Supplementary methods: ground support and surface screening

Constructed-scene verification

The fixture specifies ground elevation 0 m, project elevation 10 m, eye height 1.8 m and surface support 0.4 m at the viewer. Both models use nine positions along the same normalized sample schedule. The intervening midpoint obstruction is 5.8 m in the agreeing scene and 6.0 m in the differing scene. A strictly higher obstruction blocks the ray; equality is clear. Curvature and refraction are omitted.

The expected midpoint sightline elevations are 5.9 m with ground support and 6.1 m with surface support. Elevation assertions use an absolute tolerance of 0.000002 m, while visible and blocked classifications must match exactly. This tolerance checks the numerical fixture, not landscape elevation accuracy. The full scalar trace is compared with the raster result, and the differing scene must identify an intervening blocker rather than a blockage at the viewer.

The fixture and all scientific plots were evaluated on the Work PC. The computational record retains the fixture, sampled profile CSV, scalar trace and SHA-256 checksums that identify the evaluated geometry.

Ground support and obstruction roles

The accompanying model pseudocode explains the physical roles without prescribing a particular interpolation or ray algorithm. A reproducible implementation additionally specifies coordinate reference systems, horizontal and vertical units, datum assumptions, sampling positions, equality handling, missing-data behavior and endpoint inclusion. A separate exclusion mask records receiver eligibility after geometric visibility has been evaluated.

In the landscape comparison, the resolved surface uses prepared DTM elevations only where DSM values are missing. Valid DSM elevations below DTM elevations remain unchanged. Ground support, surface support and the screening difference are sampled at the same receiver query. These controls distinguish a change of elevation roles from a change of preparation. They are an experimental sampling configuration, not an unchanged execution of the toolbox's ordinary preparation workflow.

Sampling and reporting domains

The radius domain uses the production distance plane from output-cell centres to the requested project point. Receiver support uses the evaluator's actual query coordinates. Public-property

membership is rasterized at those query coordinates; membership at output-cell centres is retained separately as a sensitivity check. The scheduled raster target and requested project coordinate are recorded separately because they can differ. Profiles use normalized schedule position where physical distance would misdescribe the evaluated sequence.

The actual receiver query applies the output affine transform to the column and row indices, rather than their cell-centre offsets. Equivalently, it applies the endpoint affine transform to column plus 0.5 and row plus 0.5. In Groton, the requested project point has easting 363395.1369135049 m and northing 213696.97089452852 m in EPSG:26956. The scheduled raster target is displaced by +1 m easting and -1 m northing. The accepted radius mask remains based on the prepared cell-centre distance plane to the requested project point. These distinctions are preserved in receiver selection, resource membership and profile coordinates.

Each comparison uses its own valid pair of model outputs. Missing classifications stay outside its two-by-two table and are counted separately. Historical-output reconciliation uses a separate common-valid domain and does not define the principal surface-supported versus ground-supported comparison. Unknown mask eligibility remains unresolved in resource aggregation. A resource is potentially visible if it has at least one known-eligible location with a valid visible result; a complete no-visible result requires every included sample to be determinate and blocked. Empty and wholly excluded domains are reported separately.

With common receiver sampling and a cutoff greater than eye height, every known height-excluded ground eye lies below its opaque local surface. If the receiver sample is tested, the paired model blocks those locations. For valid classifications and known eligibility throughout a domain, whole-domain agreement of zero-coded surface-only results with the unmasked paired result then depends on the retained sightlines. At a cutoff equal to eye height, equality requires separate attention: the strict mask excludes it, whereas an equality-clear intersection convention can admit it. These conditions do not equate exclusion with evaluated blockage or resolve unknown elevations.

Analytical condition for a retained difference

For the planar, common-sampling explanation, let ground support be g, eye height be h, surface support be s, and $\delta = s - g$. At a sampled position t_i, measured from zero at the viewer to one at the project, let the obstruction elevation be o_i. With the fixed project elevation z_P, the eye height above ground required to clear every evaluated sample before the project is

$$h_{\mathrm{req}} = \max_{i:t_i<1} \left[\frac{o_i - t_i z_P}{1 - t_i} - g \right]. \tag{S1}$$

The expression uses the same valid sample set in both models and the convention that equality

is clear. A sampled viewer endpoint belongs in this maximum and may control it. A sampled project endpoint instead requires the separate common condition $o_P \leq z_P$. Shared invalid-data and eligibility rules must also be satisfied. Coincident endpoints require their own declared rule.

