BRIDGE VULNERABILITY AND ADAPTATION MATRIX

Index	SLR	SS	PC	RR	Vulnerability	How to identify vulnerability	Primary inspection element	Decision			Engineering Adaptation	Operations & Maintenance Adaptation	Resources
1	SLR	SS	PC		Roadway uplift due to soil saturation and roadway overtopping	Observed cracking in pavement of approaches and deck? End bents anchored? High water table? Exposure to SLR? SS? PC?	Standing water in drainage conveyances, pavement condition	Now	Future	No	Raise roadway if possible; install diversion and conveyance structures; improve roadway/pavement design; increased monitoring of infrastructure and conditions; consider asphalt/concrete mixtures that withstand flood conditions	Install diversion and conveyance structures	Issues would be accounted for in design. Maryland 2018 pavement design guide
2	SLR	SS			Steel/concrete corrosion from nearer saltwater	Type of substructure material? Exposure to SLR? SS?	High water marks, substructure condition	Now	Future	No	-	Change coating type or apply coating; utilize more rebar cover and exclude material types susceptible to corrosion(e.g., weathering steel); increased monitoring of infrastructure and conditions	MDOT SHA Standards Specifications for Construction and Materials; FHWA-HRT-24-127: Best Practicies for Corrosion Control and Mitgation
3	SLR	SS			Structural instability due to buoyancy	Freeboard below substructure to expected high-water elevation? Exposure to SLR? SS?	High water marks	Now	Future	No	Anchor superstructure to abutments and piers	Temporary placement of mass on superstructure	Various Maryland SHA details can be found at the online, including guidance on anchoring bridge superstructure to piers (See 03-09 for Bearings) FHWA-HRT-09-028: Hydrodynamic Forces on Inundated Bridge Decks
4	SLR	SS			Mechanical systems of moveable structures (e.g., drawbridges) damaged by water	Elevation of mechanical system with respect to expected high-water elevation? Exposure to SLR? SS?	High water marks, mechanical system/vault condition	Now	Future	No	Flood proofing	Install pumps and/or backup power	Mechanical systems mentioned in recent version of the Manual on Uniform Traffic Control Devices (MUTCD), but no mention of mechanical systems placement in case of flooding Hazards can be addressed using FEMA utility requirements for structures
5	SLR	SS			Damage or failure of utilities attached to bridges	Elevation of attached utilities with respect to expected high-water elevation? Casing type/material? Exposure to SLR? SS?	High water marks, condition of utility casings	Now	Future	No	-	Raise the utility above the anticipated SLR and/or design SS elevation where applicable	Hazards can be addressed using FEMA utility requirements for structures
6	SLR				Expansion of tidal range leading to tidal erosion where previously there was none.	Exposure to SLR but not currently tidally influenced? Scour protection countermeasures present?	Scour/erosion on banks and/or channel bed	Now	Future	No	Scour protection; increase bridge opening;	Increased monitoring of infrastructure and conditions	Site dependent based on a hydraulic analysis. FHWA National Bridge Inspection Standards for inspections. FHWA Hydraulic Engineering Circular 18 Evaluating Scour at Bridges.
7	SLR				Raising tailwater leading to less stormwater conveyance capacity	Exposure to SLR but nt currently tidally influenced?	Observed water elevation, standing water in drainage conveyances	Now	Future	No	Install backflow preventers on closed systems; reevaluate stormwater conveyance systems, upgrade if warranted	-	Tailwater discussed in the Highway Drainage Manual (HDM) but backflow preventers are not included. FHWA-HIF-24-006: Urban Drainage Desig contains information on flap gates.
8		SS	PC	RR	High velocity flows beyond design level of service causing scour	Scour protection countermeasures present? Type of countermeasures? Exposure to SS? PC? RR?	Scour/erosion near bents	Now	Future	No	Reevaluate the scour analysis and add additional counter measures as warranted	Increase monitoring/inspection of critical structures on emergency routes; provide enhanced scour protection; retrofit/replace bridges as required for new scour conditions	Site dependent based on a hydraulic analysis. FHWA National Bridge Inspection Standards for inspections. FHWA Hydraulic Engineering Circular 18 Evaluating Scour at Bridges.
9		SS	PC		Floating debris damages	Debris reported/observed? Exposure to SS? PC?	Observed debris at bents and substructure	Now	Future	No	Depends on the hydraulic analysis. Evaluate likelihood of upstream debris; if replacement/rebuild needed, elevate the bottom of the bridge (aka the "low chord") during design phase to provide additional freeboard.Consider changes to design standards.	station equipment for rapid debris removal	MDOT SHA Stormwater Management Facility Routine Maintenance Manual; MDOT SHA Highway Design Manual FHWA HEC-09 Debris-Control Structures; TRB NCHRP Report 653: Effects of Debris on Bridge Pier Scour
10		SS	PC		Debris settling on roadways with subsiding floodwater	Expect high water elevation with respect to bridge deck and approaches? Exposure to SS? PC?	Observed debris accumulation on approaches or roadside	Now	Future	No	Provide open parapets for debris flow-through; if bridge needs to be replaced/rebuilt increase the bottom of the bridge (aka "low chord") elevation in design phase. Consider changes to design standards.	Station equipment for rapid debris removable	MDOT SHA Stormwater Management Facility Routine Maintenance Manual; MDOT SHA Highway Design Manual FHWA HEC-09 Debris-Control Structures; TRB NCHRP Report 653: Effects of Debris on Bridge Pier Scour
11		SS			Increased structural loading due to wind and/or waves	Exposure to SS?	Substructure and/or superstructure cracking at bent connections	Now	Future	No	Reevaluate structural design of inland bridges. Retrofit or replace as warranted.	-	MDOT SHA Office of Structures Guidelines and Procedures Memorandums;Several FHWA guidelines (e.g., FHWA-NHI-15-044: Enginering for Structural Stability in Bridge Construction)
12			PC		Scour due to increases in peak discharges and volumes	Scour countermeasures present? Type of countermeasures? Exposure to PC?	Observed scour/erosion at drainage conveyance outfalls and/or channel banks and bottom	Now	Future	No	Reevaluate hydraulic analysis for changes to hydrology and sediment supply; provide countermeasures if scour potential increases	-	FHWA Hydraulic Engineering Circular 18 Evaluating Scour at Bridges.
13			PC		Increase in stormwater peak due to upstream land use changes	Increase in upland impervious land cover? Exposure to PC?	High water marks, erosion/scour	Now	Future	No	Reevaluate hydrologic analysis; ensure bridge opening is still sufficient; increase hydraulic opening if needed	-	FHWA Hydraulic Engineering Circular 18 Evaluating Scour at Bridges.
14				RR	Runoff from approach roadway eroding embankments	Vegetated embankments on approaches? Stabilization measures on embankments? Exposure to RR?	Erosion/scour on embankments, rills forming on embankments	Now	Future	No	Consider retrofit with closed drainage system around the structure	Add robust slope protection such as matting, riprap armoring, or vegetation	Issues would be accounted for in design. Maryland Highway Drainage Manual
15				RR	Scupper capacity exceeded from high intensity rainfall	Scuppers present? Spacing of scuppers? Exposure to RR?	Water ponding on bridge during rain events, sediment/debris accumulation at scuppers	Now	Future	No	Add additional scuppers; upgrade bridge deck and drainage systems	Clean debris from existing scuppers; monitor drainage system during extreme precipitation events	Site dependent based on a hydraulic analysis. FHWA HEC-21 Design of Bridge Deck Drains

Sea Level Rise
Storm Surge
Precipitation Change
Rainfall Runoff