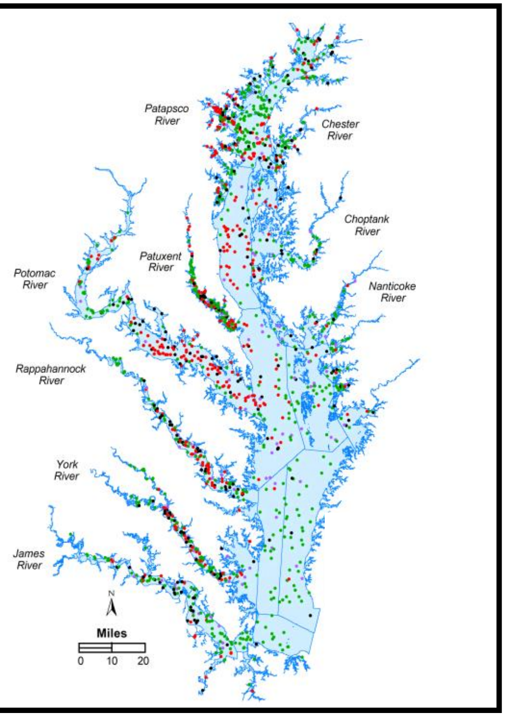
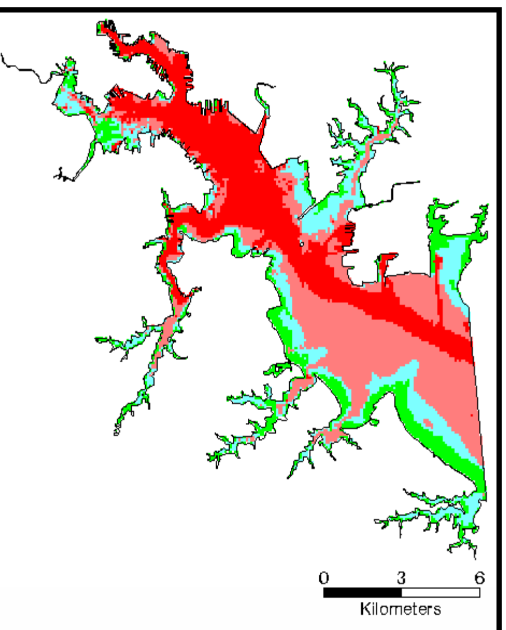
Context

- The States of Maryland and Virginia share the Chesapeake Bay and its tributaries
- Need to integrate monitoring and assessment efforts to identify impaired waters in Chesapeake Bay under requirements of the Clean Water Act
- Integration Issues include consistency in overall assessment and designation of impaired waters on the 303(d) list





Chesapeake Bay Benthic Monitoring Program

Restoration Goals

Benthic Index of Biotic Integrity

Probability Survey Design

Framework
For application of B-IBI
To the States'
Water quality inventories
(305b Report)

Objectives

- Develop a procedure for 303(d) impairment decisions based on the benthic index of biotic integrity (B-IBI)
- Produce an assessment of Chesapeake Bay segments (equivalent to water bodies in the European Water Framework Directive)

Approach

- The impairment assessment for each segment was based on the proportion of samples with low B-IBI scores (*i.e., below a threshold*) determined from comparison to a reference distribution
- Is the proportion of sites with low B-IBI scores in a segment significantly different from what would be expected from chance alone?

Considerations

- Multiple habitats
  - The B-IBI combines multiple benthic habitat-dependent indices

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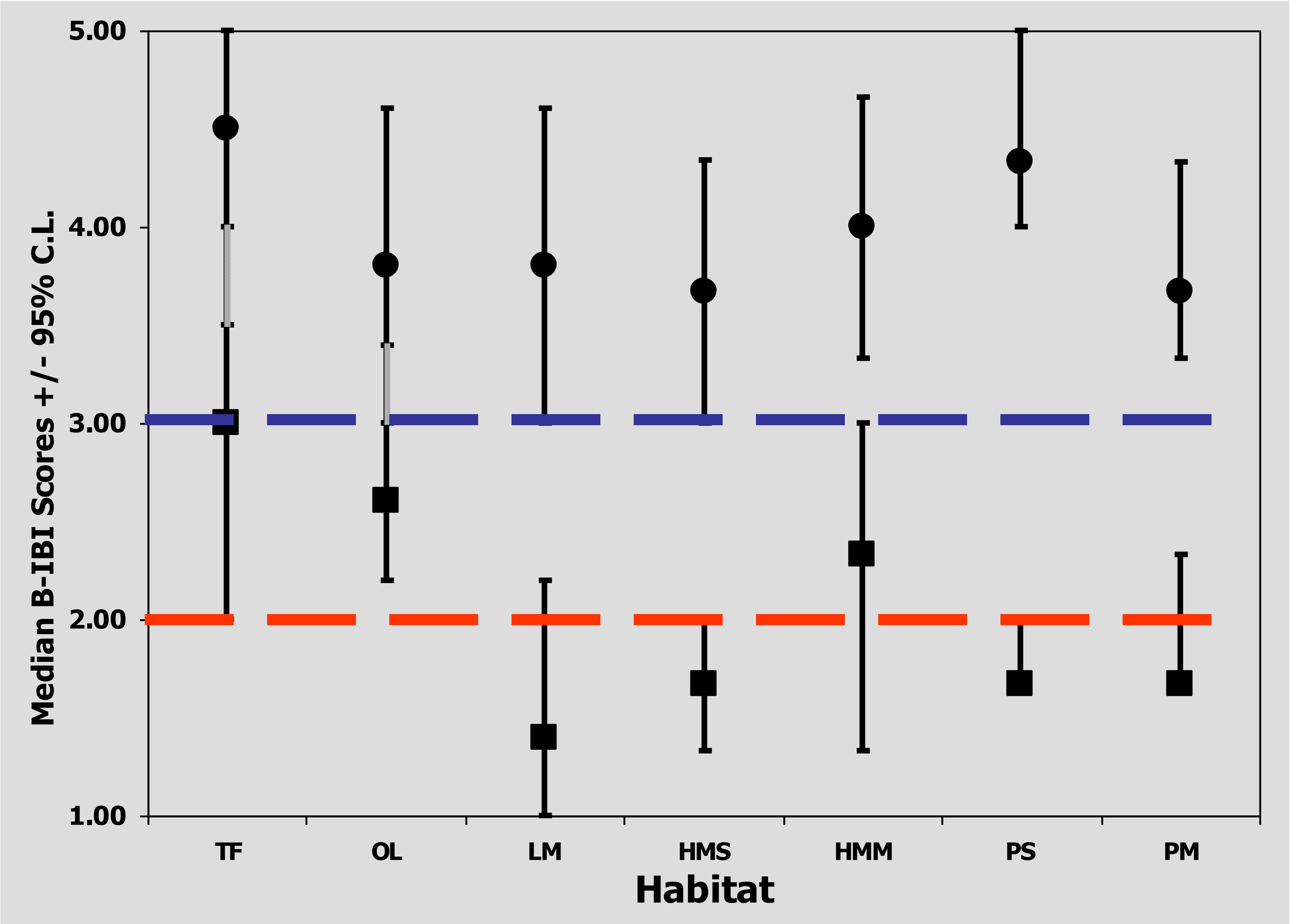
  - Reference B-IBI distributions were significantly different among habitats; therefore, it was not appropriate to pool distributions across habitats.


5.00
4.00
3.00
2.00
1.00
Median B-IBI Scores +/- 95% C.L.
TF
OL
LM
HMS
HMM
PS
PM
Habitat

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  - Small and unbalanced reference data sets
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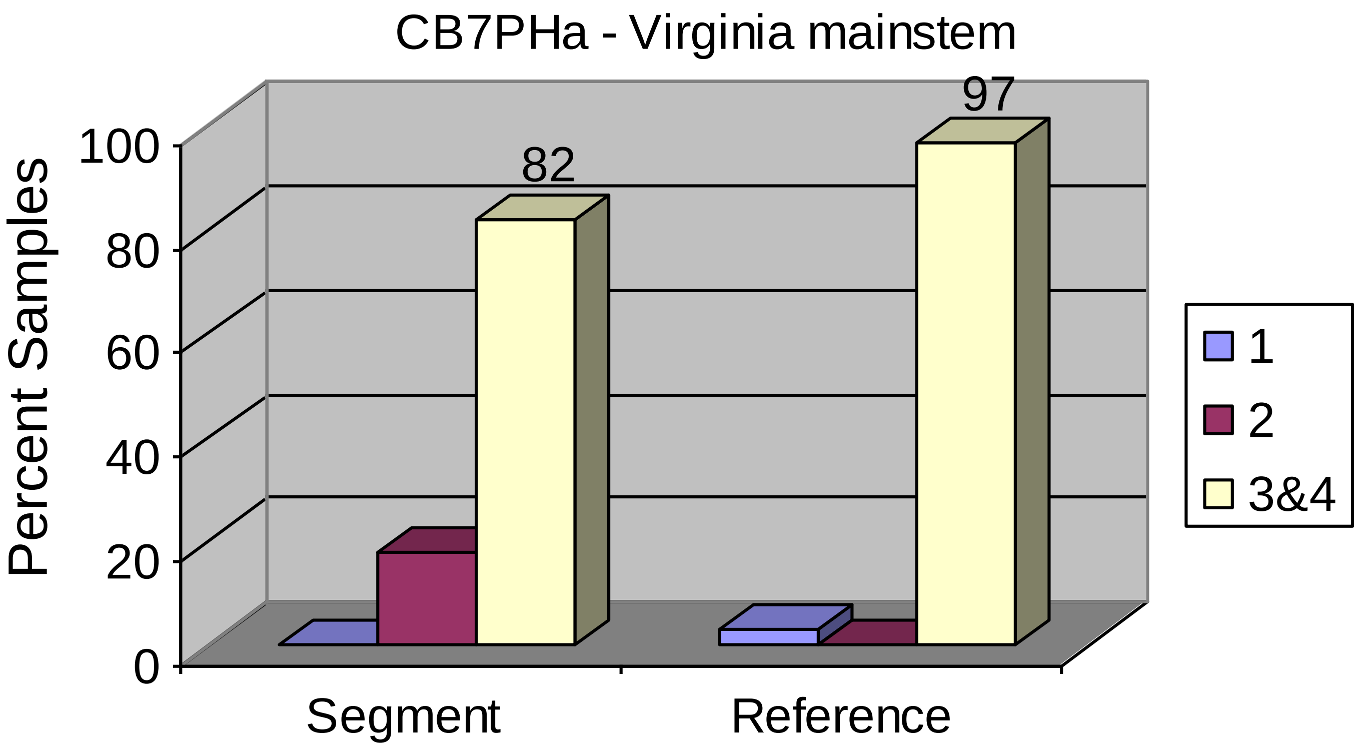
- Sample size
  - Small and unbalanced reference data sets
  - Small sample size
- Sampling variability

