UNDERSTANDING THE IMPACT OF REFORESTATION AT REGIONAL SCALES USING SWAT

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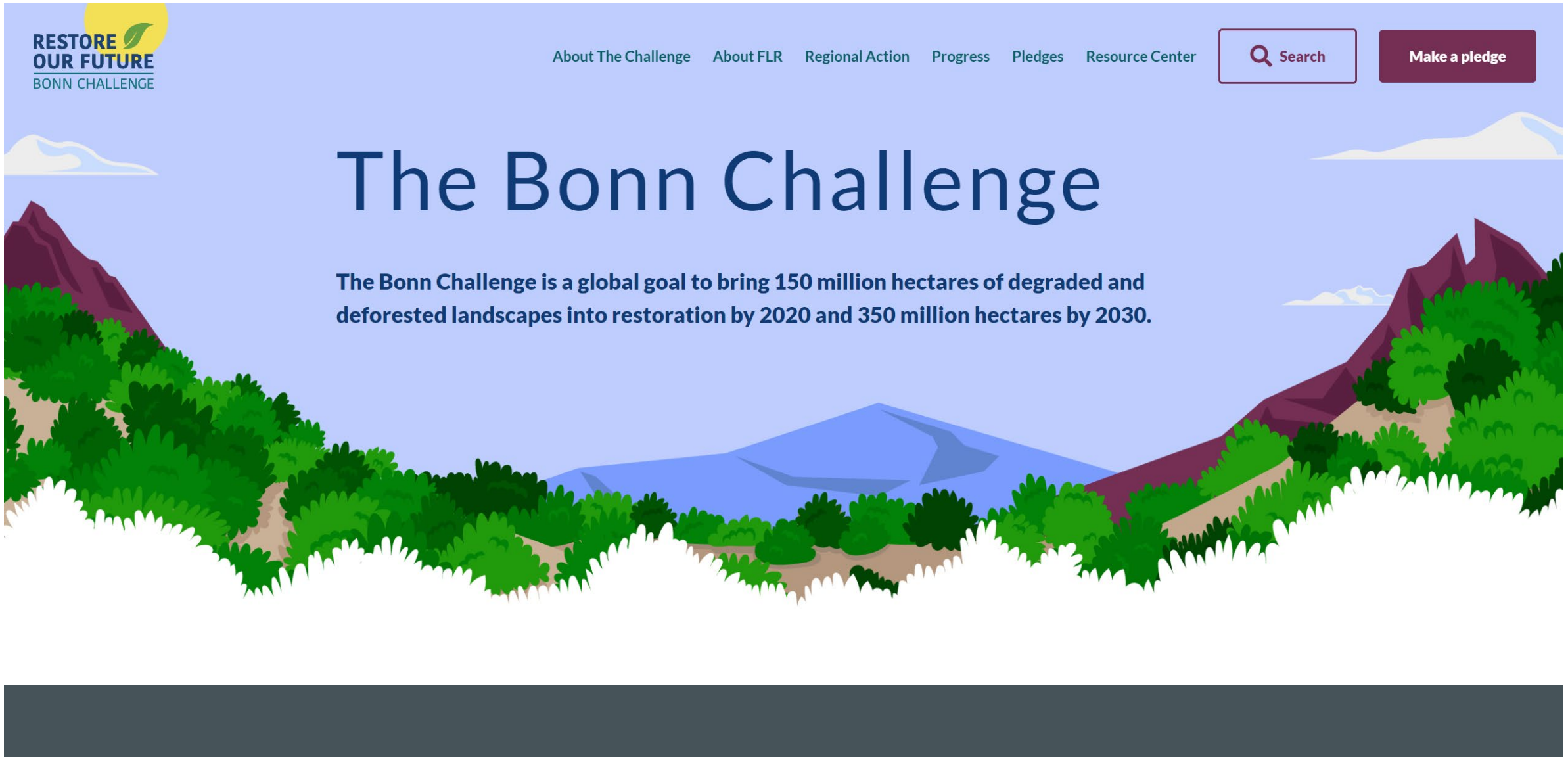
1 THE NATURE CONSERVANCY

2 TEXAS AGRILIFE RESEARCH

TEXAS A&M AGRILIFE RESEARCH

The Nature Conservancy

BEZOS EARTH FUND


RESTORE OUR FUTURE
BONN CHALLENGE
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The Bonn Challenge
The Bonn Challenge is a global goal to bring 150 million hectares of degraded and deforested landscapes into restoration by 2020 and 350 million hectares by 2030.

- Represents hydrological responses to different land covers and land uses
- Depicts water quality in response to different land management strategies
- Scenario analysis focused
- Demonstrated performance in data-scarce environments
- Readily integrates remotely sensed data products for model set up and calibration
- Allows modeling on a gridded format, no greater that 10 km^2 resolution
- Extensive user base and peer reviewed literature to support reforestation parameterization practices
- Open source

DATA USED

Data	Spatial Resol'n	Temporal Resol'n	Source	Use
DEM - CGIAR-CSI SRTM V4	90m	-	https://srtm.csi.cgiar.org/srtmdata/	Set-up
DEM - Copernicus GLO-90	90m	-	https://portal.opentopography.org/	Set-up
2009 GlobCover Land Cover	300m	-	http://due.esrin.esa.int/page_globcover.php	Set-up
Dams – GRanD v 1.3	-	-	https://globaldamwatch.org/grand/	Set-up
FAO Soils	0.05°	-	https://data.apps.fao.org/map/catalog/static/search?keyword=DSMW	Set-up
Precipitation – CHIRPS 2.0	0.05°	Daily	https://data.chc.ucsb.edu/products/CHIRPS-2.0/global_daily/tifs/p05/	Set-up
Temperature – CHIRTS	0.05°	Daily	http://data.chc.ucsb.edu/products/CHIRTSdaily/v1.0/	Set-up
Relative Humidity – CHIRTS	0.05°	Daily	http://data.chc.ucsb.edu/products/CHIRTSdaily/v1.0/	Set-up
Evapotranspiration – MOD16	500m	Monthly	https://www.ntsg.umt.edu/project/modis/mod16.php	Calibration
Stream discharge – GRDC	-	Monthly	https://www.bafg.de/GRDC/EN/Home/homepage_node.html	Validation

