Table 1
Design Element, Risks, Testing Requirements, Performances Standards, Preferred Design Element and Remedial Plan Elements for Development in Karst Terrain
Township of Union

High-load and broad load structures (high-rise buildings, parking decks, warehouses, water towers, etc.)	Settlement Structural damage/loss Personal injury/death	Evaluate available data Reconnaissance - prior to design Test pits - to confirm shallow bedrock where suspected Borings - 1 per 5,000 square feet area of building footprint; depth based on column/slab load proposed Geophysics - at foundation elements Conceptual failure model – discretionary Bridging analysis – discretionary Inspection of footings - intermittent during construction	Optimal layout Redundancy of support elements Pre-drill foundation sites, depths determined by proposed loads High-tensile strength slabs, with load transfer capability Use pile tips Drill caisson sites, depths determined by proposed loads Pre-construction grouting	Inspection Evaluation plan Remedial grouting plan Remedial designs
Low-load structures (single-family homes, small offices, stores, etc.)	Settlement Collapse Property damage Personal injury	Evaluate available data Inspection of footings - during installation of trench or footing	Foundation areas show no evidence of creep or settlement Drainage directed away from foundation	Foundation reinforcement Occasional inspection by owner
Bridges	Settlement Collapse Embankment failure	Test pits - to competent bedrock Borings - 5 to 10 feet into competent bedrock	Piles, caissons to competent bedrock Redundancy Footing with bridging of anticipated failure Pre-construction grouting	Alternate route Abutment reinforcement modifications Evacuation plans Escrow to recover repair

Underground tanks	Settlement/failure Undermining/failure Undetected leaks	Test pits - in excavation Borings - in or near excavation, 10 feet into competent bedrock	Soil and rock void-free Voids grouted Above-ground tanks	
Roads and Parking Areas	Settlement Undermining Collapse Contaminated runoff	Analysis of existing data Reconnaissance of route Test pits or borings - installed in depressions, or other likely karst features Geophysics - where warranted, and to link boring/test pit data	Layout to avoid karst features Minimize paved areas Control drainage under pavement Controls on blasting Use of ripping Compaction of roadbase Reinforced roadbed	Alternative route Evacuation route Repair procedures Subsidence monitoring Bridging over sinkholes
Drainage features: conduits swales catch basins detention basins ponds injection pits	Settlement Leaks Collapse Undermining of adjacent areas Injection of pollutants to groundwater	Analysis of existing data Reconnaissance of route - prior to design Test pits, probes at select catch basin sites Inspection schedule - continuous during construction Borings into bedrock - locations and depth based on geology, and practical considerations, ± 2 per acre Permeability lasting - for injection sites	Route consistent with site evaluation results Swales/lined swales Water-tight joints Impermeable backfill Layout to avoid karst features Liners/compacted substrate Velocity reducers Ponds at water-table elevation On-stream ponds Facilities remote from structures	Inspection schedule Repair proposal/escrow Reserve area Grouting specifications Repair escrow Abandonment plan
Utility conduits	Leaks Conduit failure Pollution/explosion/fire Property damage	Reconnaissance of route - prior to design Inspection schedule - continuous during construction Test pits, borings, probes - at key locations to identify possible areas of undermining	Route consistent with site evaluation results Backfill with native soils Geotextiles Piers, where appropriate Strong, flexible conduit Proper backfill procedures	Evacuation plan Shutoffs in key locations Alternate routes

Subsurface sewage disposal systems	Groundwater contamination Structural failure	Test pits - 1 per 1,000 square feet 2 at a minimum	Pressure-closed disposal beds Beds not located next to rock pinnacles, nor in natural depressions	Alternate sites Closed systems (holding tanks)
Wells	Washed-out subsidence during drilling Subsidence due to dewatering Excessive grout needs Turbidity Natural water-quality hardness, metals, radium, radon	Careful oversight Intermittent reconnaissance, monitoring Sampling of parameters of concern	Well screen and gravel pack Minimize well loss Reconnaissance/monitoring of subsidence	Alternate site Grout modifications Pumpage modifications Casing off of mud zones Well screen and gravel pack