Alternative methods

Stratified Wilcoxon Rank Sum test

- Compare B-IBI scores between segment and reference distributions (test for shift in location toward lower B-IBI scores in segment)



Alternative methods (cont.)

Weighted Mean Approach

	Reference		Segment		
	Mean	**SE**	**Mean**	**SE**	**Weight**
Hab 1	4.1	0.69	2.7	0.69	3/10
Hab 2	3.1	0.58	2.1	0.58	3/10
Hab 3	3.5	0.55	1.8	0.35	4/10
Hab 1-3	3.56	0.35	2.16	0.30	

Weighted Estimates

Alternative methods (cont.)

Weighted Mean Approach

- One-sided t-test, the difference in weighted means divided by the pooled standard error

$$t = \frac{\overline{X}_r - \overline{X}_s}{SE_p} = \frac{3.56 - 2.16}{0.461} = 3.04 > t_{0.05,18}$$

Procedure

- Two steps, estimate:

1. Proportion of sites in a segment with scores below a threshold (P)

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1. Proportion of sites in a segment with scores below a threshold (P)
2. Difference between P and the expected proportion under the null hypothesis (P_o),

   i.e., if the segment were in good condition (no low DO, contaminant, or nutrient enrichment problems), we would still expect a small proportion of sites to have "low" scores (e.g., because of natural variability); this proportion under the null hypothesis was defined as 5%.

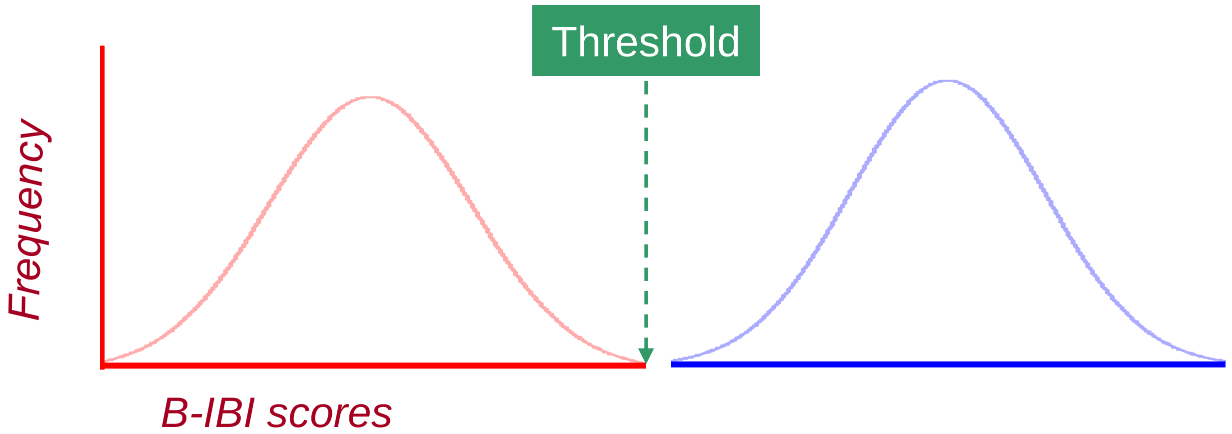
Step # 1

- Thresholds were set for each of seven benthic habitats.

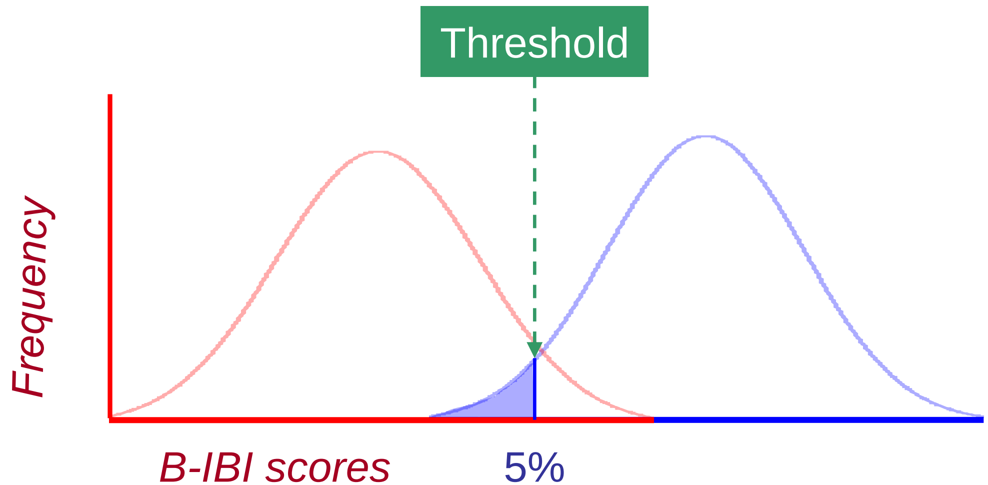
Step # 1 (cont.)

- Thresholds were set for each of seven benthic habitats.
- The threshold was set as the smaller of two values:
    1. Maximum B-IBI score for the *degraded* reference distribution
    2. 5Th percentile B-IBI score for the *undegraded* reference distribution

Habitat A



Habitat B



Step # 1 (cont.)

