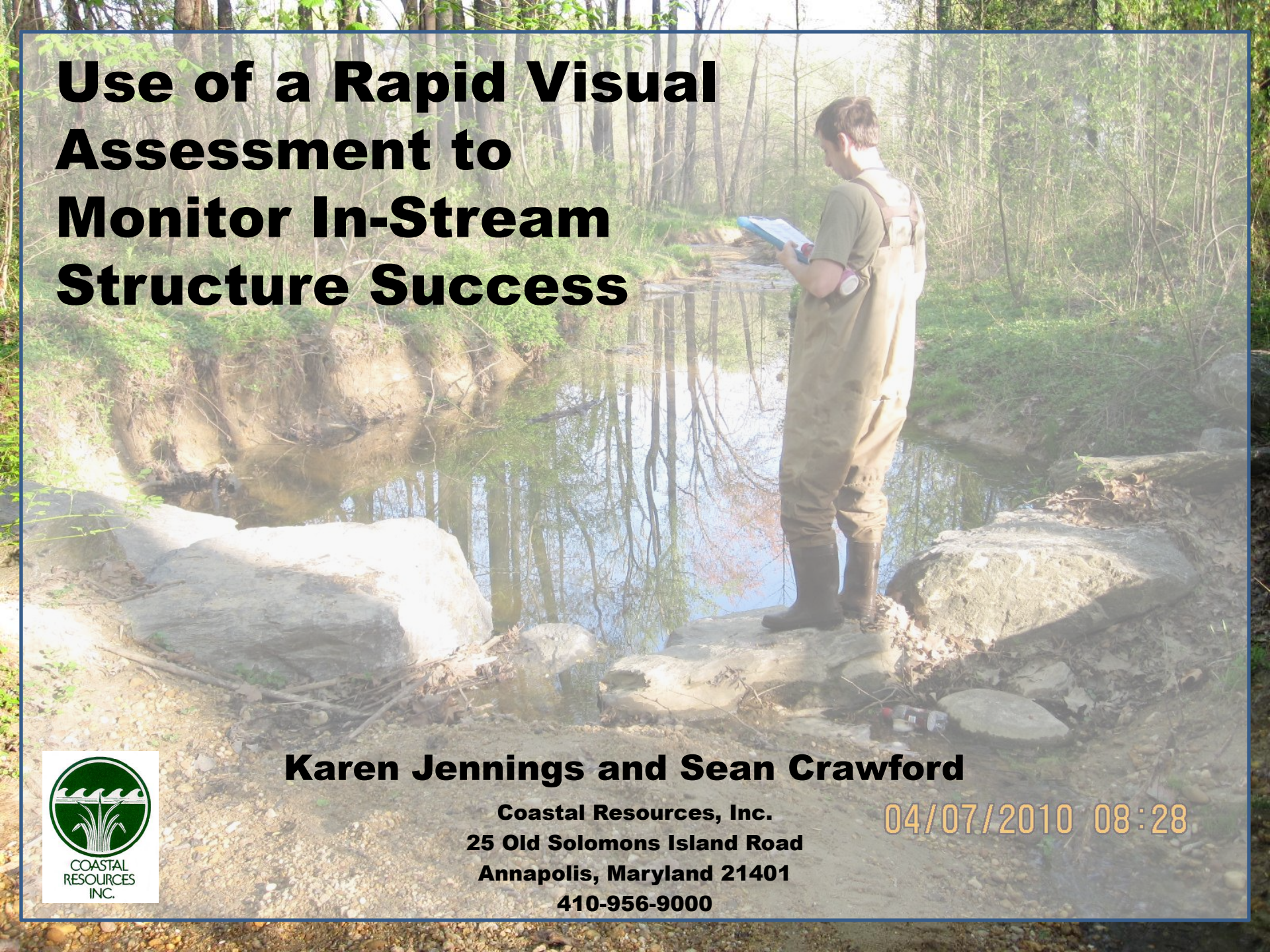
Use of a Rapid Visual Assessment to Monitor In-Stream Structure Success