2009 GlobCover

Irrigated Area
Convert Cropland to Irrigated where Irrigation >50%

Groundwater = >50%

Surface water = >50%

2009 GlobCover with Irrigation

Natural Earth Urban Areas
Areas > 10km^2

Population Density
High >1500 ppl/km^2
Medium >750 ppl/km^2

2009 GlobCover with Irrigation, Urban

Forests between 23.5° N and 23.5° S reclassified as Tropical

2009 GlobCover with Irrigation, Urban, Tropical Forests

Grasses above 40° N = C3 and below 40° S = C4

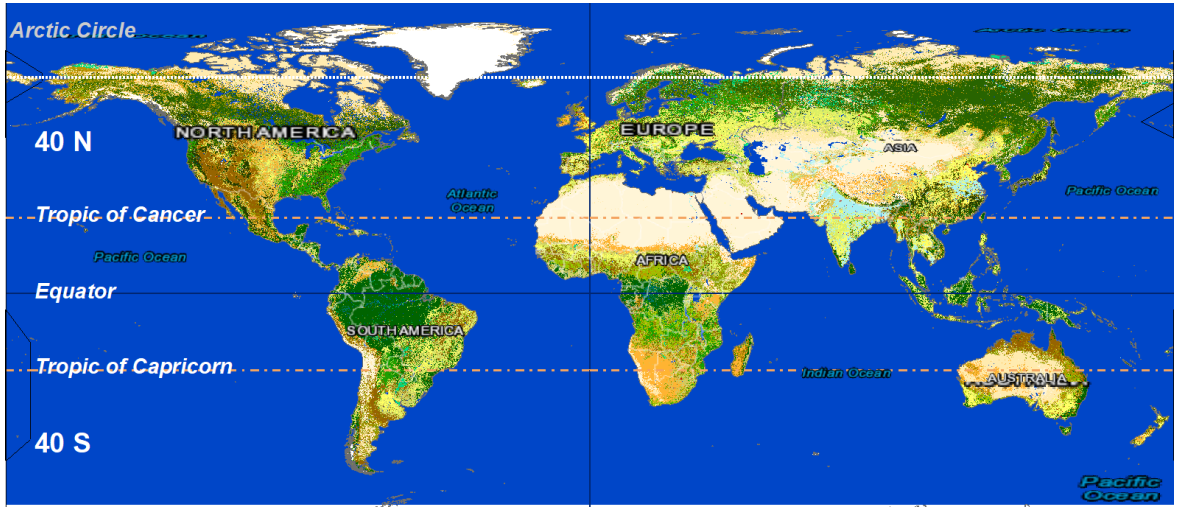
2009 GlobCover with Irrigation, Urban, Tropical Forests, C3 and C4 grasses

Why: GlobCover irrigated areas represent only flood irrigation. Irrigation is a significant water user and impacts overall water balance calibration potential. We are using satellite ET for model calibration.

Why: GlobCover underrepresents urban areas. Urban areas have high runoff potential, which influences peak flows. We are using GRDC data as available to calibrate flows where possible. The final gridded model is 10km^2, so urban areas smaller than this were not considered.

Why: Tropical forest have different growth parameters than those in temperate regions and will require separate parameterization in SWAT.

Why: C3 grasses are adapted to cool season and C4 grasses are adapted to warm or hot seasonal conditions