- Thresholds were set for each of seven benthic habitats.
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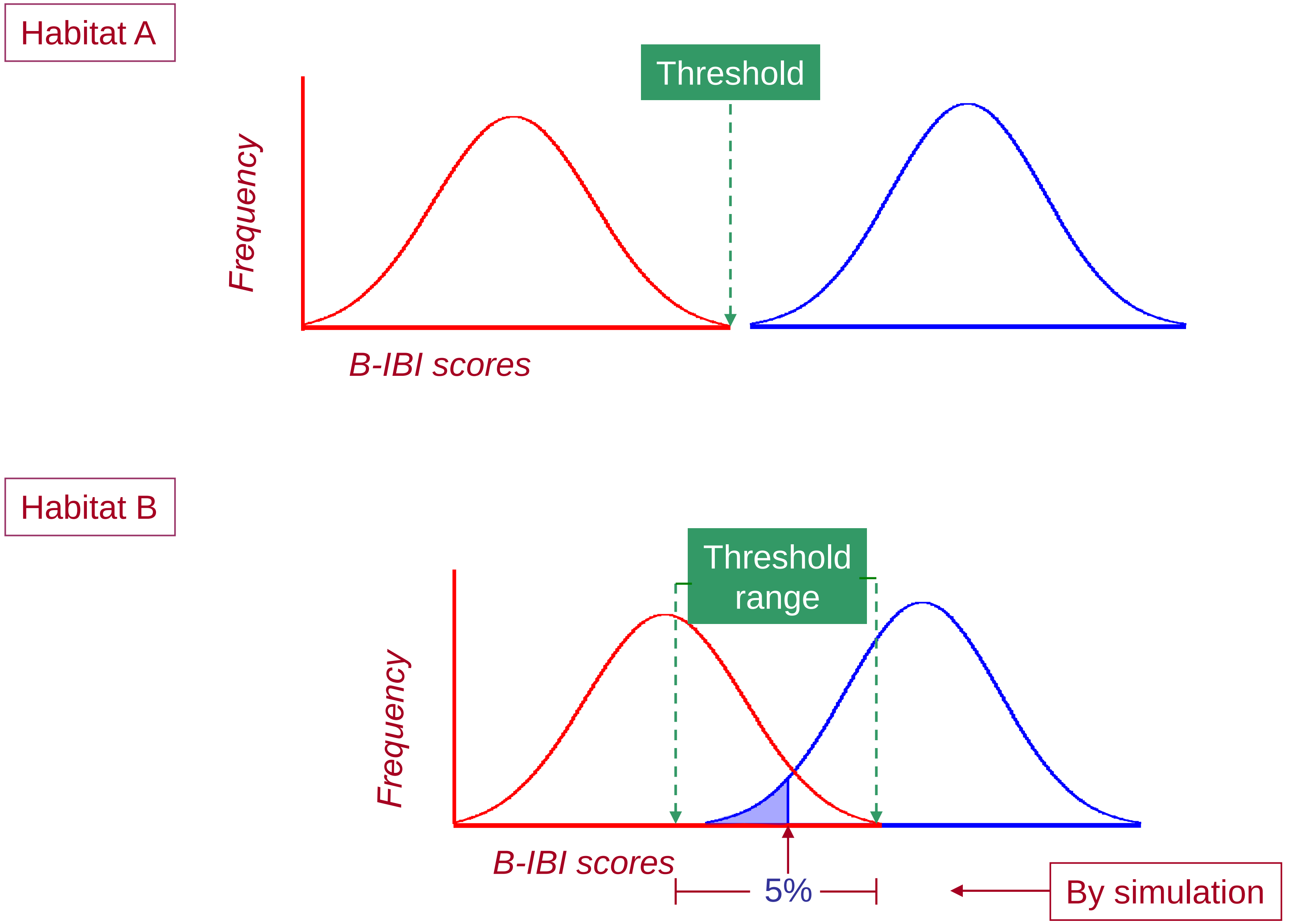
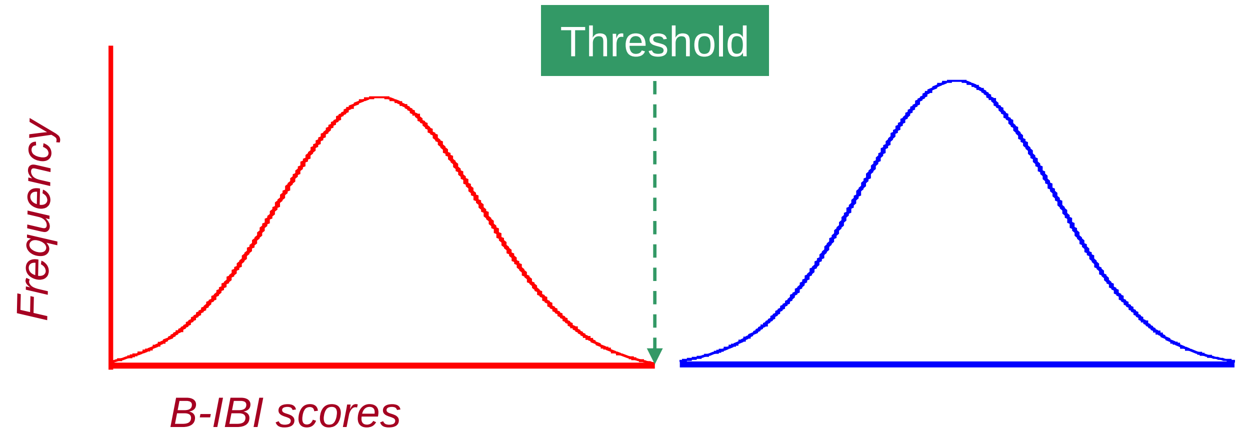
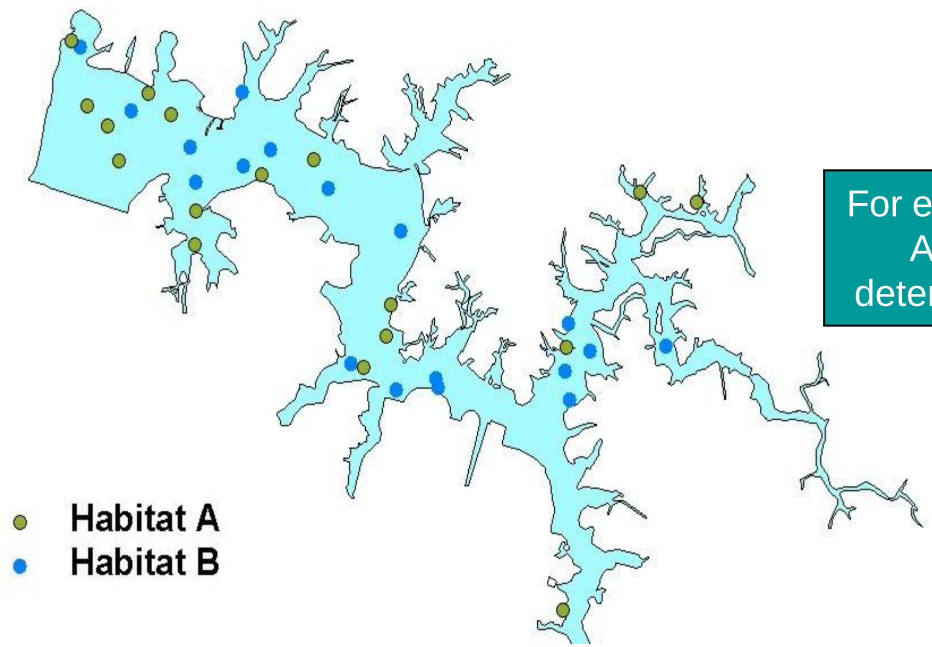
Step # 1 (cont.)

- Thresholds were set for each of seven benthic habitats.
- The threshold was set as the smaller of two values:
  1. Maximum B-IBI score for the degraded reference distribution
  2. 5^{Th} percentile B-IBI score for the undegraded reference distribution
- Because reference distributions were sometimes based on a small number of samples, the 5th percentile score and its variance was estimated by *bootstrap simulations*


Habitat A
Threshold
Frequency
B-IBI scores
Habitat B
Threshold range
Frequency
B-IBI scores
5%
By simulation

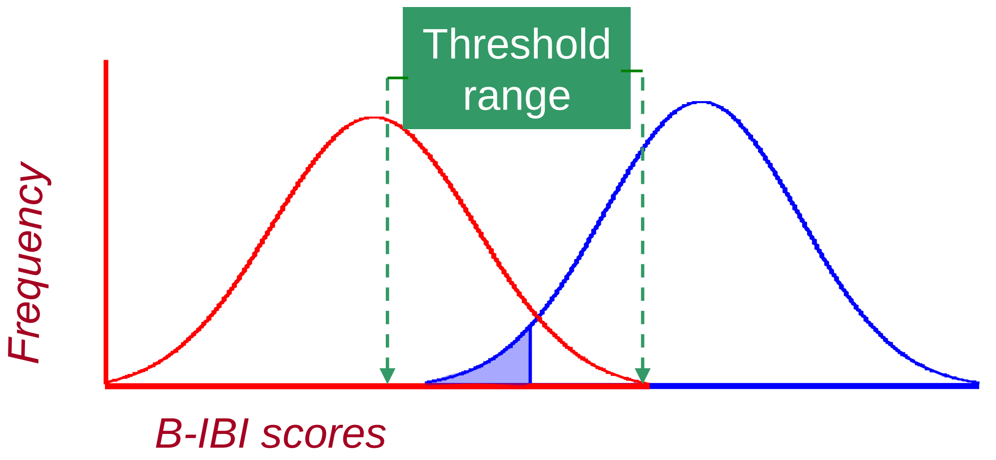
Habitat A

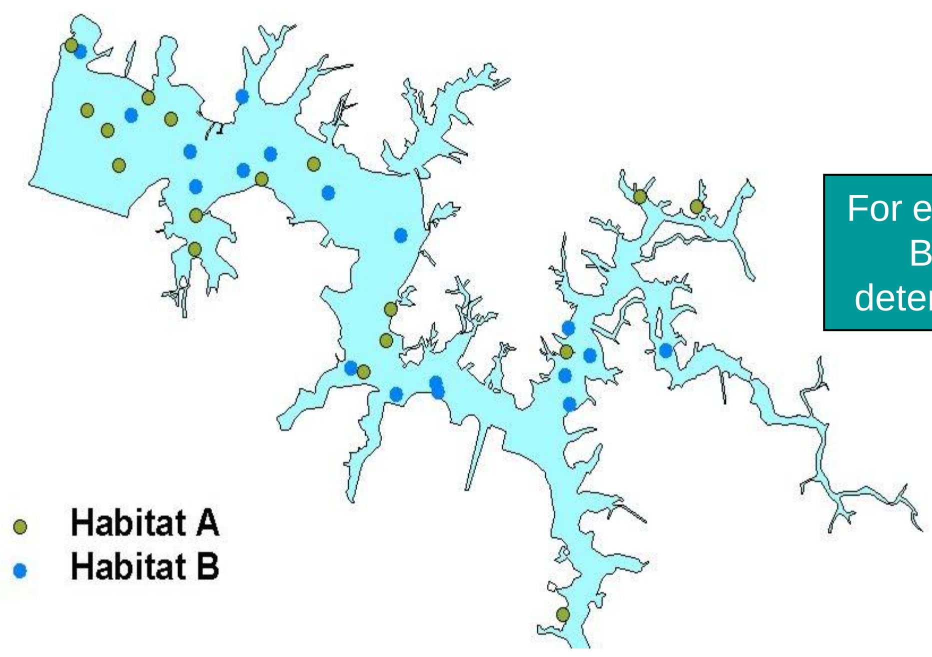




For each iteration, compare Habitat A site scores to threshold to determine % sites below threshold

