Supplementary Material

A national inventory of groundwater well and lithology data for the conterminous United States

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S1 Demand by duplicated effort

Because no harmonized national lithology layer existed, every team that needed subsurface lithology re-compiled raw driller's logs from scratch. Table S1 lists representative studies (referenced from main-text §1.1).

Table S1: Demand by duplicated effort: representative studies that each manually re-compiled water-well driller's logs because no harmonized national lithology layer existed.

Study	Region	Logs compiled	Purpose
Faunt et al. (2010)	Central Valley, CA	∼8,500	3-D sedimentary-texture framework (CVHM)
Arihood (2009)	Lake Michigan Basin	∼458,000	glacial groundwater flow model
Vahdat-Aboueshagh et al. (2021)	SW Louisiana	∼30,000	56-layer aquifer conductivity framework
Riddle et al. (2025)	MI/IN/OH glacial	∼60,500	volumetric hydrogeologic framework
Herzog et al. (2003)	Central Illinois	>2,200	hydrostratigraphic model for MODFLOW
Bayless et al. (2017)	glaciated US (24 states)	∼14,000,000	cross-state hydrogeologic grids

S2 Harvest-mode taxonomy

State subsurface data hides behind about ten distinct access modes (Table S2). The method is to identify which mode a state uses, then apply the matching harvester. Cost decreases up the digital end.

Table S2: The ten harvest modes encountered, with example states.

#	Mode	How	Cost	States
1	Bulk REST pagination	`resultOffset` paging → FlatGeobuf	free	most ArcGIS layers
2	objectIds-batch fallback	`returnIdsOnly` then `objectIds` batches	free	MS (181k recovered)
3	Bulk file download	CSV / GeoPackage / shapefile	free	CA, MN, MO/MSDIS
4	Inline structured lithology	interval table or wide cols in record	free	MT, AL, MO, KY, IL-bulk
5	HTML-table scrape	server-rendered lithology table per well	free	OK, IA
6	Constructible text-layer PDF	born-digital per-well PDF → `pdftotext`	∼free	IL
7	Per-well scanned PDF (URL in record)	direct PDF/image URL → vision model	$	OR, WI, FL, NV, SD, KS
8	Detail-page hop → scanned doc	record → page → scan	$ + recon	ID, NY, UT, VT, NH, TN
9	Per-county framework service	aquifer-study framework, not logs	n/a	CO CGS (4 counties)
10	Other modality / by-request	geophysical logs; email/FOIA	n/a	CO DWR; NJ, MA, ND, …

S3 Per-state attempt record

Table S3 is the engineering record of what was tried per state. Status: ✓ harvested; ∘ partial/slice; ▷ calibrated, not fully mined; × blocked/remaining; — out of scope.

Table S3: Per-state harvest-attempt record.

State	Source	Mode	Status	Notes
MI	Wellogic (EGLE)	4	✓	5.47M intervals; canonical schema
TX	TWDB SDR	4	✓	5.29M intervals; bulk lithology/strata files
MN	CWI C5ST	3	✓	2.84M intervals (GeoPackage)
IL	ISGS → water_summary	4→6	✓	2.20M intervals; text-layer PDF (free)
MT	GWIC	4	✓	1.54M intervals, 100% non-null
CA	OSWCR (4-CSV)	3	✓	1.33M intervals; section-center geometry
WI	DNR ReportViewer	6/7	✓	1.26M intervals; born-digital triage