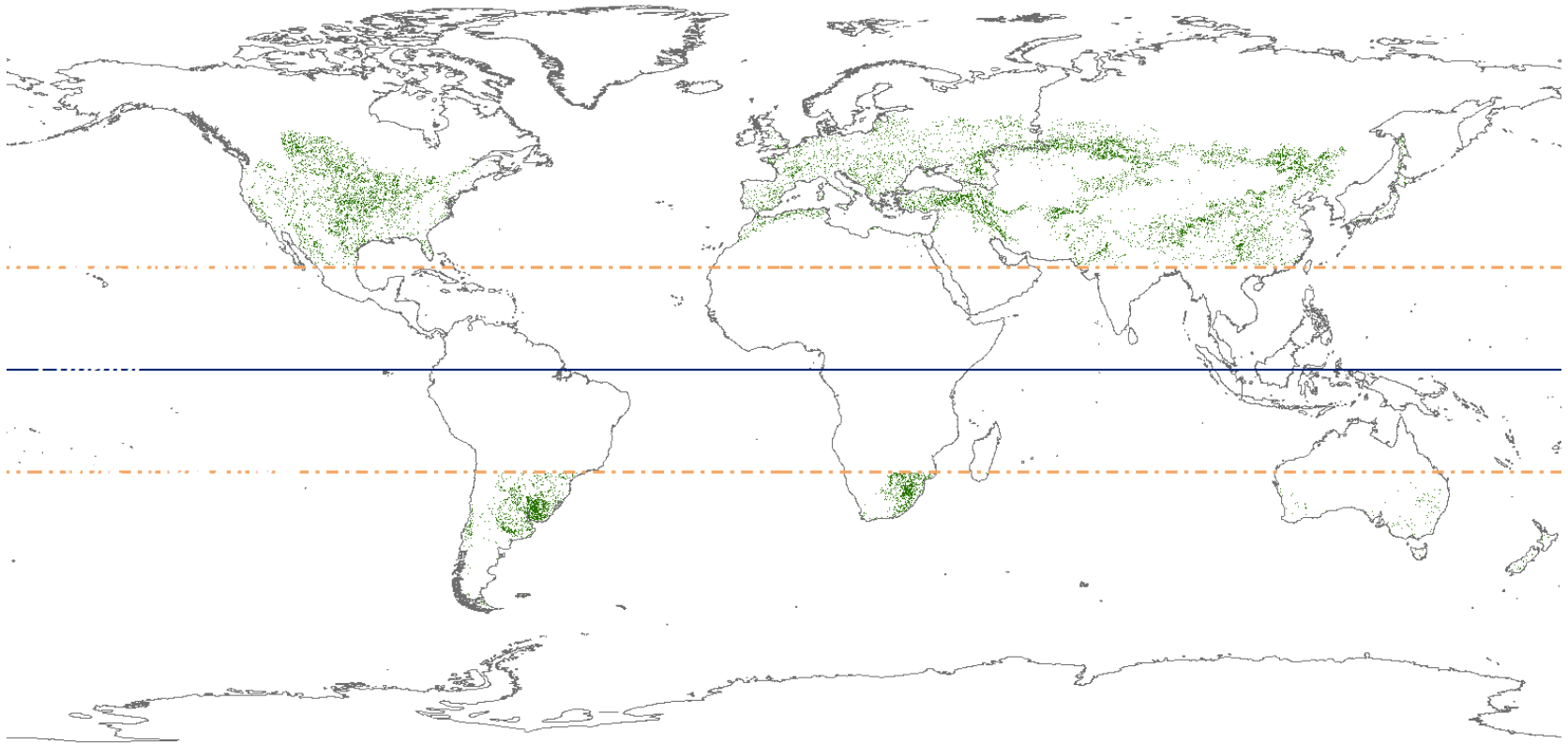


- 11 - Irrigated croplands
- 14 - Rainfed croplands
- 20 - Mosaic Croplands/Vegetation
- 30 - Mosaic Vegetation/Croplands
- 40 - Closed to open broadleaved evergreen or semi-deciduous forest
- 50 - Closed broadleaved deciduous forest
- 60 - Open broadleaved deciduous forest
- 70 - Closed needleleaved evergreen forest
- 90 - Open needleleaved deciduous or evergreen forest
- 100 - Closed to open mixed broadleaved and needleleaved forest
- 110 - Mosaic Forest-Shrubland/Grassland
- 120 - Mosaic Grassland/Forest-Shrubland
- 130 - Closed to open shrubland
- 140 - Closed to open grassland
- 150 - Sparse vegetation
- 160 - Closed to open broadleaved forest regularly flooded (fresh-brackish water)
- 170 - Closed broadleaved forest permanently flooded (saline-brackish water)
- 180 - Closed to open vegetation regularly flooded
- 190 - Artificial areas
- 200 - Bare areas
- 210 - Water bodies
- 220 - Permanent snow and ice
- 230 - No data

52 Land Cover Classes

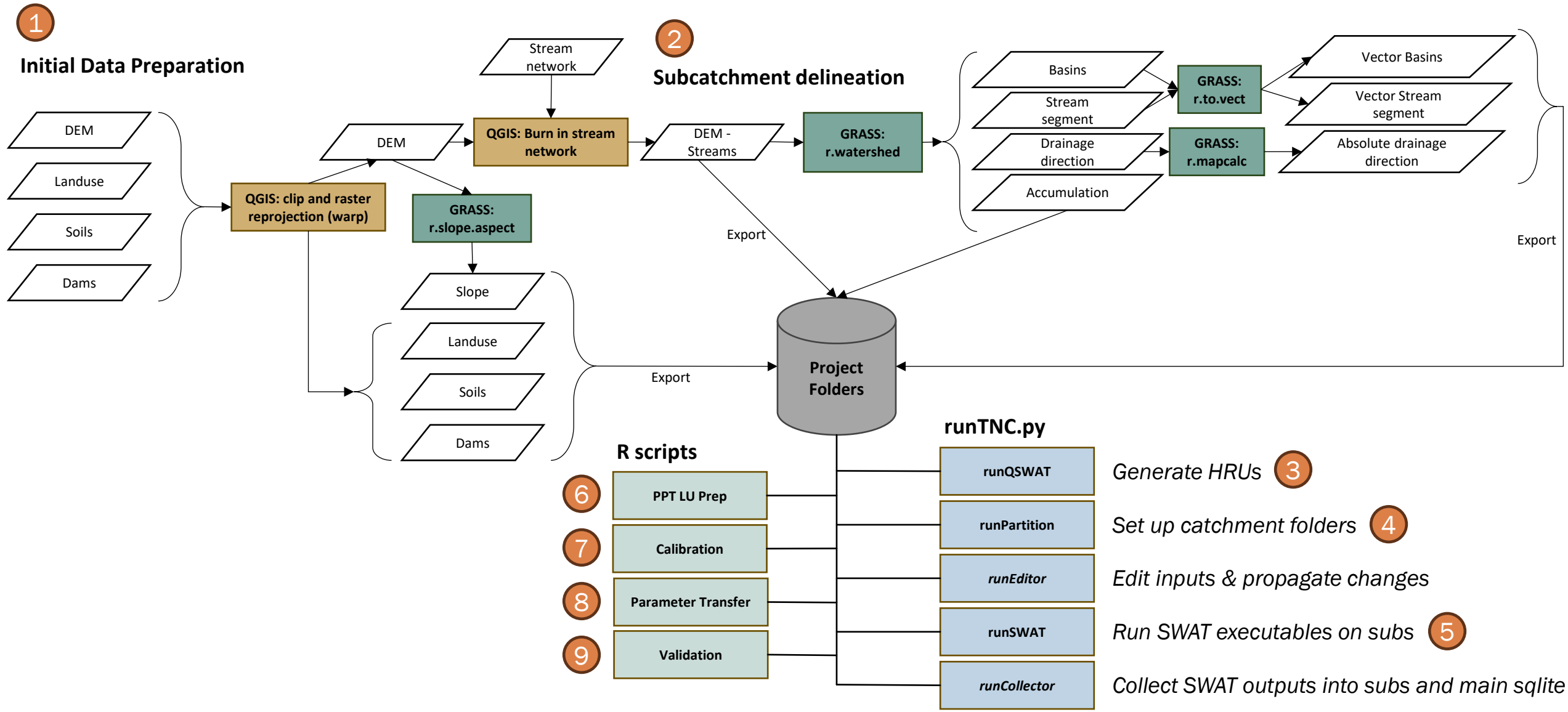
CROP DATABASE

Example: Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)



	BLAI	RDMX	T_OPT	T_BASE	USLE_C	RSDCO_PL	CN2A	CN2B	CN2C	CN2D	ALAI_MIN	BIO_LEAF	MAT_YRS	BMX_TREES
Default	5	3.5	30	0	0.001	0.05	25	55	70	77	0.75	0.3	30	1000
Update	4	3.5	30	10	0.001	0.05	46	63	74	79	0.69	0.03	30	100