Habitat B





For each iteration, compare Habitat B site scores to threshold to determine % sites below threshold

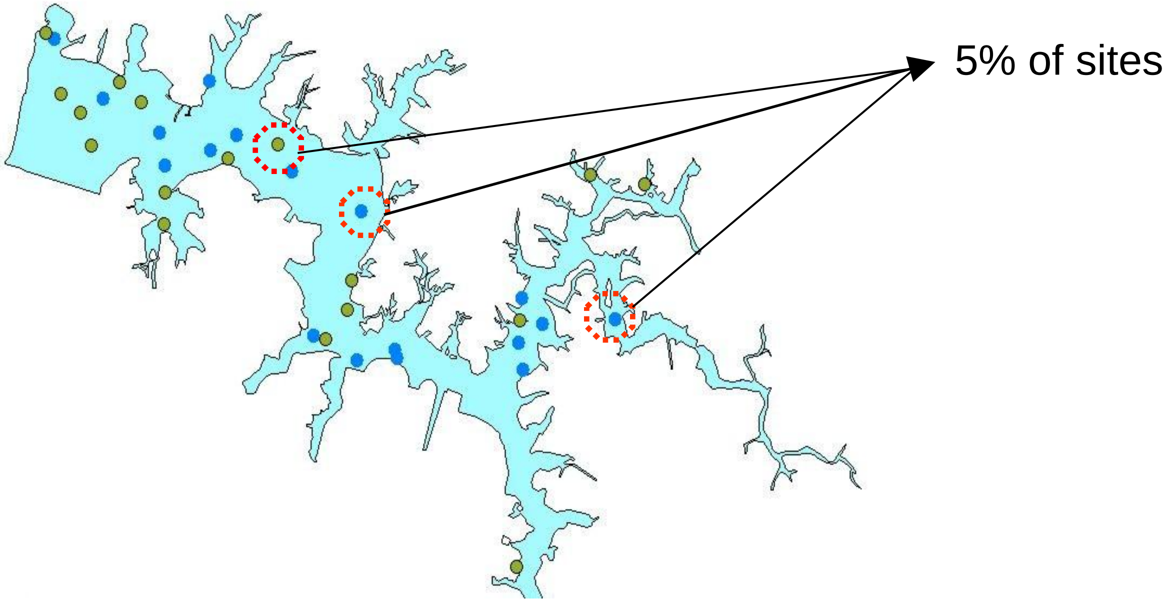
Step # 1 (cont.)

- The final proportion of sites in a segment below threshold (i.e. the degraded area) was
  - The average proportion from all bootstrap iterations, combined for all habitats:

$$(nP_A + nP_B)/(n_A + n_B)\text{, expressed as percent}$$

Step # 2

- Under the null hypothesis, 5% of the sites (P_o) would be expected to have low IBI scores, even if all sites in a segment were in good condition (i.e, no low DO, contaminant, nutrient enrichment problems)



- Segments declared impaired if *P* greater than expected under the null hypothesis

$$P - P_0 > 0 \text{ (with 95\% confidence)}$$

Variance

- Variance components in *P* added
  - Variance in P due to estimating thresholds – from bootstrap
  - Sampling variation within segment – binomial
- Confidence interval of $P - P_o$ =

  $P - P_o \pm 1.96(SE_P + SE_{P_o}) = P - P_o \pm 1.96 * SQRT(Var_P + Var_{P_o})$

  Var_P = Variance from bootstrap = $\sum_{i=1}^{i=5000} \frac{(P_i - \overline{P})^2}{5000-1}$ plus variance from segment = (pq/N-1)

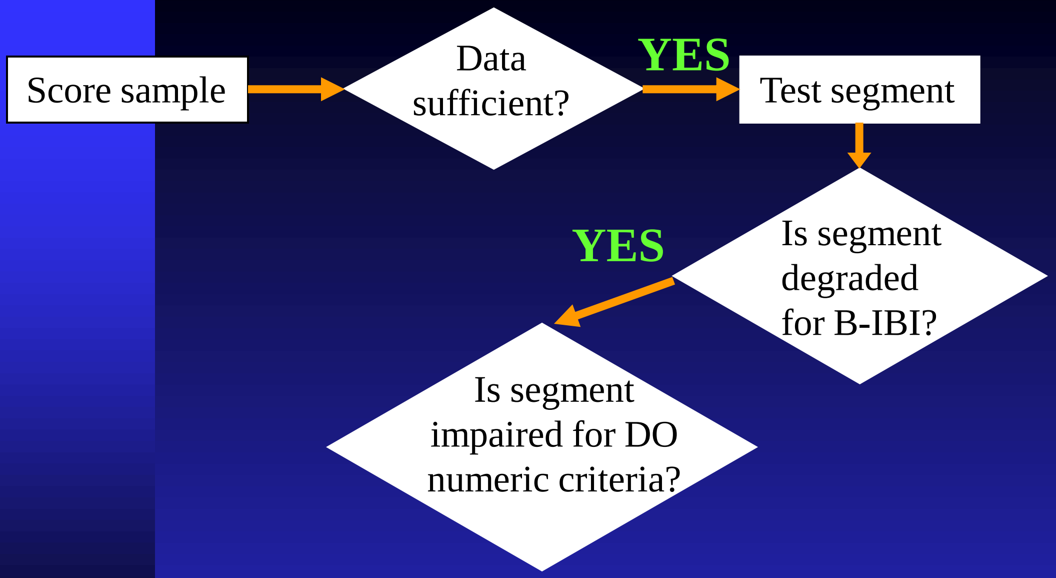
List of Impaired Segments

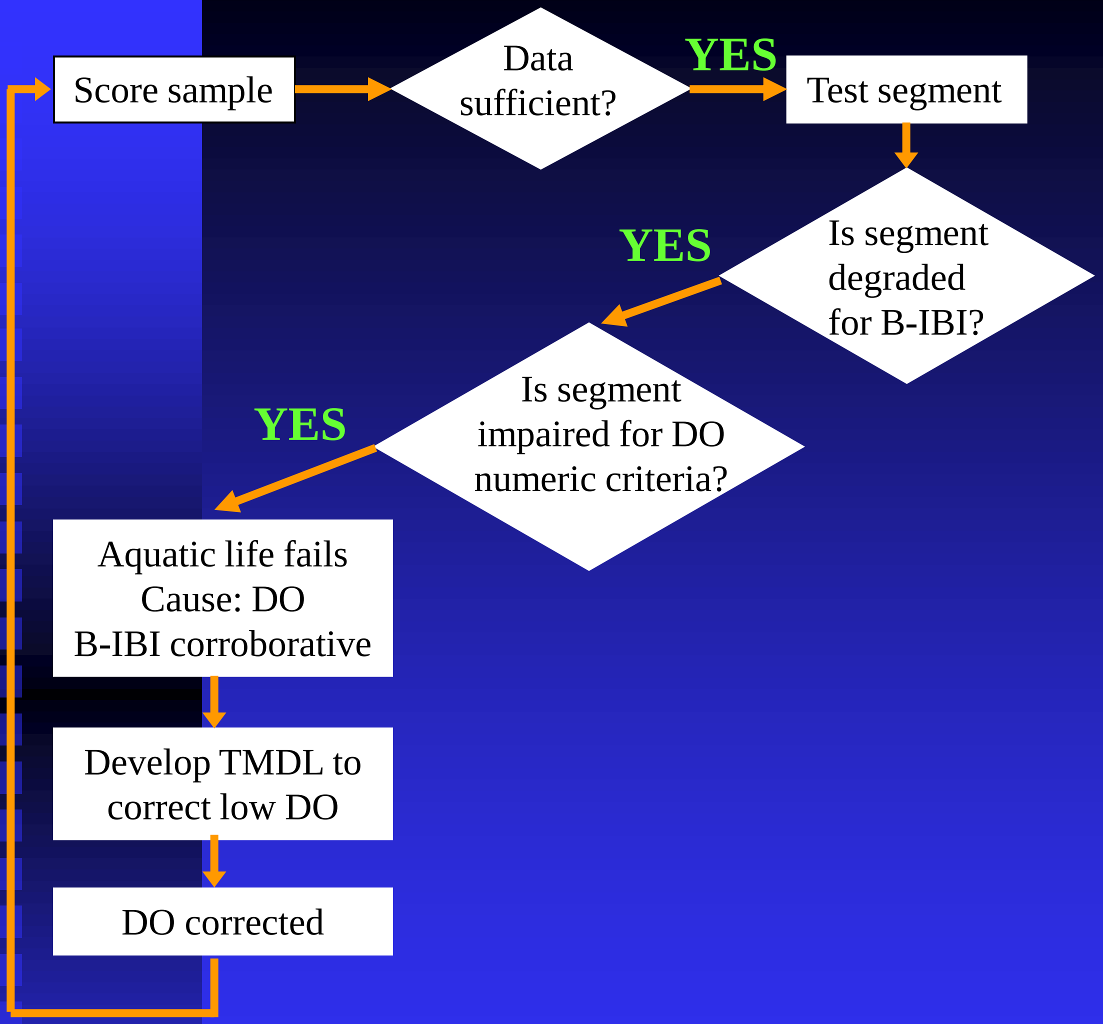
Segment	Name	Sample Size	P	Po	P-Po	CL-L(P-Po)	CL-U(P-Po)	Mean B-IBI
POTMH	Potomac River mesohaline	112	0.62	0.05	0.57	0.36	0.79	1.7
PATMH	Patapsco River	65	0.51	0.05	0.46	0.31	0.61	2.4
SOUMH	South River	12	0.65	0.05	0.60	0.27	0.94	2.0
SBEMHa	Southern Branch Elizabeth River	47	0.57	0.05	0.52	0.19	0.86	2.0
LYNPHa	Lynnhaven Bay	176	0.50	0.05	0.45	0.14	0.75	2.1
PAXMH	Patuxent River mesohaline	135	0.34	0.05	0.29	0.13	0.45	2.4
JMSOHa	James River oligohaline	26	0.36	0.05	0.31	0.11	0.52	2.8
RPPMHa	Rappahannock River mesohaline	127	0.29	0.05	0.24	0.10	0.38	2.4
SEVMH	Severn River	16	0.40	0.05	0.35	0.09	0.61	2.6
MPNOHa	Mattaponi River	10	0.48	0.05	0.43	0.09	0.77	2.6
CB3MH	Maryland mainstem	77	0.24	0.05	0.19	0.06	0.31	2.8
CB5MH	Maryland mainstem	62	0.27	0.05	0.22	0.06	0.39	2.6
CB4MH	Maryland mainstem	35	0.32	0.05	0.27	0.06	0.48	2.3
ELIMHa	Elizabeth River mesohaline	54	0.39	0.05	0.34	0.05	0.63	2.4
JMSMHb	James River mesohaline	17	0.36	0.05	0.31	0.04	0.57	2.4
EBEMHa	Eastern Branch Elizabeth River	15	0.44	0.05	0.39	0.04	0.74	2.3
MAGMH	Magothy River	16	0.32	0.05	0.27	0.03	0.50	2.4
CHSMH	Chester River mesohaline	43	0.24	0.05	0.19	0.02	0.37	2.7