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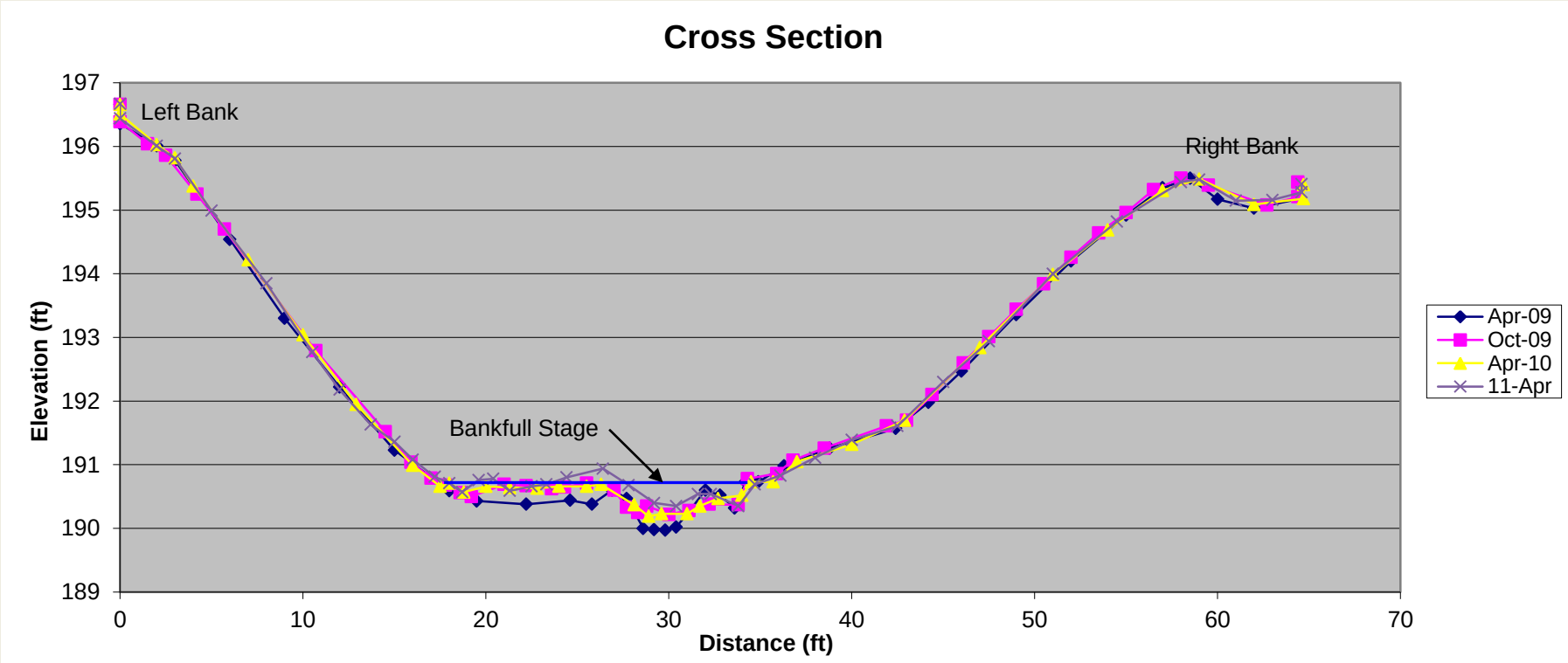
Reasons for monitoring in-stream structures:

- High cost item
- Key features of design (grade control, channel alignment)
- Lessons learned for future designs
- Early identification and remediation of problems can save money