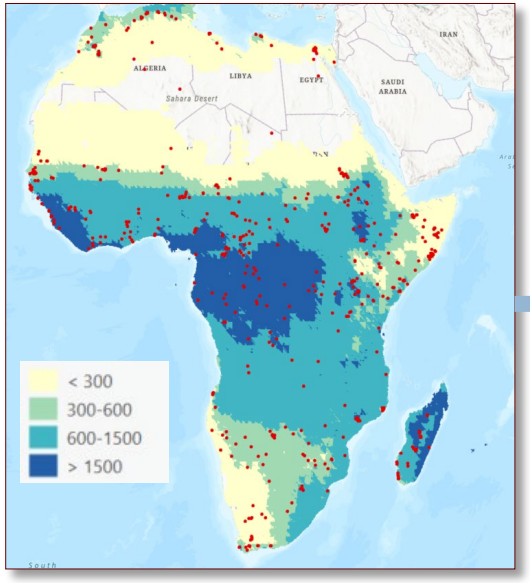
GLOBAL MODEL WORKFLOW

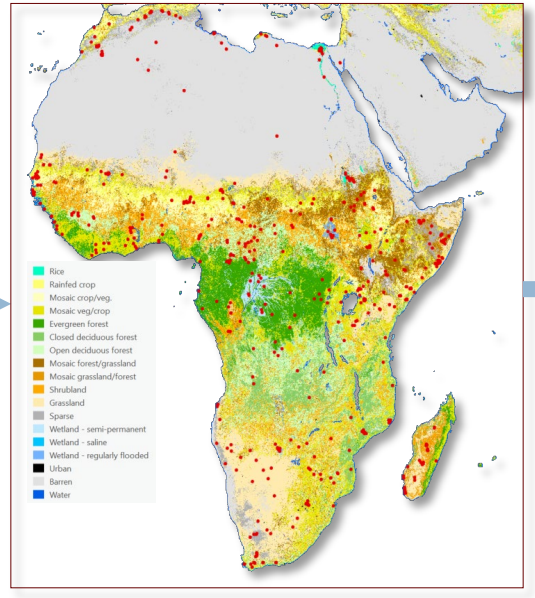


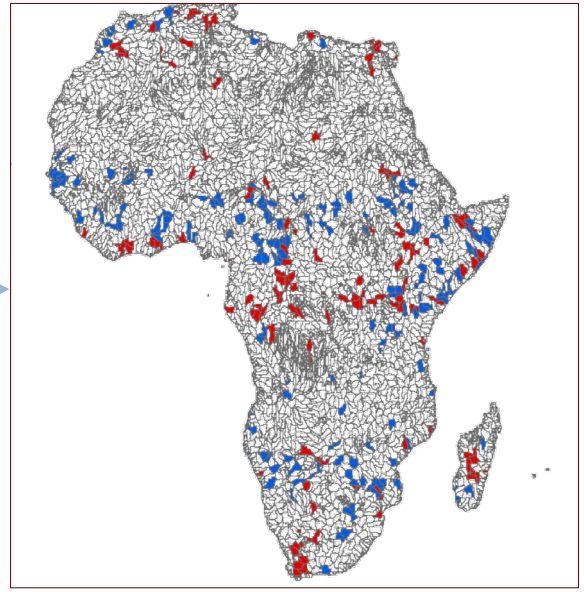
RUNTNC.PY

```
# parameters controlling what runs
# run QSWAT to make HRUs.  Rerun if dem, grid size, landuses or soils change
runQSWAT = False
# run partition to set up catchment folders.  Rerun if maxSubCatchment changes
runPartition = False
# run SWATEditor on global project and propagate changes to catchments.  Run to editing inputs
runEditor = False
# run SWAT executable on catchments
runSWAT = True
# collect SWAT outputs into catchment and main results database
runCollect = True

# Parameters to be set befure run
startYear = 2015  # setting this to a year causes it to be used instead of weather data start and
numYears = 6   # setting this together with startyear causes the run to be from 1 Jan startYear tc

TNCDir = 'C:/Users/tracy.baker/Documents/SWAT/NorthAmerica'  # 'E:/Chris/TNC'
Continent = 'NorthAmerica' # NorthAmerica, CentralAmerica, SouthAmerica, Asia, Europe, Africa, Aus
ContDir = 'UM' # can be same as Continent or Continent plus underscore plus anything for a part pr
                               # DEM, landuse and soil will be sought in TNCDir/ContDir
maxSubCatchment = 10000 # maximum size of subcatchment in sq km, i.e. point at which inlet is inse
soilName = 'FAO_DSMW' # 'FAO_DSMW', 'hwsd3'
weatherSource = 'CHIRPS' # 'CHIRPS', 'ERA5'
gridSize = 100  # DEM cells per side.  100 gives 10kmx10km grid when using 100m DEM
catchmentThreshold = 150  # minimum catchment area in sq km.  With gridSize 100 and 100m DEM, this
maxHRUs = 5  # maximum number of HRUs per grid cell
demBase = '100albers' # name of non-burned-in DEM, when prefixed with contAbbrev
maxCPUSWATCount = 10 # maximum number of CPUs used to run SWAT
maxCPUCollectCount = 5 # maximum number of CPUs to collect outputs (may be lower than maxCPUSWATCc
slopeLimits = [2, 8]  # bands will be 0-2, 2-8, 8+
SWATEditorTNC = TNCDir + '/SwatEditorTNC/SwatEditorTNC.exe'
SWATApp = TNCDir + '/SWAT/Rev_688_CG_64rel.exe'
```