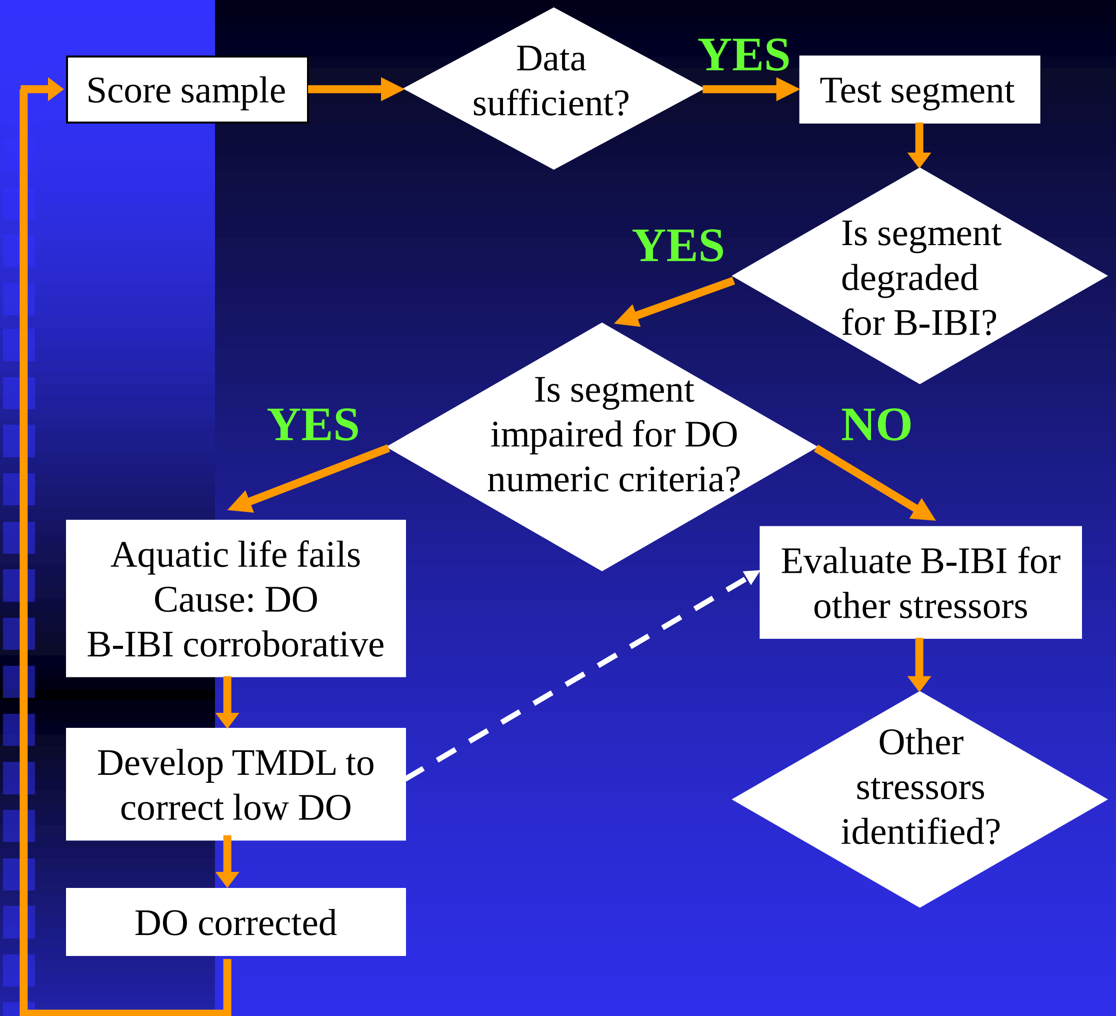
2001-2006 Data, 85 Segments

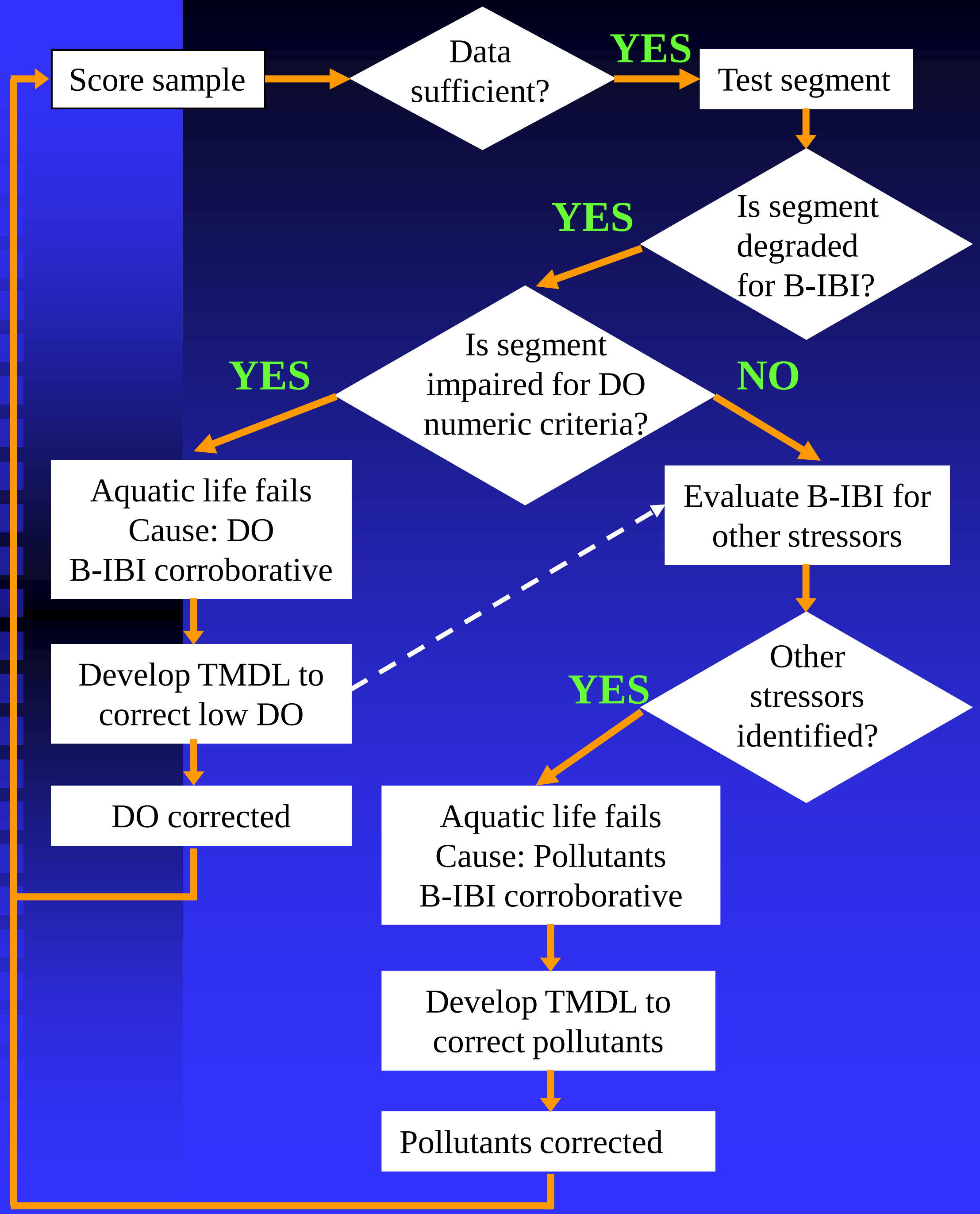
How is this approach used by the States to evaluate aquatic life use support?