For a positive support displacement, surface-supported visibility and ground-supported blockage occur together when

$$h < h_{\mathrm{req}} \leq h + \delta. \tag{S2}$$

A height mask retains this difference if $0 < \delta < \tau$. A particular resource domain can contain no locations in this interval even though the complete map contains some. This explains how unequal eye elevations can still give identical binary results over that resource.

The eye-height deficit $h_{\mathrm{req}} - h$ differs from the signed vertical clearance at its controlling sample. At that sample the clearance is $-(1 - t_i)(h_{\mathrm{req}} - h)$. The first blocking sample, the sample with the smallest vertical clearance and the sample controlling required eye height need not be the same. The profile record distinguishes these quantities when reporting clearance and blockage.

These conditions describe real arithmetic under the stated planar geometry. Floating-point evaluation near equality, changed interpolation, missing samples or a changed obstruction surface can alter classifications. The diagnostic expression therefore explains the model but does not supersede the recorded evaluator output or establish an elevation-error distribution.

Implementation qualification

Toolbox/backend agreement tests the ArcGIS entry point, input interpretation and preparation path shared by those interfaces. Native Global Mapper comparisons address a separate software correspondence claim. Neither replaces independent observations of visibility. The qualification record identifies the tested software versions, source revisions, input bytes, status encoding and comparison domains; a passing subset does not establish behavior for untested configurations.

The ArcGIS Pro 3.7.2 qualification contains 21 declared cases: 19 exact toolbox/backend status matches and two expected input rejections. The cases cover independent horizontal and elevation units, metadata detection and manual overrides, entered heights and distances, raster preparation, selected-point input and missing-data fallback. Physically equivalent metre, international-foot and US-survey-foot inputs require identical classification arrays. Grid coordinates are checked relative to the stored feature point at an absolute tolerance of 0.0000001 m; the stored point's displacement from the requested coordinate must separately remain within half the feature class's declared XY resolution plus that tolerance. Untagged elevation inputs in automatic mode and multiple selected points are rejected in the corresponding cases.

Six retained single-source Global Mapper controls, spanning file/product versions 25.11.0.0

and 27.1.0.0, agree with the reconstructed implementation at all 168 eligible export-grid cells per comparison after full production preparation. The native indicator is positive rendered alpha from transparent exports, while the reconstructed indicator is a visible classification. Native categorical blocked and unknown statuses were not recovered from those exports. All eligible reconstructed results in these controls are visible or blocked. This result qualifies the specified rendered-indicator comparison; it does not validate the Desktop receiver ground-layer selector or establish general dual-surface equivalence. The archive's shipped synthetic sample separately passes an extracted-package ArcPy run with no classification differences from the backend.

Additional native controls test the endpoint interpretation through absolute receiver elevations. On a flat 100-m DTM with a 104-m surface and a 116-m wall, absolute receiver elevations of 110 and 114 m produce exact visible-indicator agreement at all 193 eligible cells in each native version. The lower eye is equivalent to 10 m above the flat DTM; one selected wall-crossing ray is blocked at 110 m and visible at 114 m. A spatially varying DTM then assigns six preselected query locations ground elevations of 100, 104 or 108 m. Each paired-model result is compared with the native absolute-height export at that query's ground-plus-10-m eye elevation. All six links match in each version, covering positive, zero and negative surface-minus-ground differences. These are pointwise absolute-endpoint checks, not full-raster verification of a varying ground layer or a test of the Desktop ground-layer selector.

Retained fixed-absolute-endpoint controls also distinguish layer composition from endpoint support. With both endpoints at 5 m, a 10-m DTM ridge and a valid 0-m DSM, reversing import order changes 43 cells with common input support in each tested build, including 18 downstream of the ridge. Importing the DTM last matches the DTM-only output; importing the DSM last matches the DSM-only output. These recorded script configurations therefore do not use an order-invariant highest-elevation composition. They do not establish whether a separately selected ground layer contributes to obstruction sampling in the Desktop workflow.

Complete landscape model totals

Table S1. Visible receiver locations before and after the common height screen. Each model is evaluated over the same site's complete radius domain. The retained columns condition all three models on the same strict surface-ground difference below 1.8288 m; they do not imply that terrain-only screening ordinarily uses that exclusion. All three models have valid classifications throughout each listed domain. Counts are sampled locations, not independent observations or measured visible areas.