CALIBRATION – PARAMETER REGIONALIZATION







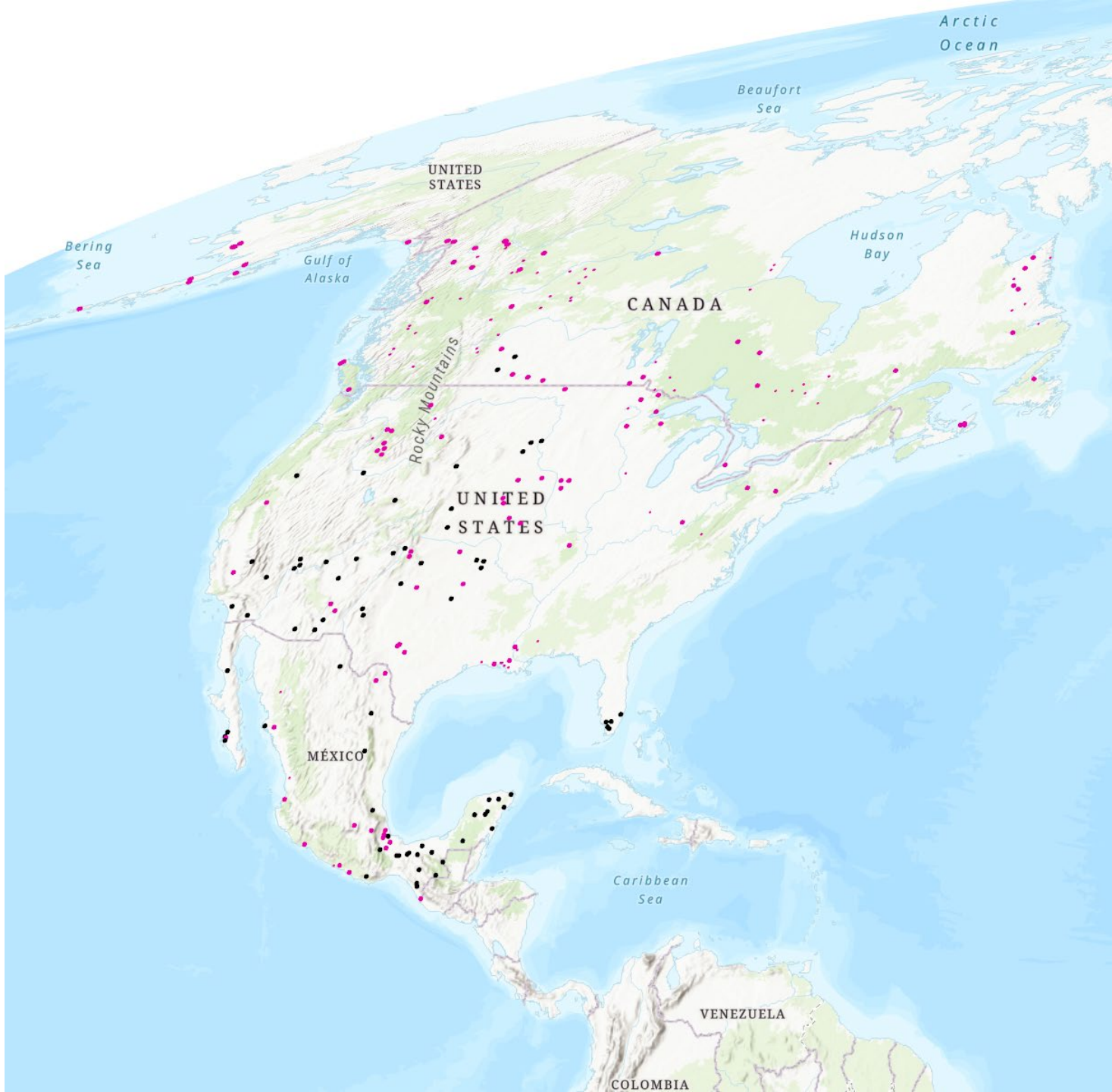
ET Calibration subbasin selection

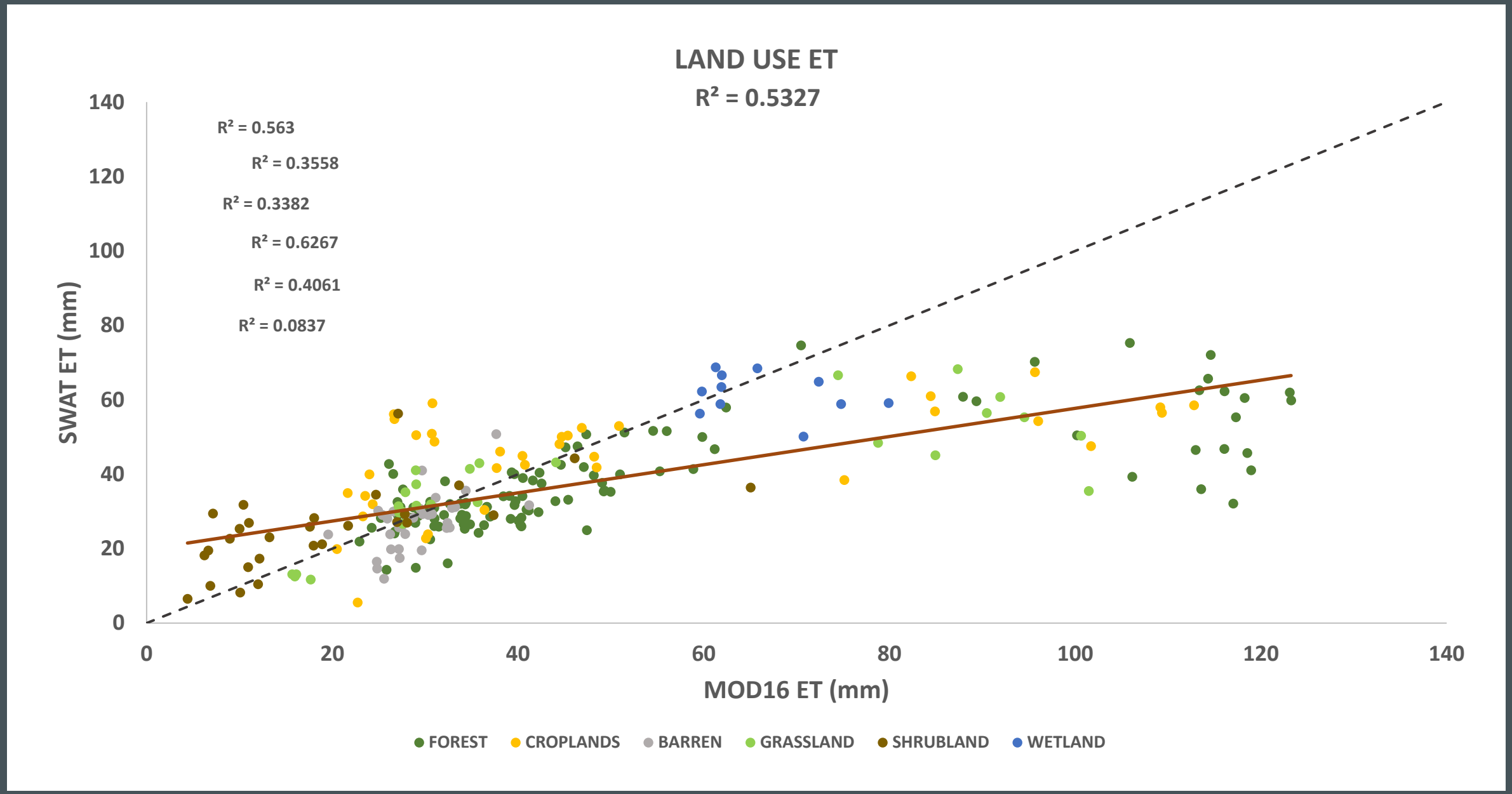
- 10 subbasins per landcover in each precipitation zone
- MOD16- monthly