Score sample
Data sufficient?
YES
Test segment


Score sample
Data sufficient?
YES
Test segment
Is segment degraded for B-IBI?
YES
Is segment impaired for DO numeric criteria?


Score sample
Data sufficient?
YES
Test segment
Is segment degraded for B-IBI?
YES
Is segment impaired for DO numeric criteria?
YES
Aquatic life fails
Cause: DO
B-IBI corroborative
Develop TMDL to correct low DO
DO corrected


Score sample
Data sufficient?
YES
Test segment
Is segment degraded for B-IBI?
YES
Is segment impaired for DO numeric criteria?
YES
NO
Aquatic life fails
Cause: DO
B-IBI corroborative
Evaluate B-IBI for other stressors
Develop TMDL to correct low DO
Other stressors identified?
DO corrected


Score sample
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Is segment impaired for DO numeric criteria?
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NO
Aquatic life fails
Cause: DO
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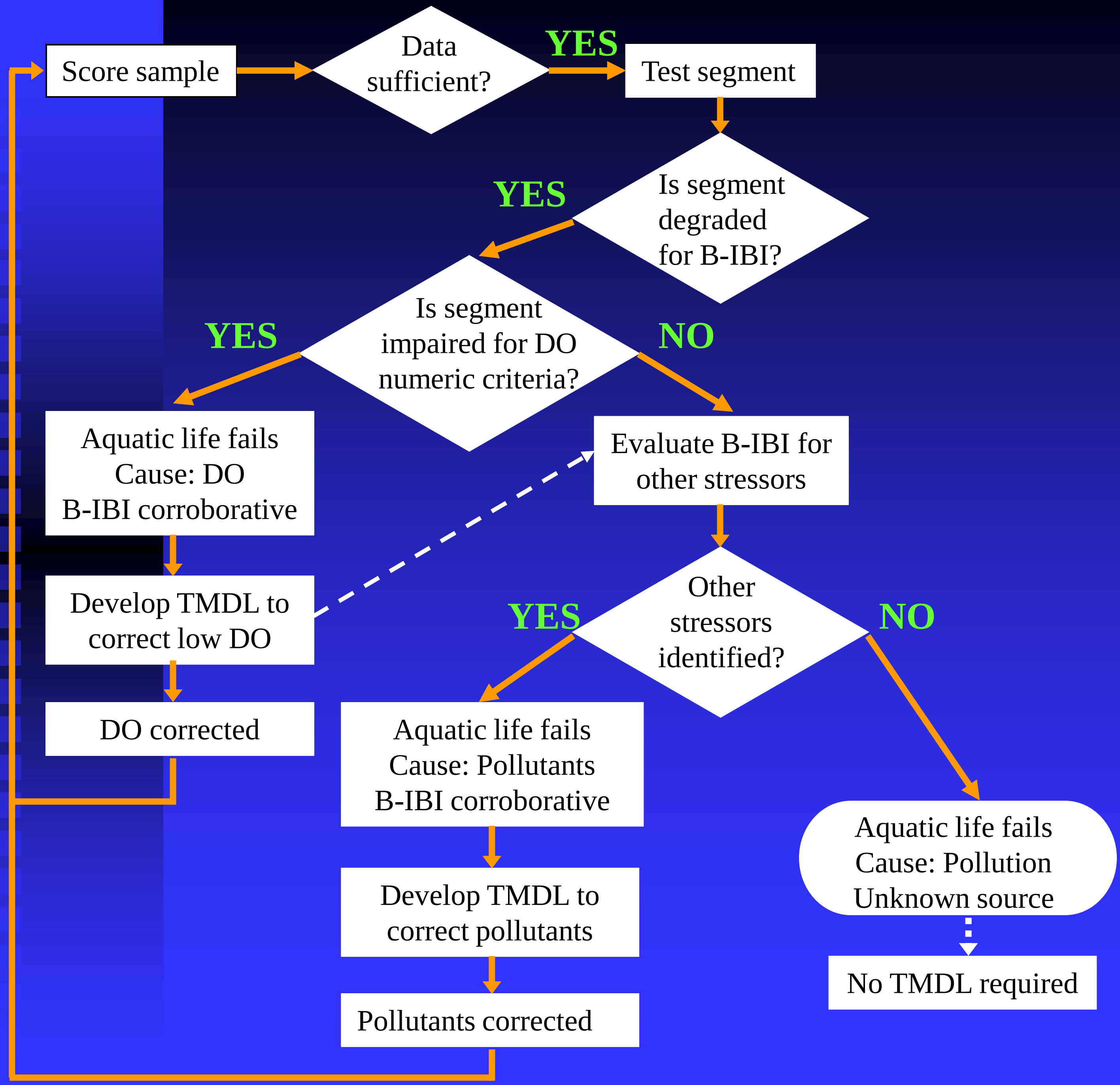
Evaluate B-IBI for other stressors
Develop TMDL to correct low DO
DO corrected
Other stressors identified?
YES
Aquatic life fails
Cause: Pollutants
B-IBI corroborative
Develop TMDL to correct pollutants
Pollutants corrected