Model	Groton: all 785,321	Groton: retained 133,286	South Salem: all 785,301	South Salem: retained 264,288
Terrain only	179,231	41,747	506,763	175,664
Surface only	353,778	18,561	95,475	21,016
Ground and surface	16,917	16,917	20,662	20,662

For South Salem, the complete surface-supported/ground-supported comparison contains 20,662 jointly visible locations, 74,813 visible only with surface support and 689,826 jointly blocked locations. Within the retained set, the corresponding counts are 20,662, 354 and 243,272. No location is visible only with ground support. Among the retained locations, 140 have negative surface-ground differences and 568 have zero differences; both groups are blocked in both models. Of 262,976 locations with positive differences below stored eye height, 332 have a surface-visible/ground-blocked disagreement, all with intervening first blockers. The interval from stored eye height to the cutoff contains 604 locations, including 22 such disagreements with receiver-end first blockers and 582 jointly blocked results.

These are computations within the retained South Salem pair under its recorded unit interpretation. Unresolved original vertical units, datum, acquisition and construction history limit physical interpretation. Neither this table nor agreement with the evaluator resolves that provenance.

The South Salem inputs are metric exports with approximately 0.979-m spacing and EPSG:32115 coordinates. Horizontal unit conversion preserved samples documented as metre-valued, but did not resolve conflicting original vertical-unit metadata. The legacy rasters' acquisition date, construction procedure and vertical datum could not be established; a separately identified raw LiDAR collection does not establish their lineage. The recorded project elevation remains approximately 203.91 m under the retained interpretation, with its exact value in the computational record.

The computational record identifies the completed aggregate, its builder and the two-site run receipt by SHA-256. The production preparation, kernel and study-runner sources match the frozen baseline in both runs, despite different repository HEAD revisions at launch. Repository revision,

execution-source identity and generated-output identity are recorded separately.

Table S2. Joint surface-supported and ground-supported classifications in Groton. Both calculations use the same obstruction samples and fixed project elevation. The common retained set applies the strict six-foot height rule to the same receiver queries. Reverse disagreements occur where the sampled surface elevation is below the sampled ground elevation.

Classification pair	Before height exclusion	Common retained set
Both visible	16,902	16,902
Surface-supported visible; ground-supported blocked	336,876	1,659
Surface-supported blocked; ground-supported visible	15	15
Both blocked	431,528	114,710
Valid comparison locations	785,321	133,286
Excluded by the height rule	0	652,035

The terrain-only and paired Groton models agree on 16,915 visible locations; 162,316 are visible only in the terrain-only calculation and two only in the paired calculation. Replaying the two reverse cases with identical endpoints and sample schedules confirms that intervening DSM elevations below the DTM cause the reversals. At query 916353, the terrain-only model first blocks at sample 1, where surface is 3.085 m below terrain. At query 918398, it first blocks at sample 4, where surface is 4.461 m below terrain. The paired model clears every sampled obstruction in both cases. Their receiver surface-ground differences are positive, so negative endpoint displacement does not explain them. Retaining valid DSM elevations below terrain means the comparison does not impose the surface-above-terrain condition required for universal containment.

Documented software interfaces

Table S3. Separate viewer support and obstruction in ordinary raster viewshed interfaces. Primary documentation was reviewed on 10 October 2026. The question is whether one raster-output operation exposes a spatially varying ground reference independently of the obstruction surface. Scalar offsets, output minimum-height grids and fields that vary between point observers do not by themselves supply such a reference for every output cell. The table describes documented interfaces; it is not a numerical conformance test or an inventory of every plugin and possible multi-step workflow.

Interface	Documented elevation inputs and alternatives
Global Mapper Desktop View Shed	A layer selector assigns the reference for ground-relative transmitter and receiver heights. Current documentation describes visibility against the highest elevations among loaded layers. This separates the stated endpoint and obstruction roles; it does not establish the numerical composition rule for a particular version and layer configuration.
ArcGIS Pro Geodesic Viewshed and Visibility	One input surface raster per operation. Observer elevation may be supplied explicitly or through a feature field, but the surface offset is not a spatially varying target-cell ground raster. Explicitly constructed 3D links can instead be evaluated with Line Of Sight or Intervisibility.
GDAL raster viewshed	One input elevation band and scalar height parameters. Its ground-mode output reports minimum target height relative to that same input surface; it does not add a separate DTM support input.
GRASS r.viewshed	One elevation raster, a point viewpoint and scalar observer and target offsets above that raster. No separate receiver-support raster is documented.
QGIS 3.44 GDAL Viewshed provider	The documented provider exposes the single-surface GDAL operation. Other providers and third-party plugins require their own version-specific review; a limit of this provider is not a limit of the whole QGIS platform.