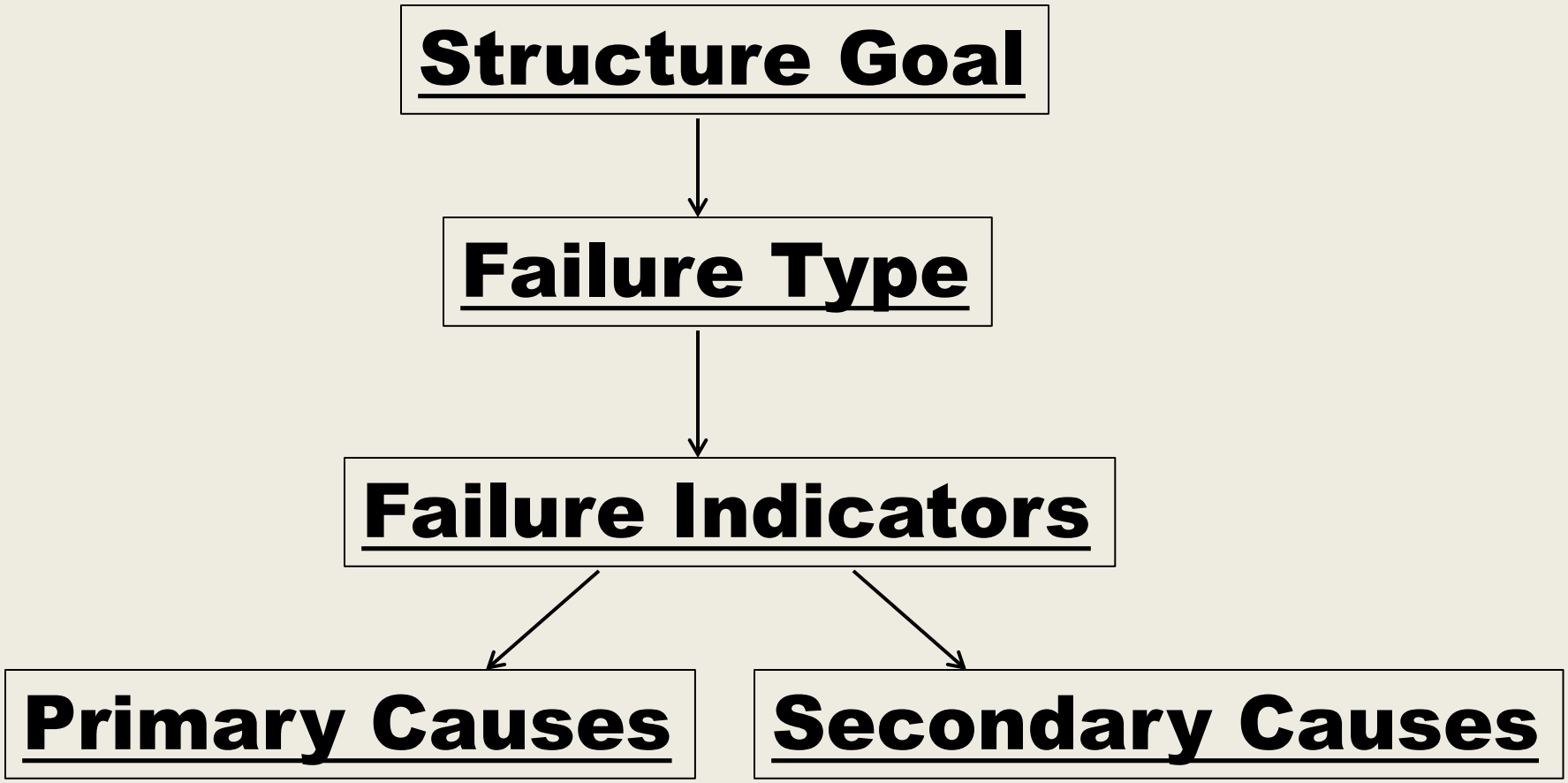
Traditional monitoring methods:

- **Cross Sections and Longitudinal Profiles only show a 2-D view**
- **Visual observations may be subjective - results are difficult to reproduce amongst different people involved**
- **Photos may not reveal small or obscured problems (i.e. piping)**



Structure Performance and Failure Risk Analysis

- Uses the Rock Cross Vane Rapid Assessment Tool (Puckett, 2007) and expands to include other structure types
- Focuses on failure mechanisms
- Guides attention to visual indications of failure
- Objective and repeatable
- Quantitative
- All encompassing


Structure Goal
Failure Type
Failure Indicators
Primary Causes
Secondary Causes

A failure indicator is the visual clue or observation that indicates the structure is not durable, or that it is not performing its intended function.