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Data sufficient?
YES
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Is segment degraded for B-IBI?
YES
Is segment impaired for DO numeric criteria?
YES
NO
Aquatic life fails
Cause: DO
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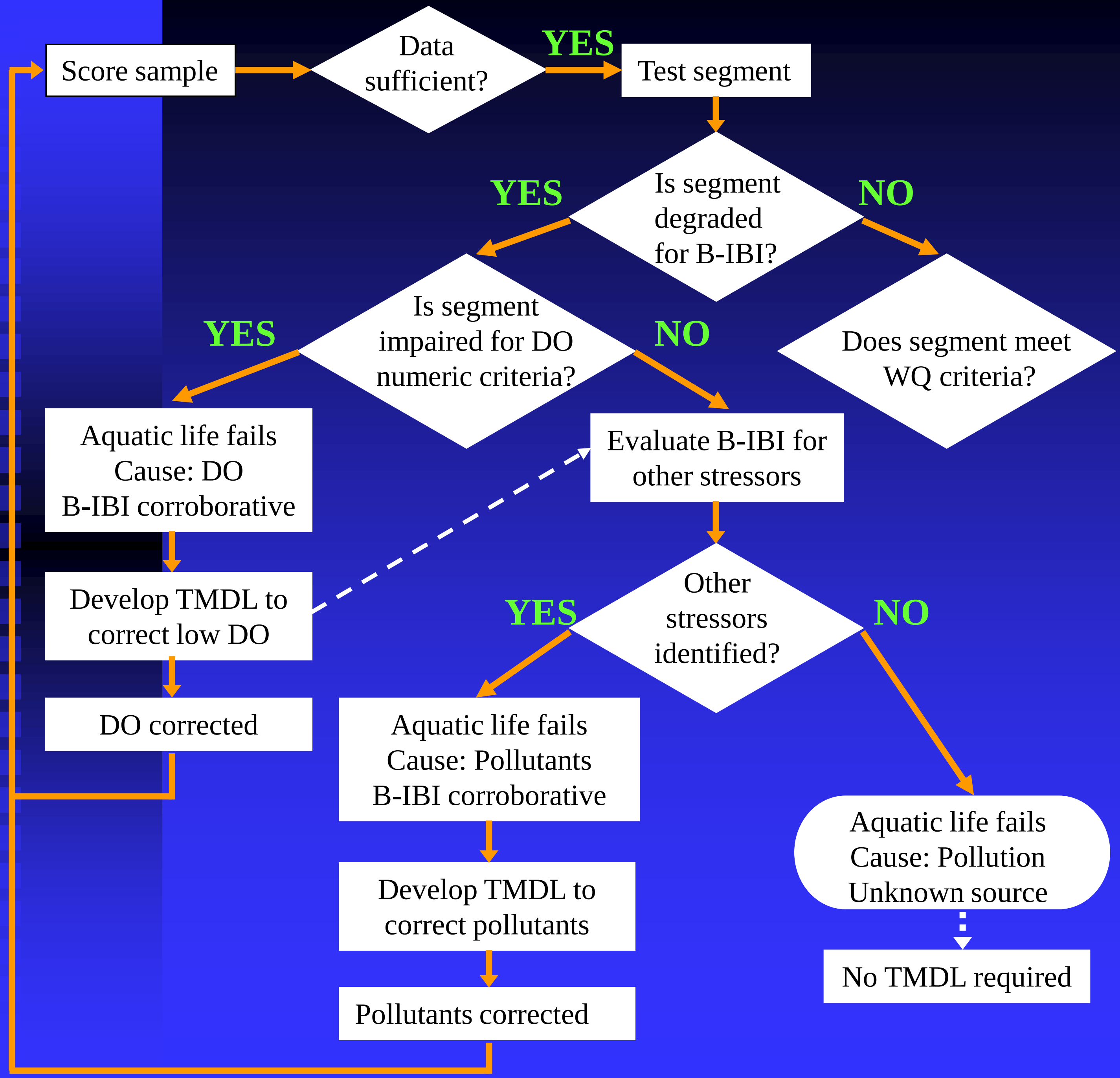
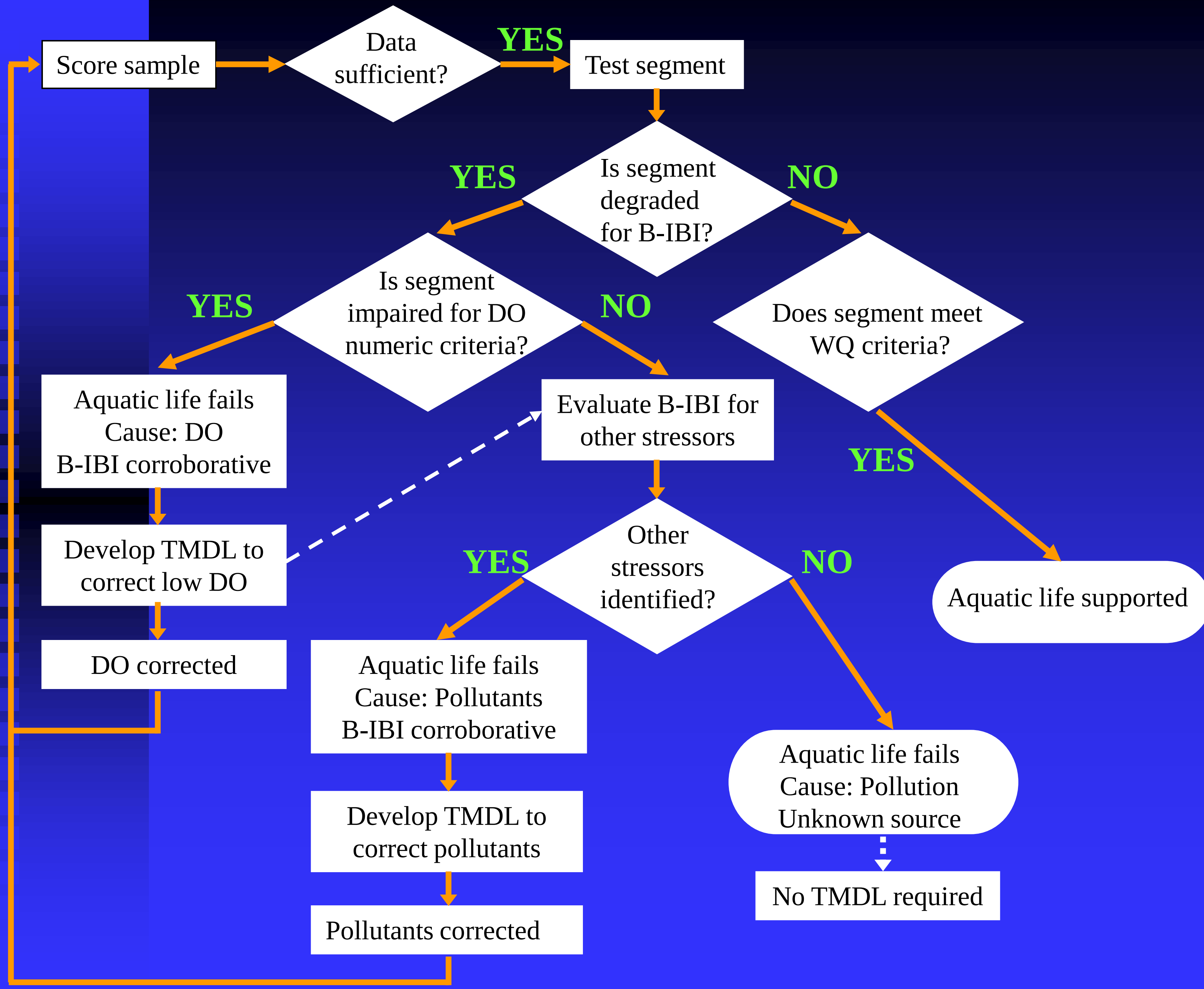
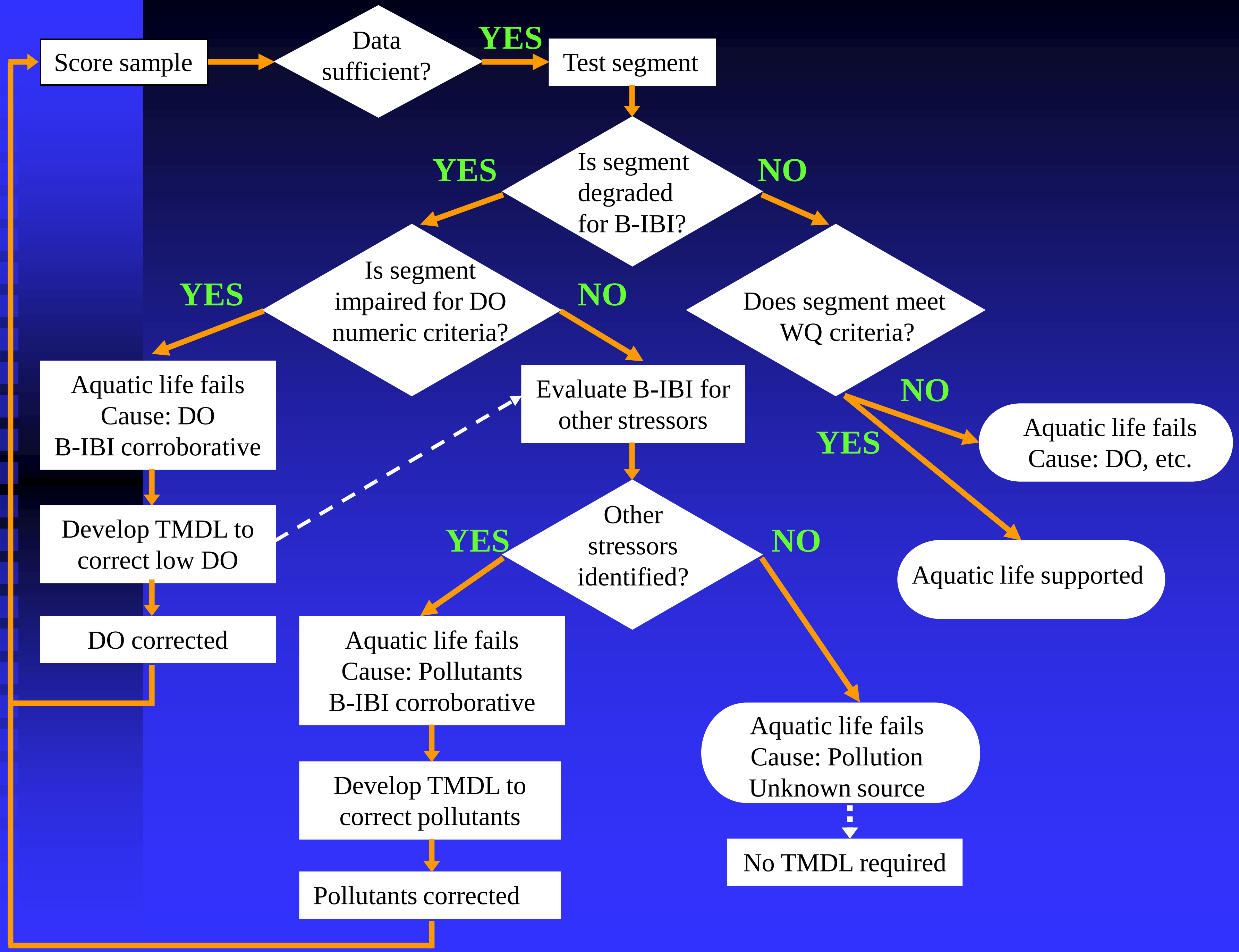
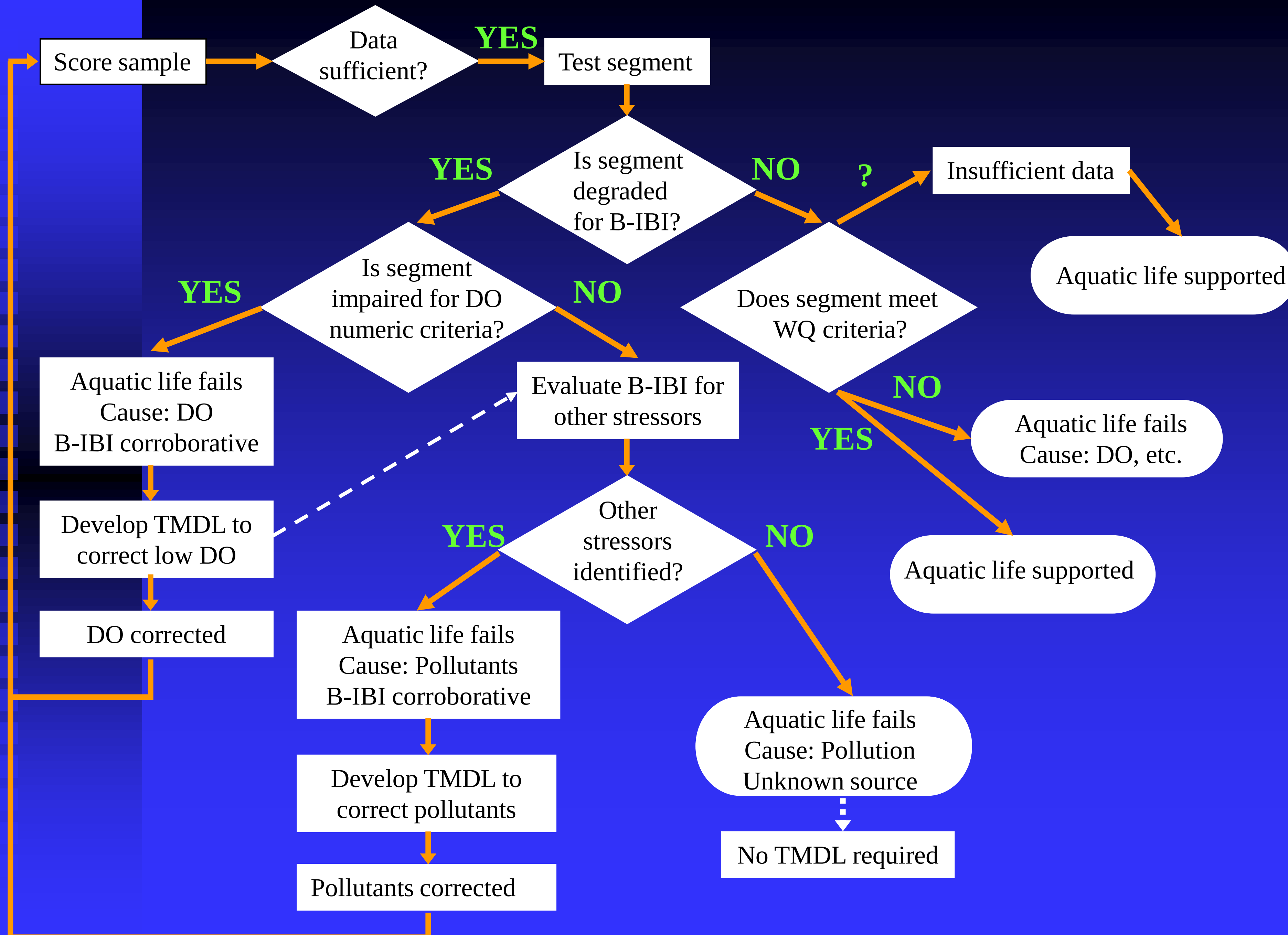
Develop TMDL to correct low DO
DO corrected
Evaluate B-IBI for other stressors
Other stressors identified?
YES
NO
Aquatic life fails
Cause: Pollutants
B-IBI corroborative
Develop TMDL to correct pollutants
Pollutants corrected
Aquatic life fails
Cause: Pollution
Unknown source
No TMDL required