- 4 pcp zones X 5 LULC X 10 each
- Selecting parameter set with best stats for each LULC in each precipitation zone

CALIBRATION

- 168 out of 240 samples > 0.5 R^2
- Best parameters are used for each land use and precipitation zone
- Calibration Parameters
  - EPCO
  - CN2
  - ALPHA_BF
  - GW_DELAY
  - GWQMN
  - GW_REVAP
  - RCHRG_DP
  - REVAPMN
  - ESCO
  - SOL_AWC
  - CANMX
  - SLSOIL
  - LATTTIME
  - ALPHA_BF_D
  - SMTMP
  - SFTMP
  - SMFMX
  - SMFMN
  - TIMP




LAND USE ET
R² = 0.5327
R² = 0.563
R² = 0.3558
R² = 0.3382
R² = 0.6267
R² = 0.4061
R² = 0.0837
SWAT ET (mm)
MOD16 ET (mm)
0
20
40
60
80
100
120
140
FOREST
CROPLANDS
BARREN
GRASSLAND
SHRUBLAND
WETLAND

BEST PARAMETER SUMMARY

Catchmen	Variable	main_sub	R2	NSE	PBIAS	KGE	Sim_Mea	Obs_Mea	Sim_Stde	Obs_Stde	Cal_decisio	Cal_ste	landuse	EPCO	CN2	ALPHA_B	GW_DELA	GWQMN	GW_REVA	RCHRG_D	REVAPMN	ESCO	SOL_AWC	CANMX	SLSOIL	LATTIME	ALPHA_BF_	SMTMP	SFTMP	SMFMX	SMFMN	TIMP
14975	37	37	0.9	0.83	1.7	0.8	28.77	29.26	24.4	20.57	YES	Pre	FOEN	0.9318	-0.04672	0.05029	-11.7188	467.188	0.103109	0.049297	-488.6719	0.94332	0.0457	10.35938	27.77344	5.479687	0.002344	1.93594	-1.27188	3.99805	2.07227	0.23359
15433	10	10	0.9	0.84	15.7	0.83	26.09	30.97	25.78	25.95	YES	Pre	FOEN	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
15433	10	10	0.9	0.88	0	0.85	30.95	30.97	29.58	25.95	YES	Pre	FOEN	0.89242	-0.08703	0.07645	-12.0938	273.438	0.100859	-0.00273	608.20313	0.83457	0.04836	3.828125	26.60156	6.354687	0.550781	0.59219	-1.08438	3.23242	1.84961	0.71484
15433	16	10	0.9	0.83	18	0.77	28.09	34.25	26.38	30.52	YES	Pre	FOMI	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
15433	16	10	0.9	0.89	6.2	0.91	32.12	34.25	29.65	30.52	YES	Pre	FOMI	0.89242	-0.08703	0.07645	-12.0938	273.438	0.100859	-0.00273	608.20313	0.83457	0.04836	3.828125	26.60156	6.354687	0.550781	0.59219	-1.08438	3.23242	1.84961	0.71484
15433	10	16	0.9	0.84	15.7	0.83	26.09	30.97	25.78	25.95	YES	Pre	FOEN	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
15433	10	16	0.9	0.88	0	0.85	30.95	30.97	29.58	25.95	YES	Pre	FOEN	0.89242	-0.08703	0.07645	-12.0938	273.438	0.100859	-0.00273	608.20313	0.83457	0.04836	3.828125	26.60156	6.354687	0.550781	0.59219	-1.08438	3.23242	1.84961	0.71484
15433	16	16	0.9	0.83	18	0.77	28.09	34.25	26.38	30.52	YES	Pre	FOMI	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
15433	16	16	0.9	0.89	6.2	0.91	32.12	34.25	29.65	30.52	YES	Pre	FOMI	0.89242	-0.08703	0.07645	-12.0938	273.438	0.100859	-0.00273	608.20313	0.83457	0.04836	3.828125	26.60156	6.354687	0.550781	0.59219	-1.08438	3.23242	1.84961	0.71484
18072	57	57	0.7	0.68	17.5	0.76	25.94	31.46	21.11	23.42	YES	Pre	FOEN	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
18072	57	57	0.7	0.7	14.7	0.76	26.82	31.46	20.64	23.42	YES	Pre	FOEN	0.62945	-0.02453	0.05282	67.59375	-629.688	0.175953	0.000234	176.95313	0.88824	-0.00023	0.828125	148.4766	0.229687	0.508594	0.10156	-0.60938	4.26367	0.7168	0.88984
18193	60	60	0.8	0.58	35.5	0.54	26.03	40.35	23.22	32.16	YES	Pre	FOMI	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
18193	60	60	0.8	0.66	29.8	0.61	28.34	40.35	24.48	32.16	YES	Pre	FOMI	0.71664	-0.03453	0.03285	-12.4688	129.688	0.178766	0.016172	-118.3594	0.93465	0.00258	0.015625	85.19531	2.417187	0.744531	1.47969	0.32188	2.98633	0.50195	0.64453
18218	59	59	0.9	0.86	14.7	0.83	31.27	36.64	28.44	30.46	YES	Pre	FOMI	0.98523	0.08766	0.0389	15.09375	-476.563	0.112391	-0.02023	106.64063	0.81465	-0.00367	0.921875	80.50781	2.854687	0.074219	0.30781	-1.20938	3.08398	0.39258	0.74922
18218	59	59	0.9	0.86	14.7	0.83	31.27	36.64	28.44	30.46	YES	Pre	FOMI	0.98523	0.08766	0.0389	15.09375	-476.563	0.112391	-0.02023	106.64063	0.81465	-0.00367	0.921875	80.50781	2.854687	0.074219	0.30781	-1.20938	3.08398	0.39258	0.74922
19788	103	103	0.8	0.77	9.3	0.83	28.11	31	21.74	19.43	YES	Pre	FOEN	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