Bank undercutting and streambed scour.

Piping under structure boulders.

Includes restoration goals, not just durability.

Buried step pools are no longer performing the restoration goals of dissipating water energy or providing pool habitat.

Failure indicators are given a numerical rating based on severity.

	Score	0	1	3	5
Failure Indicator	Arm or Side Washout	Indicator is not present.	Less than 10% of the arms or sides have washed out (i.e. one or two boulders missing) or observable signs of boulder shifting are present.	11% to 30% of the boulders are missing.	Greater than 30% of the boulders are missing.
	Head Cut	Indicator is not present.	Observable signs of boulder shifting are present, or there is slight side cutting and/or undercutting of the sill.	Undercutting travels all the way under the sill, or the bed around the sill has begun down-cutting (as opposed to the sill simply being installed above bed elevation)	A visible head cut has occurred and/or is migrating upstream.
	Bank Erosion at Structure	Indicator is not present.	Vegetation has been washed off at the toe of banks and/or there are sparse patches of erosion on less than 25% of the bank area.	Patchy erosion covers 25% to 50% of the bank area, bank slumping has occurred but is still covered by vegetation, vegetation has been washed off the banks at half-bankfull, or there are small bank scour spots.	Most of the vegetation up to bankfull has been washed off, banks have slumped or sheared off, or there are large areas of deep scour.
	Insufficient Scour Pool	Indicator is not present.	The pool is shallow compared to design intensions (pools were designed to have minimum depths of 1ft in step pools, and 0.75ft at cross and J-hook vanes).	The pool is shallow and there is accretion of larger material or washed out structure boulders in the pool.	The pool is shallow with an accretion of fine material, or the pool is non-existent.

Primary vs Secondary Causes of Failure

Primary cause of failure:

Results from stream flow and associated hydraulics.

Secondary cause of failure:

Mechanisms which influence the stream flow, for example design or installation flaws.

Structure	Indicator	Failure Score	Primary	Secondary
Cross Vane	Arm Washout	3	Undercutting	Insufficient Backfill
	Bank Erosion at Structure	5	Side Cutting	Arms Washed Out
	Downstream Bank Erosion	4	Side Cutting	Placed in a Bend

Structure	Indicator	Failure Score	Primary	Secondary
Weir	Boulder Washout	3	Drag and Lift or Tipping	Insufficient Backfill
	Bank Erosion at Structure	3	Side Cutting	Boulders Washed Out
	Downstream Bank Erosion	3	Flow Directed at Banks	Improper Alignment

Failure paths can be mapped out for any type of structure.

Table of Failure Mechanisms for Rock Cross Vanes, J-Hooks, and Step Pools (based on Puckett, 2007)

Failure Types	Failure Indicators	Primary Causes	Secondary Causes
Lack of Durability	F1. Arm Washout	P.01 Direct Contact of Flow with Banks	S.01 Improper Alignment
Lack of Grade Control	F2. Sill Washout	P.02 Flow Directed at Banks	S.02 Backed into a Pool
Lack of Bank Protection	F3. Head Cut	P.03 Drag and Lift or Tipping	S.03 Placed in a Bend
Lack of Pool/Pattern Development	F4. Bank Erosion at Vane	P.04 Flow Expansion Out of Vane	S.04 Placed on Bedrock
Lack of Dissipated Water Energy	F5. Downstream Bank Erosion	P.05 Piping	S.05 Arms not Tied in
	F6. Insufficient Scour Pool	P.06 Protected from Scour	S.06 Arms too Short
	F7. Downstream Streambed Scour	P.07 Side Cutting	S.07 Arms too Flat
	F8. Lack of Pool Habitat	P.08 Undercutting	S.08 Arms too Steep
		P.09 Weak Jet / Low Velocity Ratio	S.09 Arms Washed Out
		P.10 Insufficient Energy Dissipation	S.10 Sill too High
			S.11 Sill Washed Out
			S.12 Spacing of Boulders
			S.13 Boulders in Pool
			S.14 Undersized Boulders
			S.15 Drop too Short
			S.16 Drop too High
			S.17 Exposed Banks
			S.18 Insufficient Backfill
			S.19 No footers
			S.20 Oversized Rock Cross Vane
			S.21 Undersized Rock Cross Vane
			S.22 Insufficient Pool Depth or Length
			S.23 Structure too Steep
			S.24 Flow Not Concentrated in Center
			S.25 Angle Between Arm and Bank too High