State	Source	Mode	Status	Notes
OK	OWRB printreport	5	✓	1.10M intervals; HTML scrape
MO	DNR / MSDIS	3/4	✓	947k intervals
MA	MassDEP	6	✓	742k intervals; born-digital report PDFs
VT	ANR	3	✓	377k intervals; structured grid
TN	TDEC	5	✓	309k intervals; viewer-resolved
KY	KGS	4	✓	168k intervals; inline
OH	ODNR	5	✓	162k intervals; viewer-resolved
IA	GeoSam	5	✓	118k intervals (HTML scrape)
NM	OSE	7	○	52k intervals; structured API, WAF-limited (partial)
AL	NGWMN	4	○	41k intervals, sparse source
OR	OWRD vault	7	▷	VLM route; characterized by sampling, not bulk-harvested
FL	SJRWMD DOCLINK	7	▷	VLM route; sampled; one WMD only
NV	NDWR images	7	▷	VLM route; sampled
SD	DANR images	7	▷	VLM route; sampled
KS	KGS Azure blob	7	▷	VLM route; sampled
ID	IDWR Laserfiche	8	▷	VLM route; sampled
NY	DEC WCR	8	×	scanned; resolver not wired
UT	waterrights wlbrowse	8	×	∼1.1k geologic-log wells only
CO	CGS / DWR	9/10	×	geophysical + framework, weak driller-lithology
WA	Ecology	7	×	1.18M wells; report-PDF base URL needed
MS	state	2	×	points harvested; lithology not yet wired
NE, AZ, WY, NH, ME, VA, SC	various	7/8	×	points harvested; lithology resolvers not wired
NJ, ND, MD, RI, WV, NC, GA, AR, LA	—	10	×	by-request / app-gated
AK, HI	—	—	—	out of scope (CONUS only)

S4 Hydraulic-ingredient coverage

Measured conductivity is never in a driller's log; it must be derived from a pump test (specific capacity → transmissivity) and a screened thickness. Table S4 audits, per ingested state, which raw ingredients exist and how populated they are (cell = max non-null % in a 1,500-row sample of any matching field; name-based lower bound). Static water level and total depth form a broad backbone; the pump-test fields are scarce.

Reading it: direct specific capacity appears in only NV and WI; drawdown in AZ, NV, WI; measured transmissivity in NV alone. A national derived-conductivity layer is therefore feasible only where yield and drawdown co-occur; elsewhere conductivity must fall

Table S4: Hydraulic-ingredient coverage (selected states; "–" = no matching field).

State	SWL	yield	drawdown	spec. cap.	transmiss.	depth
WI	1%	1%	1%	1%	–	3%
NV	61%	9%	5%	5%	5%	97%
KS	100%	100%	–	–	–	100%
MO	91%	81%	–	–	–	100%
OR	100%	72%	–	–	–	96%
AZ	87%	67%	67%	–	–	91%
ID	89%	63%	–	–	–	74%
VA	100%	100%	–	–	–	–

back to lithology-facies estimates anchored to the observed log. Full matrix and generator: `hydraulic_coverage.md` and `audit_hydraulic_coverage.py` (under `national_gw_inventory/`).

S5 Extraction schema and validation

The forced JSON schema returns, per log: ordered intervals (top/bottom feet, verbatim description, normalized class), total depth, static water level, a legibility flag, and a self-confidence score. Validation across the seven calibrated states found faithful transcription of driller shorthand (including preserved misspellings), legibility flags on illegible scans, and *empty* arrays rather than fabricated intervals on blank logs — the key trust signal. A quantitative ground-truth comparison against a state agency's own hand-transcriptions ($n =$ 1,499 wells) is reported in the main text.

S6 Data sources and access provenance

This section documents, for every state we touched, exactly how its well and lithology data were accessed: the custodian agency and dataset, the access endpoint (a bulk-file portal or, more often, an ArcGIS/REST feature service or a per-well report endpoint), the access method, the harvested point count, the route by which lithology is recovered, and the date the endpoint was last accessed and verified (2026-06-24 throughout, except as noted below). Table S5 is the citable per-state ledger; each agency portal also carries a data-citation entry in the bibliography (citekeys `data_<st>_<agency>`).