Score sample
Data sufficient?
YES
Test segment
Is segment degraded for B-IBI?
YES
NO
Is segment impaired for DO numeric criteria?
YES
NO
Does segment meet WQ criteria?
Aquatic life fails
Cause: DO
B-IBI corroborative
Evaluate B-IBI for other stressors
Develop TMDL to correct low DO
Other stressors identified?
YES
NO
DO corrected
Aquatic life fails
Cause: Pollutants
B-IBI corroborative
Aquatic life fails
Cause: Pollution
Unknown source
Develop TMDL to correct pollutants
No TMDL required
Pollutants corrected


Score sample
Data sufficient?
YES
Test segment
Is segment degraded for B-IBI?
YES
NO
Is segment impaired for DO numeric criteria?
YES
NO
Does segment meet WQ criteria?
Aquatic life fails
Cause: DO
B-IBI corroborative
Evaluate B-IBI for other stressors
YES
Develop TMDL to correct low DO
Other stressors identified?
YES
NO
Aquatic life supported
DO corrected
Aquatic life fails
Cause: Pollutants
B-IBI corroborative
Aquatic life fails
Cause: Pollution
Unknown source
Develop TMDL to correct pollutants
No TMDL required
Pollutants corrected


Score sample
Data sufficient?
YES
Test segment
Is segment degraded for B-IBI?
YES
NO
Is segment impaired for DO numeric criteria?
YES
NO
Does segment meet WQ criteria?
NO
YES
Aquatic life fails Cause: DO B-IBI corroborative
Evaluate B-IBI for other stressors
Aquatic life fails Cause: DO, etc.
Develop TMDL to correct low DO
Other stressors identified?
YES
NO
Aquatic life supported
DO corrected
Aquatic life fails Cause: Pollutants B-IBI corroborative
Aquatic life fails Cause: Pollution Unknown source
Develop TMDL to correct pollutants
No TMDL required
Pollutants corrected


Score sample
Data sufficient?
YES
Test segment
Is segment degraded for B-IBI?
YES
NO
?
Insufficient data
Aquatic life supported
Is segment impaired for DO numeric criteria?
YES
NO
Does segment meet WQ criteria?
Aquatic life fails
Cause: DO
B-IBI corroborative
Evaluate B-IBI for other stressors
NO
YES
Aquatic life fails
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Other stressors identified?
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Aquatic life fails
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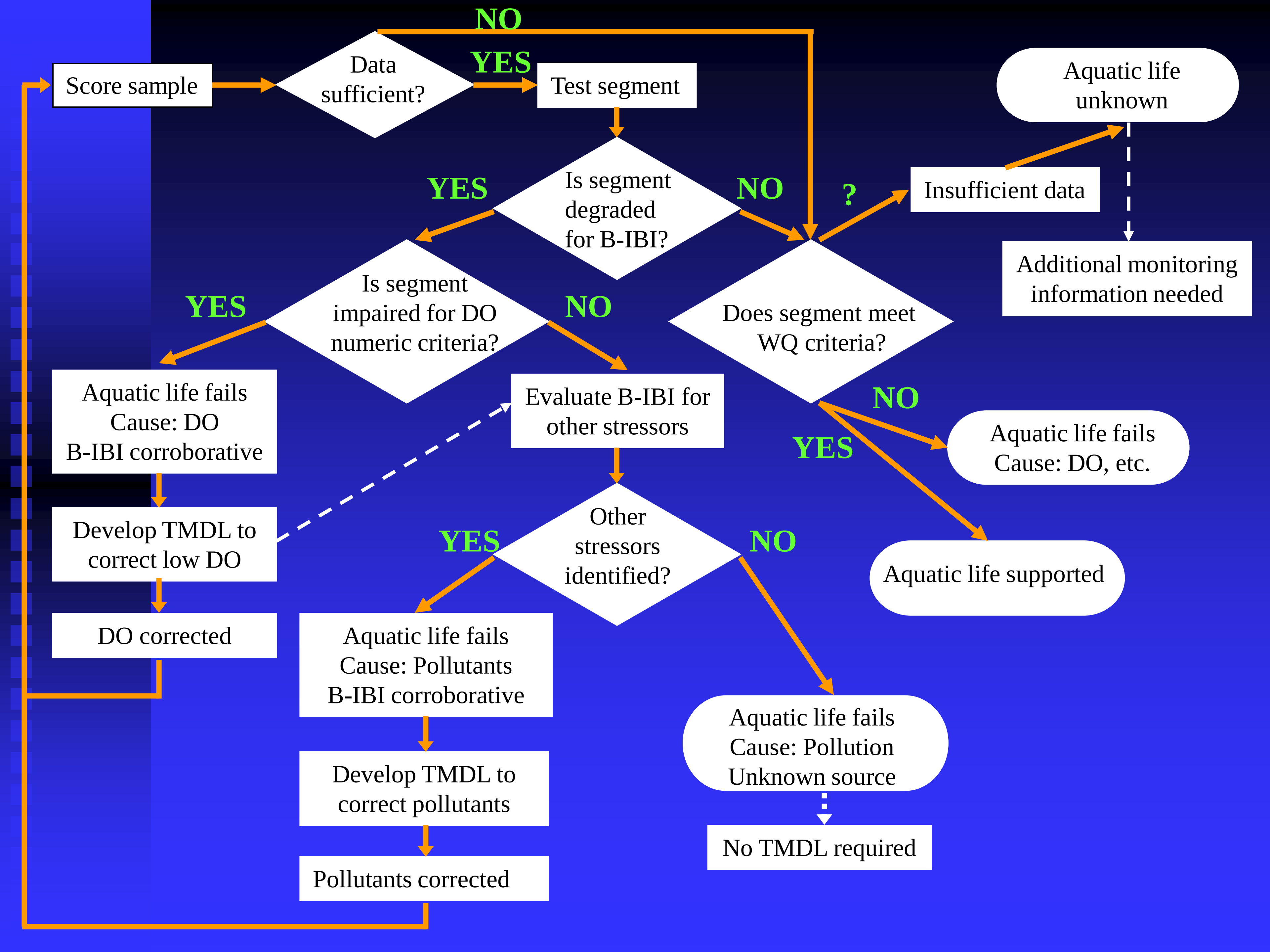
Score sample
Data sufficient?
NO
YES
Test segment
Is segment degraded for B-IBI?
YES
NO
Is segment impaired for DO numeric criteria?
YES
NO
Aquatic life fails
Cause: DO
B-IBI corroborative
Develop TMDL to correct low DO
DO corrected
Evaluate B-IBI for other stressors
Other stressors identified?
YES
NO
Aquatic life fails
Cause: Pollutants
B-IBI corroborative
Develop TMDL to correct pollutants
Pollutants corrected
Aquatic life fails
Cause: Pollution
Unknown source
No TMDL required
Does segment meet WQ criteria?
?
Insufficient data
Aquatic life unknown
Additional monitoring information needed
NO
YES
Aquatic life fails
Cause: DO, etc.
Aquatic life supported