Table of Failure Mechanisms for Fish Passage

Lack of Fish Passage	F9. Fish Barrier	P.11 Debris blockage	S.26 Channel too wide
		P.12. Shallow Water Depth	S.27 Flow Constriction
		P.13. Excessive Turbulence	S.28 Channel too rough
		P.14. Water Surface Drop	S.29 Drop in Channel Elevation
			S.30 Insufficient Base Flow

Example of data form.

Field Assessment Form for Step Pools		
Step Pool #		
Date		
Notes		
Score each indicator from 0 (indicator not present) to 5 (severe), circle each primary and sceondary cause that is applicable.		
Indicator	**Primary**	**Secondary**
F1. Side Boulder Washout **Score____**	P.03 Drag and Lift or Tipping	S.01 Improper Alignment
		S.03 Placed in a Bend
		S.12 Spacing of Boulders
		S.14 Undersized Boulders
		S.18 Insufficient Backfill
	P.08 Undercutting	S.01 Improper Alignment
		S.03 Placed in a Bend
		S.16 Drop too High
		S.18 Insufficient Backfill
		S.19 No footers
		S.21 Undersized Step Pool
F2. Step Boulder Washout **Score____**	P.03 Drag and Lift or Tipping	S.10 Step too High
		S.12 Spacing of Boulders
		S.14 Undersized Boulders
		S.18 Insufficient Backfill
		S.21 Undersized Step Pool
	P.08 Undercutting	S.02 Backed into a Pool
		S.16 Drop too High
		S.18 Insufficient Backfill
		S.19 No footers
		S.21 Undersized Rock Cross Vane
F3. Head Cut **Score____**	P.05 Piping	S.12 Spacing of Boulders
		S.18 Insufficient Backfill
	P.07 Side Cutting	S.01 Improper Alignment
		S.03 Placed in a Bend
		S.05 Sides not Tied in
		S.09 Sides Washed Out
		S.10 Step too High
		S.12 Spacing of Boulders
		S.21 Undersized Step Pool
	P.08 Undercutting	S.02 Backed into a Pool
		S.03 Placed in a Bend
		S.11 Step Washed Out
		S.16 Drop too High
		S.19 No footers
F7. Downstream Streambed Scour **Score____**	P.10 Insufficient Energy Dissipation	S.16 Drop too High
		S.21 Undersized Step Pool
		S.22 Insufficient Pool Depth or Length
		S.23 Structure too Steep