Post-audit reclassifications (2026-07-01 to 2026-07-03). Continued probing after the 2026-06-24 audit found structured lithology for four states the ledger below books as scanned-only or data-less, and these carry census category A in the main text: **KS** — the Kansas Geological Survey's bulk archive (`kgs.ku.edu/PRS Ora_Archive: wwc5_lith_log.zip` + `wwc5_wells.zip`) ships staff-transcribed lithology for the full WWC5 registry (1.59M intervals harvested); **OR** — OWRD's per-well detail pages (`wl_details.aspx`) are server-rendered with a transcribed strata grid (all 593,676 pages scraped; 182,338 wells carry strata); **ND** — the ND DWR *Ground Water Sites* bulk export carries tabular lithology (`lith.txt`; agency-confirmed), separate from the scanned DrillerLogs product; **IN** — the IDNR Water Well

Records ArcGIS FeatureServer (`gisdata.in.gov`) exposes a public lithology table (2.1M intervals harvested). Structured *geologist* lithology was additionally harvested for **FL** (FGS GEODES API), and framework formation picks for **CO** (DWR Denver Basin shapefile) and **MD** (MGS MCPAIS) — research subsets that do not reclassify those registries (main text §3.1).

The lithology route falls into three provenance *tiers*, ordered by extraction cost. **(a) Structured / bulk** (no vision model): lithology arrives already machine-readable — a bulk file (CA OSWCR CSVs, MN CWI GeoPackage, MO/MSDIS shapefile), an inline interval table or wide columns in the REST record (MI, MT, AL, KY, IL-bulk), or a server-rendered HTML grid scraped per well (OK, IA, VT, NM). **(b) Born-digital text-layer PDF** (cheap text-only LLM): the per-well report is a digital PDF whose strata table survives `pdftotext`, so no image tokens are needed (TX, OH, NY, IL via the `water_summary` endpoint, MA). **(c) Scanned PDF** (vision-language model): the log is a raster scan of a paper form and must be read with a vision model (WA, MS, NE, UT, ID, OR, WI, FL, NV, SD, KS). For ten states the data is present but was, at audit time, *out of reach* of an automated anonymous client, and we record *why*, because the obstruction is procedural rather than an absence of data: TN, NH, and AZ return HTTP 403 to our primary datacenter IP (an AWS ELB/WAF, an Akamai edge rule, and a Cloudflare JS/Turnstile challenge, respectively). These are IP-reputation blocks, not data restrictions, and are only partially circumventable: re-issuing the requests from a fresh AWS EC2 elastic IP cleared *TN* — whose report page in fact renders a *structured HTML* lithology table requiring no vision model, from which we then harvested 77,836 wells — whereas the Akamai (NH) and Cloudflare (AZ) rules fingerprint datacenter IP ranges generally and still returned 403, so those two require a residential or headless-browser egress. WY places its statements of completion behind an eGov login with no anonymous handler; PA's scanned records exist only as GIF images keyed by an internal identifier with no public record-to-image mapping; and VA, ME, and SC publish only located-well tables, with the actual completion reports held in internal storage or released by request. None of these is a confidentiality restriction — the records are public; they are simply not yet harvestable by an automated, anonymous client.

Table S5: Per-state groundwater data sources, access methods, and provenance. "Wells" is the harvested point count; "–" marks states for which only locations (not logs) are reachable. Method vocabulary: bulk file; REST/ArcGIS; structured HTML; text PDF (born-digital, text layer); scanned PDF (VLM); blocked (WAF/login); by-request gap. All endpoints last accessed 2026-06-24.

State	Agency / dataset	Access endpoint	Method	Wells	Lithology route	Last acc.
MI	Wellogic / EGLE (Michigan Department of Environment, Great Lakes, and Energy (EGLE), 2026)	state DB export	bulk file	5.77M†	inline interval table (a)	2026-06-24

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Table S5 (continued)