Supplemental property parameters

This comparison was designed after inspecting the nominal landscape and property results. It preserves the original 2,761 actual receiver queries, geometry memberships, radius domain, sampled fields and fixed project elevation. Four eye-height passes each evaluate the three models; three strict height cutoffs reuse each pass. The nominal pass precedes the other heights and exactly reproduces sampled ground, surface and difference values at all 2,761 locations, plus all 8,283 model classifications, first-blocker indices and schedule lengths. This check does not separately compare every interior sample value against the original complete run.

The heights include the reported metric values 1.6 and 1.8 m, the international-foot conversion of 5.25 feet (1.6002 m), and six feet (1.8288 m). The cutoffs include 5.5 feet converted to 1.6764 m, the reported rounded value 1.7 m, and six feet. Every cutoff in this experiment is strict. This isolates numerical parameter effects; it does not reproduce the New York Bight report's inclusive threshold or an assessment's surface modifications.

Table S4. Property-domain results across twelve height/cutoff combinations. Every row starts with the same 2,761 queries. Excluded count equals 2,761 minus retained count; no support or classification is unknown. No retained location is visible only with ground support. The final column instead compares unmasked ground-supported visibility with zero-coded excluded surface-only results over the original cohort. All four nonzero entries in that column concern the same query, with a surface-ground difference of 1.7166214 m.

Eye height (m)	Strict cutoff (m)	Retained	Surface-supported visible; paired blocked	Unmasked paired visible, excluded by mask
1.6	1.6764	508	2	0
1.6	1.7	511	2	0
1.6	1.8288	520	3	0
1.6002	1.6764	508	2	0
1.6002	1.7	511	2	0
1.6002	1.8288	520	3	0
1.8	1.6764	508	0	1
1.8	1.7	511	0	1
1.8	1.8288	520	0	0
1.8288	1.6764	508	0	1
1.8288	1.7	511	0	1
1.8288	1.8288	520	0	0

Copp has 1,536 original queries and retains 472, 475 or 482 as cutoff increases. Great Brook has 1,225 and retains 36, 36 or 38. All retained Copp queries are blocked under both models throughout the cross. At each of the two lower heights, Great Brook has 9, 9 or 10 surface-supported visible queries and seven ground-supported visible queries. At each higher height, both models identify 9, 9 or 10 screened visible queries. Thus Copp's complete no-visible finding and Great Brook's any-visible finding agree throughout all twelve combinations. The other 156 municipal features have no original-radius queries and remain empty-domain findings, not complete no-visible results.

In the nominal retained property cohort, 26 queries have a negative surface-ground difference and 494 have a positive difference; none has exactly zero difference. Their exact classification agreement therefore does not require equal eye elevations. A separate output-cell-centre membership check contains 2,935 queries and retains 531: ten jointly visible and 521 jointly blocked. This alternative membership also gives whole-cohort equality of the zero-coded surface-only and unmasked paired indicators, but it does not replace the actual-query domain used in the principal results.

Selected surface stresses

The diagnostic selection uses the 1,576 nominal retained disagreements whose ground eye is above the local surface and whose first ground-supported blocker is intervening. Candidates are sorted by complete-schedule clearance margin, then integer query ID, and divided into four rank quartiles of 394. The margin is the smaller of the surface-supported minimum signed clearance and the negative ground-supported minimum clearance. Four cases per quartile are selected by ascending SHA-256 of the unpadded ASCII decimal integer ID. Eight agreeing-visible controls are similarly selected from 16,117 candidates and eight agreeing-blocked controls from 107,662. Selected IDs are frozen after the property height passes but before zero shift and all nonzero stresses. Selection is deterministic, not a probability sample of landscape viewers.

Zero-shift replay matches all 32 selected records and 17,988 complete-schedule surface-only/paired sample records, including positions, line and obstruction values, signed clearances, endpoint gates and first blockers. These comparisons use nominal records from the same helper; they establish replay consistency, not independent software equivalence. Complete traces extend beyond any early return and therefore distinguish first blocker from complete-schedule minimum clearance.