Indicator	**Primary**	**Secondary**
F4. Bank Erosion at Structure **Score____**	P.01 Direct Contact of Flow with Banks	S.05 Sides not Tied in
		S.09 Side Boulders Washed Out
		S.12 Spacing of Boulders
		S.17 Exposed Banks
	P.02 Flow Directed at Banks	S.01 Improper Alignment
		S.03 Placed in a Bend
	P.05 Piping	S.12 Spacing of Boulders
		S.18 Insufficient Backfill
	P.07 Side Cutting	S.01 Improper Alignment
		S.03 Placed in a Bend
		S.09 Side Boulders Washed Out
		S.10 Sill too High
		S.12 Spacing of Boulders
		S.21 Undersized Step Pool
	P.08 Undercutting	S.01 Improper Alignment
		S.03 Placed in a Bend
		S.16 Drop too High
		S.18 Insufficient Backfill
		S.19 No Footers
		S.21 Undersized Step Pool
F5. Downstream Bank Erosion **Score____**	P.02 Flow Directed at Banks	S.01 Improper Alignment
		S.03 Placed in a Bend
	P.04 Flow Expansion Out of Structure	S.13 Boulders in Pool
		S.21 Undersized Step Pool
	P.07 Side Cutting	S.01 Improper Alignment
		S.03 Placed in a Bend
		S.05 Sides not Tied in
		S.09 Sides Washed Out
		S.10 Step too High
		S.12 Spacing of Boulders
F6. Insufficient Scour Pool **Score____**	P.06 Protected from Scour	S.04 Placed on Bedrock
		S.09 Sides Washed Into Pool
		S.11 Step Washed into Pool
		S.13 Boulders put in Pool
	P.10 Insufficient Energy Dissipation	S.22 Insufficient Pool Depth or Length
		S.23 Structure too Steep
	P.05 Piping	S.12 Spacing of Boulders
		S.18 Insufficient Backfill
	P.09 Weak Jet	S.04 Placed on Bedrock
		S.11 Sill Washed Out
		S.15 Drop too Short
		S.20 Oversized Step Pool

We have successfully used this rapid assessment protocol for:

Step Pools
J-Hooks
Log Vanes
Rock Vanes
Regenerative Stormwater Conveyances
Fish Passages
Weirs
Riffle Grade Controls

Case Study: Sullivan Branch

Headwater Stream Restoration Project

Construction completed in March, 2009

Location: Prince Frederick, Maryland

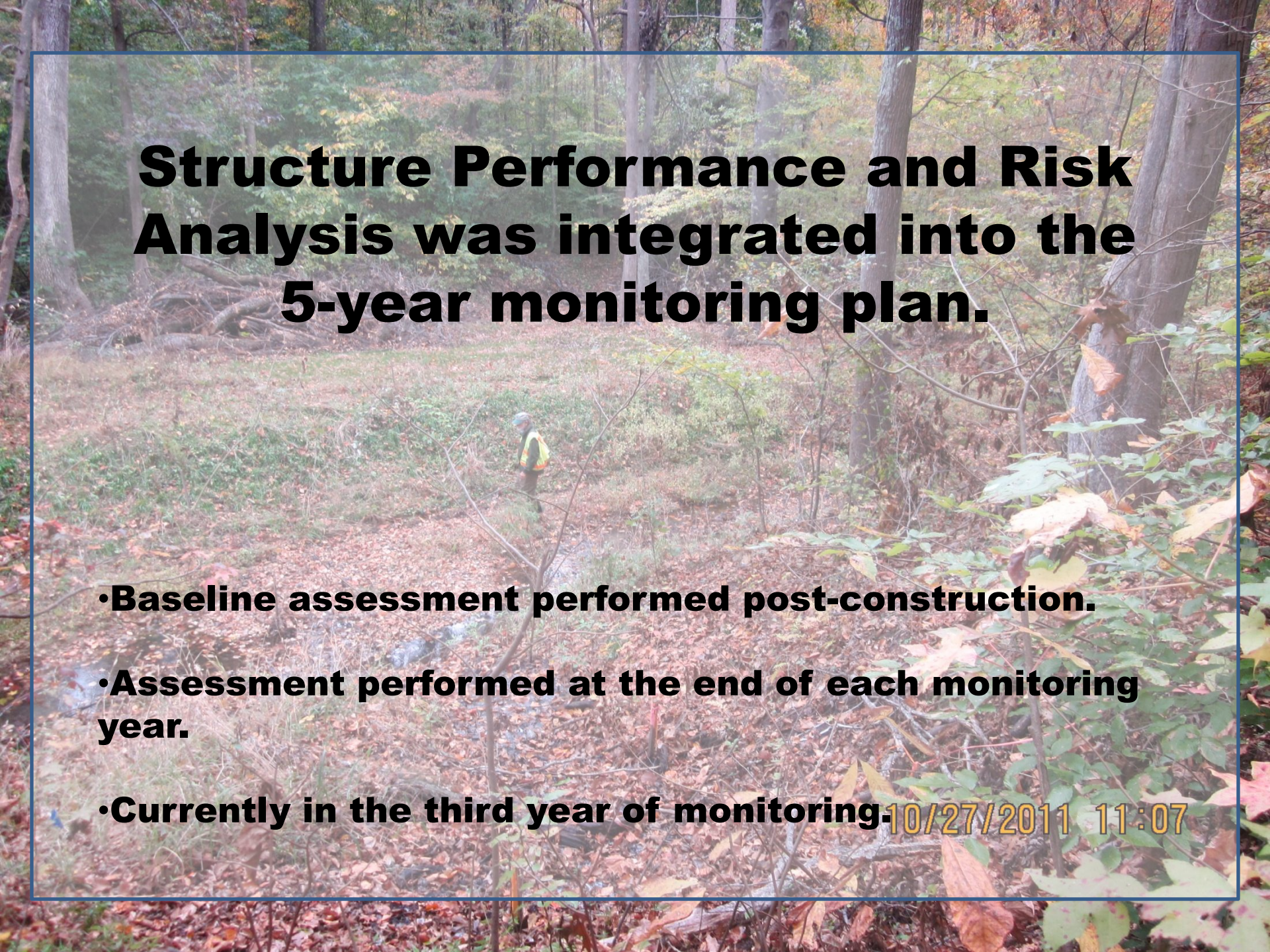
Physiographic Province: Western Coastal Plain