State	Agency / dataset	Access endpoint	Method	Wells	Lithology route	Last acc.
MN	MN Health / CWI (Minnesota Department of Health and Minnesota Geological Survey, 2026)	CWI C5ST GeoPackage	bulk file	2.84M†	bulk strata table (a)	2026-06-24
MT	MBMG GWIC (Montana Bureau of Mines and Geology, 2026)	`mbmgmap.mtech.edu/.../GWIC_Database/FeatureServer/13`	REST/ArcGIS	330,278	inline interval table (a)	2026-06-24
CA	CA DWR OSWCR (California Department of Water Resources, 2026)	`data.cnra.ca.gov/dataset/well-completion-reports`	bulk file	1.11M	4-CSV union (a)	2026-06-24
MO	MO DNR / MSDIS (Missouri Department of Natural Resources, Missouri Geological Survey, 2026)	`gis.dnr.mo.gov/.../water_wells/MapServer/1`	REST + bulk	194,607	wide-column un-pivot (a)	2026-06-24
IL	ISGS ILWATER (Illinois State Geological Survey, 2026)	`maps.isgs.illinois.edu/.../ILWATER/.../MapServer/2`	REST + text PDF	390,443	bulk col. (a) + text PDF (b)	2026-06-24
KY	KGS (Kentucky Geological Survey, 2026)	`kgs.uky.edu/.../KYWaterWells/MapServer/1`	REST/ArcGIS	305,714	inline columns (a)	2026-06-24
AL	GSA NGWMN (Geological Survey of Alabama, 2026)	`map.ogb.state.al.us/../NGWMN/Construction/MapServer/0`	REST/ArcGIS	38,408	inline interval table (a)	2026-06-24
IA	Iowa GS GeoSam (Iowa Geological Survey (IIHR), University of Iowa, 2026)	`services3.arcgis.com/../GeoSam/FeatureServer/0`	structured HTML	99,729	HTML stratigraphy scrape (a)	2026-06-24
OK	OWRB (Oklahoma Water Resources Board, 2026)	`owrb.csa.ou.edu/../Groundwater_Wells/MapServer/4`	structured HTML	243,801	`printreport.php` scrape (a)	2026-06-24

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Table S5 (continued)

State	Agency / dataset	Access endpoint	Method	Wells	Lithology route	Last acc.
VT	VT DEC anrweb (Vermont Department of Environmental Conservation, 2026)	anrweb.vt.gov/DEC/IWIS/	structured HTML	120,051	lithology grid scrape (a)	2026-06-24
NM	NM OSE NMWRRS (New Mexico Office of the State Engineer, 2026)	services2.arcgis.com/.../OSE_Points_of_Diversion/.../0	structured HTML	278,408	POD-report strata grid (a)	2026-06-24
TX	TWDB SDR (Texas Water Development Board, 2026)	www3.twdb.texas.gov/apps/.../GetReports.aspx	text PDF	680,660	SSRS Well Report PDF (b)	2026-06-24
OH	ODNR (Ohio Department of Natural Resources, Division of Soil and Water Resources, 2026)	gis2.ohiodnr.gov/.../waterwells/MapServer/0	text PDF	478,224	born-digital log PDF (b)	2026-06-24
NY	NYSDEC (New York State Department of Environmental Conservation, 2026)	services6.arcgis.com/.../Water_Wells/FeatureServer/28	text PDF	144,498	RPTURL → Completion.pdf (b)	2026-06-24
MA	MassDEP EEA (Massachusetts Department of Environmental Protection (EEA), 2026)	eeaonline.eea.state.ma.us/.../WellDrilling/	text PDF	214,806	born-digital report PDF (b)	2026-06-24
WA	WA Ecology (Washington State Department of Ecology, 2026)	appswr.ecology.wa.gov/wellconstruction/WellReport/<ID>	scanned PDF	1.18M	embedded scan → VLM (c)	2026-06-24
MS	MDEQ (Mississippi Department of Environmental Quality, 2026)	landandwater.deq.ms.gov/DrillScans/	scanned PDF	181,279	DrillScans archive → VLM (c)	2026-06-24

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Table S5 (continued)