19788	103	103	0.8	0.56	-11.7	0.56	34.62	31	27.43	19.43	YES	Pre	FOEN	0.89242	-0.08703	0.07645	-12.0938	273.438	0.100859	-0.00273	608.20313	0.83457	0.04836	3.828125	26.60156	6.354687	0.550781	0.59219	-1.08438	3.23242	1.84961	0.71484
20719	56	56	0.9	0.85	16.2	0.82	28.81	34.38	27.22	28.84	YES	Pre	FOMI	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
20719	56	56	0.9	0.89	5.9	0.92	32.35	34.38	29.81	28.84	YES	Pre	FOMI	0.72648	-0.03078	0.05999	39.46875	-360.938	0.194234	0.039141	479.29688	0.85731	0.04383	2.359375	78.39844	3.117188	0.657031	0.39844	1.77813	4.00586	2.36133	0.54766
21277	15	15	0.9	0.85	6.9	0.88	26.95	28.94	23.02	24.44	YES	Pre	FOMI	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
21277	15	15	0.9	0.84	-7.2	0.84	31.02	28.94	27.45	24.44	YES	Pre	FOMI	0.13305	-0.00172	0.02863	15.46875	198.438	0.097484	0.019141	514.45313	0.8116	0.01133	11.51563	123.6328	12.02031	0.100781	0.32031	-1.67188	4.31445	2.39258	0.98516
21913	89	89	0.9	0.73	-1.3	0.65	30.66	30.27	25.33	18.89	YES	Pre	FOEN	0.92617	-0.07422	0.02484	67.40625	-529.688	0.028859	0.029922	-394.9219	0.8934	0.01414	2.453125	88.24219	2.570313	0.325781	0.04219	-1.94063	3.28711	1.45508	0.76172
21913	89	89	0.9	0.73	-1.3	0.65	30.66	30.27	25.33	18.89	YES	Pre	FOEN	0.92617	-0.07422	0.02484	67.40625	-529.688	0.028859	0.029922	-394.9219	0.8934	0.01414	2.453125	88.24219	2.570313	0.325781	0.04219	-1.94063	3.28711	1.45508	0.76172
22844	60	60	0.9	0.7	31.2	0.6	27.55	40.05	24.85	33.03	YES	Pre	FOMI	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
22844	60	60	0.9	0.79	22.9	0.72	30.88	40.05	28.2	33.03	YES	Pre	FOMI	0.98664	-0.04484	0.08306	56.90625	-985.938	0.191984	0.038047	-655.0781	0.82098	0.03258	0.203125	24.49219	3.423437	0.364844	0.43906	1.92188	3.60742	0.91602	0.61484
24149	32	32	0.9	0.81	16.7	0.79	28.15	33.78	25.5	28.64	YES	Pre	FOMI	0.15836	0.08828	0.05873	7.40625	348.438	0.116609	-0.01789	-568.3594	0.93981	-0.04914	19.48438	59.41406	0.973437	0.130469	0.41406	-0.07188	3.64258	2.03711	0.33359
24149	32	32	0.9	0.87	4.7	0.92	32.17	33.78	28.45	28.64	YES	Pre	FOMI	0.83055	-0.01359	0.05437	-6.28125	823.438	0.115203	0.026641	-366.7969	0.80879	0.03633	14.45313	130.8984	2.154687	0.005469	0.48594	-1.29688	4.29492	1.43945	0.52109
24951	41	41	0.8	0.78	5.9	0.86	28.26	30.03	20.93	19.2	YES	Pre	FOEN	0.96695	0.03141	0.03088	-8.53125	295.313	0.188328	-0.03695	-612.8906	0.89856	0.00352	0.484375	50.97656	2.789063	0.582031	0.20469	-0.07813	2.75586	0.92773	0.47266
24951	41	41	0.8	0.78	5.9	0.86	28.26	30.03	20.93	19.2	YES	Pre	FOEN	0.96695	0.03141	0.03088	-8.53125	295.313	0.188328	-0.03695	-612.8906	0.89856	0.00352	0.484375	50.97656	2.789063	0.582031	0.20469	-0.07813	2.75586	0.92773	0.47266
24951	62	41	0.9	0.69	-0.6	0.65	29.53	29.37	23.98	17.79	YES	Pre	FOEN	0.96695	0.03141	0.03088	-8.53125	295.313	0.188328	-0.03695	-612.8906	0.89856	0.00352	0.484375	50.97656	2.789063	0.582031	0.20469	-0.07813	2.75586	0.92773	0.47266
24951	62	41	0.9	0.69	-0.6	0.65	29.53	29.37	23.98	17.79	YES	Pre	FOEN	0.96695	0.03141	0.03088	-8.53125	295.313	0.188328	-0.03695	-612.8906	0.89856	0.00352	0.484375	50.97656	2.789063	0.582031	0.20469	-0.07813	2.75586	0.92773	0.47266
24951	41	62	0.8	0.78	5.9	0.86	28.26	30.03	20.93	19.2	YES	Pre	FOEN	0.96695	0.03141	0.03088	-8.53125	295.313	0.188328	-0.03695	-612.8906	0.89856	0.00352	0.484375	50.97656	2.789063	0.582031	0.20469	-0.07813	2.75586	0.92773	0.47266
24951	41	62	0.8	0.78	5.9	0.86	28.26	30.03	20.93	19.2	YES	Pre	FOEN	0.96695	0.03141	0.03088	-8.53125	295.313	0.188328	-0.03695	-612.8906	0.89856	0.00352	0.484375	50.97656	2.789063	0.582031	0.20469	-0.07813	2.75586	0.92773	0.47266
24951	62	62	0.9	0.69	-0.6	0.65	29.53	29.37	23.98	17.79	YES	Pre	FOEN	0.96695	0.03141	0.03088	-8.53125	295.313	0.188328	-0.03695	-612.8906	0.89856	0.00352	0.484375	50.97656	2.789063	0.582031	0.20469	-0.07813	2.75586	0.92773	0.47266
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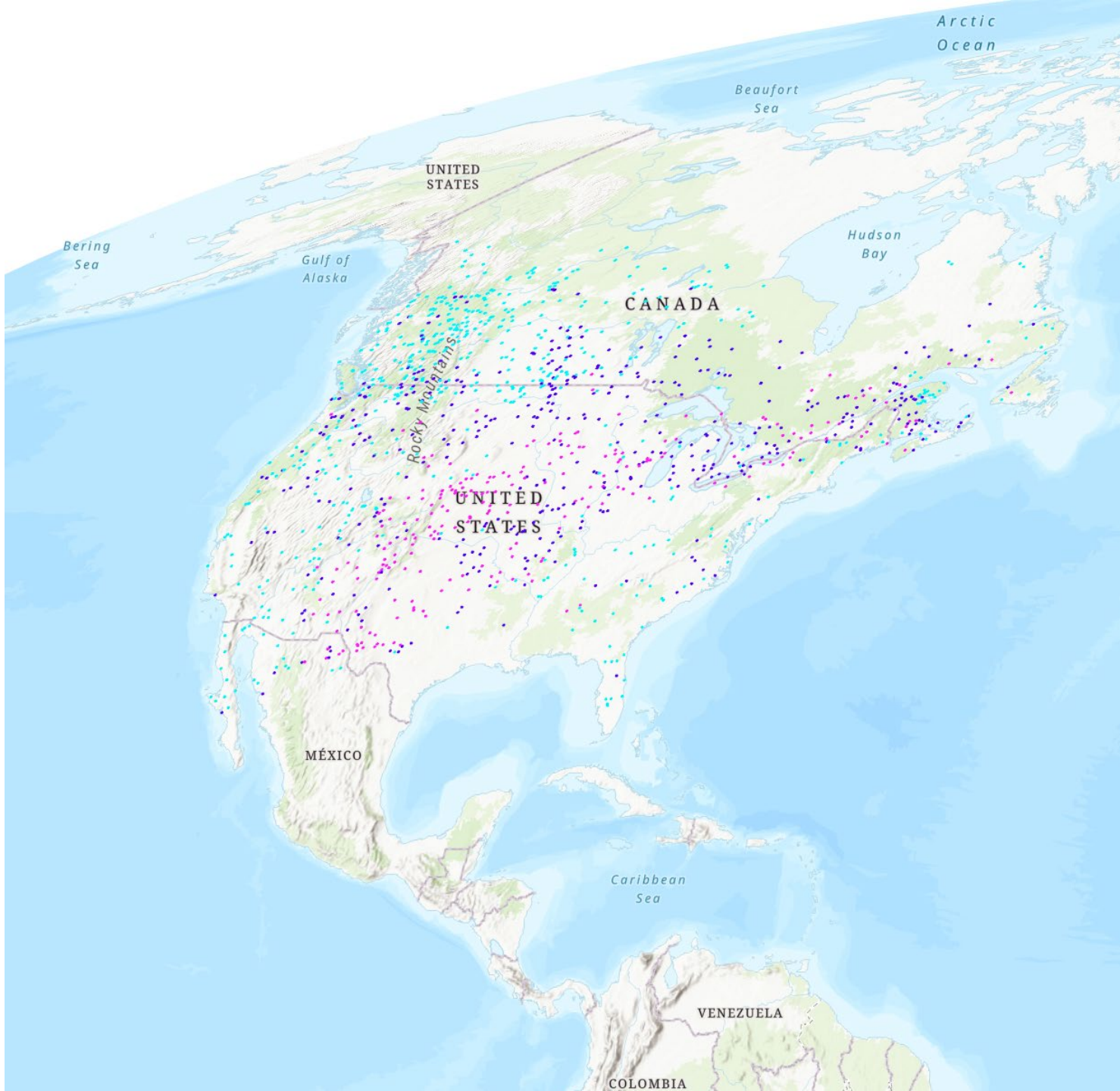
VALIDATION