Vertical stresses add or subtract 0.10 m at valid float32 nodes of one frozen prepared field before sampling. Missing-data sentinels remain unchanged. Ground-only changes leave the previously resolved surface fallback fixed. Horizontal stresses translate both fields by 1 m, half the prepared 2-m cell width, using the original sampler at the inversely shifted query position: an eastward field shift samples one metre west of each fixed query. No intermediate resampled grid is constructed.

Support, obstructions and masking use the resulting fields; query coordinates, the ray schedule, distance domain and absolute project elevation remain fixed.

Table S5. Persistence in the selected diagnostic panel. A disagreement persists only if the query remains retained, its ground eye remains above the local surface, the surface-supported ray remains visible, and the ground-supported ray first blocks at an intervening sample. Control columns report classifications, not that disagreement criterion. No selected variant has unavailable support or missing obstruction samples.

Imposed field change	Persistent disagreements of 16	Agreeing-visible controls: both visible / differing	Agreeing-blocked controls: both blocked
Ground +0.10 m	13	8 / 0	8
Ground -0.10 m	15	8 / 0	8
Surface +0.10 m	15	8 / 0	8
Surface -0.10 m	13	8 / 0	8
Both fields east 1 m	3	7 / 1	8
Both fields west 1 m	4	8 / 0	8
Both fields north 1 m	3	7 / 1	8
Both fields south 1 m	4	8 / 0	8

Only query row 902, column 334 satisfies the full disagreement criterion in every stress. This is not the minimum-ID profile shown in Figure 3, which was selected separately to explain the nominal mechanism. The counts do not estimate a landscape-wide persistence fraction or an error probability. Under the east shift, one initially agreeing-visible control becomes excluded and locally blocked with ground support. Under the north shift, the changed agreeing-visible control remains retained with a clear ground-eye endpoint and first blocks farther along its ray. All agreeing-blocked controls remain blocked, although eastward translation excludes one and changes its local ground-eye gate. Eligibility and visibility are therefore reported separately even when a binary pair is unchanged.

Supplemental road associations

Road-centreline associations provide an additional reporting geometry without moving the accepted receiver queries or calculating new sightlines. The source is Groton's Roads layer 7, retrieved in October 2026. Its edition date and road-width units were not established; the width field was not used. Complete, paginated geometry retrieval was checked against source IDs and counts. Of 56 envelope candidates, 36 segments intersect the nominal 1-km geodesic disk, represented by

a 14,400-edge polygon. Lines were transformed from EPSG:2234 to EPSG:26956. Associations use planar distance at or below 1 m, one half-cell diagonal (approximately 1.4142 m), or 2 m to the clipped lines.

The geometry and three tolerances were frozen before reading the associated visibility outcomes, after nominal landscape and property results were known. Original query IDs, actual-query coordinates, eligibility and radius membership remain unchanged. Union summaries count each associated query once; segment summaries may share queries. The comparison applies the same known height-retention rule to both models and distinguishes empty, wholly excluded, unknown and complete no-visible outcomes.

Table S6. Existing receiver queries associated with road centrelines. Directional differences are within each retained union. All support and paired classifications are known. These are counts of computational samples, not people, route lengths or observations of roadside visibility.

Association distance	Unique original queries	Retained	Excluded	Surface-supported visible; paired blocked	Paired visible; surface-supported blocked
1 m	3,780	2,845	935	10	1
Half-cell diagonal	5,366	4,056	1,310	10	1
2 m	7,577	5,689	1,888	15	1

All 36 segments remain in the reporting inventory. Two have no associated queries at the first two tolerances; every segment has an association at 2 m. At 1 m and the half-cell diagonal, three segments have a surface-supported any-visible finding and a paired complete no-visible finding; two do at 2 m. The three nominal segments—OSPREY, MERLINO and PETERS—are Navy-owned in the source. GrotonTown and StateOfCT segment-level findings agree between models. Source ownership and the attribute “Open” do not establish legal public access. These associations do not demonstrate a changed public-resource decision or replicate the corridor-modified obstruction surface in the Atlantic Shores assessment.

A separate check retrieved all 34 features designated COPP PROPERTY with Hike=Yes from the town’s TrailsWeb layer 1. Ordered geometry pages were reconciled with source IDs and counts before and after retrieval. All selected routes fall outside the original 1-km calculation disk; the nearest is approximately 6.01 m beyond its polygon boundary. No route visibility lookup was performed and the radius was not expanded. The result establishes that these mapped routes are outside the study domain, not that views from the routes are blocked.