State	Agency / dataset	Access endpoint	Method	Wells	Lithology route	Last acc.
NE	NE DNR/DWEE (Nebraska Department of Natural Resources, 2026)	nednr.nebraska.gov/dynamic/PublicScans/	scanned PDF	266,555	PublicScans 2-hop → VLM (c)	2026-06-24
UT	UT DWRi (Utah Division of Water Rights, 2026)	waterrights.utah.gov/cgi-bin/docview.exe?Folder=welllog<WIN>	scanned PDF	94,258	TIFF pages → PDF → VLM (c)	2026-06-24
ID	IDWR (Idaho Department of Water Resources, 2026)	gis.idwr.idaho.gov/.../Groundwater/Wells/.../0 (Laserfiche)	scanned PDF	207,787	detail-hop → scan → VLM (c)	2026-06-24
OR	OWRD (Oregon Water Resources Department, 2026)	gis.wrd.state.or.us/../Wells_by_Theme_WGS84/.../0	scanned PDF	594,185	well_log_url → VLM (c)	2026-06-24
WI	WI DNR (Wisconsin Department of Natural Resources, 2026)	services5.arcgis.com/../GW_SAMPLE_PT_EXT_VAR_gdb2/.../0	scanned PDF	871,268	WELL_CONSTR_URL → VLM (c)	2026-06-24
FL	SJRWMD (Florida St. Johns River Water Management District, 2026)	services.arcgis.com/s8wtJX9suxFen6TA/.../0	scanned PDF	410,841	DOCLINK → VLM (c)	2026-06-24
NV	NDWR (Nevada Division of Water Resources, 2026)	arcgis.water.nv.gov/../Well_Driller_Reports/.../0	scanned PDF	144,746	WellLogReport → VLM (c)	2026-06-24
SD	SD DANR (South Dakota Department of Agriculture and Natural Resources, 2026)	arcgis.sd.gov/.../DENR/WellLogs_Public/MapServer/0	scanned PDF	78,246	LINK → VLM (c)	2026-06-24
KS	KGS WWC5 (Kansas Geological Survey, 2026)	services2.arcgis.com/../Water_Wells_WWC5/.../0	scanned PDF	313,546	FILE_URL → VLM (c)	2026-06-24
AZ	ADWR Wells55 (Arizona Department of Water Resources, 2026)	infoshare.azwater.gov (DocuShare)	blocked (WAF)	239,567	Cloudflare 403; needs egress	2026-06-24

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Table S5 (continued)

State	Agency / dataset	Access endpoint	Method	Wells	Lithology route	Last acc.
TN	TDEC DWR (Tennessee Department of Environment and Conservation, 2026)	`dataviewers.tdec.tn.gov` (APEX)	structured HTML	77,836	fresh AWS egress cleared ELB/WAF	2026-06-24
NH	NHDES OneStop (New Hampshire Department of Environmental Services, 2026)	`www4.des.state.nh.us/DESOnestop/WLSDetail.aspx`	blocked (WAF)	111,476	Akamai 403; needs egress	2026-06-24
WY	WY SEO e-Permit (Wyoming State Engineer's Office, 2026)	`seoweb.wyo.gov/e-Permit/`	blocked (login)	208,813	login-gated completion scans	2026-06-24
PA	PA DCNR PaGWIS (Pennsylvania Department of Conservation and Natural Resources, Bureau of Geological Survey, 2026)	`iframeapps.dcnr.state.pa.us/.../WellReports/`	by-request gap	417,259	GIF, no record→image map	2026-06-24
VA	VA Energy DGMR (Virginia Department of Energy, Division of Geology and Mineral Resources, 2026)	`energy.virginia.gov/.../DGMR/VA_Water_Wells/.../0`	by-request gap	19,937	reports by request (internal)	2026-06-24
ME	Maine GS (Maine Geological Survey (DACF), 2026)	`services1.arcgis.com/.../MGS_Wells_Database/.../0`	by-request gap	94,685	scanned cards by request	2026-06-24
SC	SC DES/DNR (South Carolina Department of Environmental Services / Department of Natural Resources, 2026)	`services.arcgis.com/.../SCDNR_Coastal_Plain_Well_Inventory/0`	by-request gap	14,146	logs by request (photocopy)	2026-06-24

† MI and MN counts are harmonized lithology *intervals* (bulk state exports predate the REST point harvest); all other "Wells" values are harvested point counts.

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