Length: 550 Linear Feet

Structures: 6 rock cross vanes, 4 rock J-hooks, and 7 step pools

Structure Performance and Risk Analysis was integrated into the 5-year monitoring plan.

- Baseline assessment performed post-construction.
- Assessment performed at the end of each monitoring year.
- Currently in the third year of monitoring.



Advantages

- **Able to identify construction changes**

- **Detailed inventory of channel adjustment around the structures**

- **Documented tipped boulders that might have gone unnoticed**

Tracking both deterioration and improvement over time.

Structure	Date	Failure Indicators Exhibited	Failure Score (1-5)	Primary Causes Identified	Secondary Causes Identified
J-Hook	April 2009	Bank Erosion at Vane	1	Piping	Insufficient Backfill
	Dec. 2009	Bank Erosion at Vane	1	Flow Directed at Banks Piping Side Cutting	Placed in a Bend Insufficient Backfill
		Downstream Bank Erosion	2	Flow Directed at Banks	Improper Alignment
	Dec. 2010	Bank Erosion at Vane	3	Direct Contact of Flow with Banks Flow Directed at Banks Undercutting	Exposed Banks Improper Alignment Placed in a Bend Drop too High
		Downstream Bank Erosion	4	Direct Contact of Flow with Banks Flow Directed at Banks Weak Jet	Exposed Banks Improper Alignment Flow not Concentrated in Channel Center
Cross Vane	April 2009	Insufficient Scour Pool	2	Protected From Scour Weak Jet	Cobbles Put in Pool Arms too Flat Drop too Short Oversized Rock Cross Vane
	Dec. 2009	Insufficient Scour Pool	1	Weak Jet	Drop too Short
	Dec. 2010	No Failure Indicators Observed.			

Applications beyond use as a monitoring tool

- Prioritizing structure rehabilitation projects
- Research applications (instead or in conjunction with flume studies)
- Stream response to structures
- Identify fatal flaws at design stage
- Better understanding of why particular structures are or are not achieving design goals
- Inform how projects are built in future

Summary

- **Supplements traditional monitoring methods to give a multi-dimensional and detailed view.**

- **Provides consistent, quantitative results**

- **Flexible protocol can be used for a variety of structures or applications**

- **Provides information for future designs on the placement and use of certain structures, or improved specifications for construction**

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