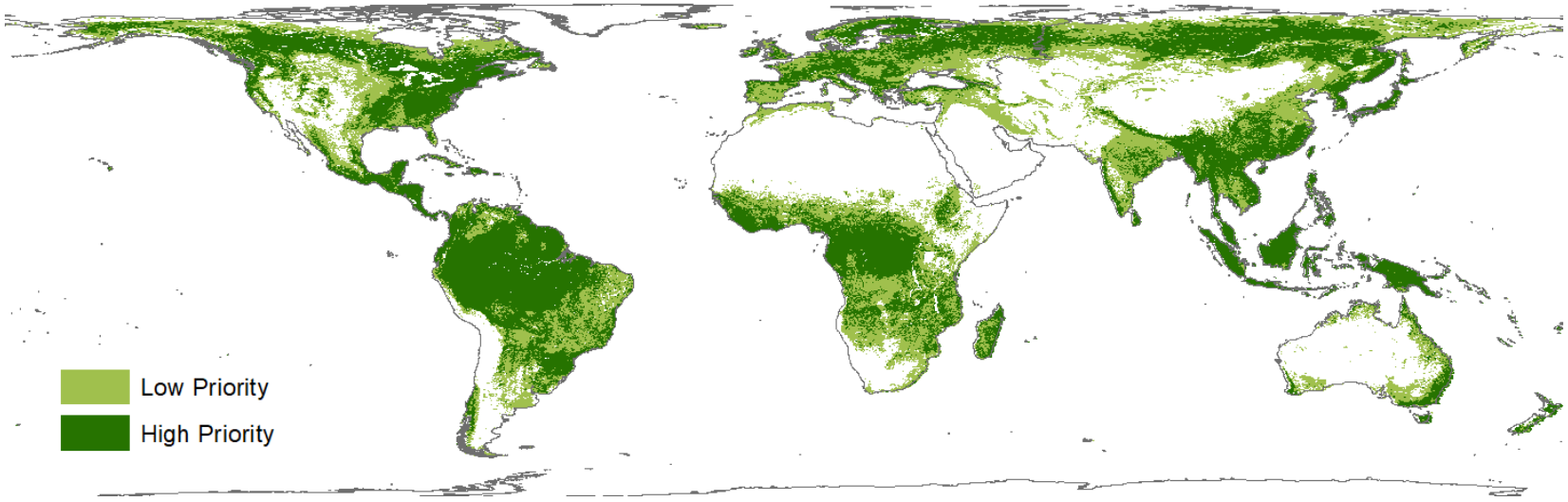
- 1,174 Gauges
- 20% KGE > 0.5
- 60% KGE > 0
- Water withdraws in Western US
- Recheck some gauges in Appalachia
- Western Canada



NEXT STEPS

- Global reforestation priority
- Methods Paper in Environmental Modelling & Software
  - Data and scripts released
- Finalize calibration and validation for Asia, Australia, and South America
- Paper assessing carbon and water benefits globally
- Extend work on Africa to include impacts of CMIP6 climate change scenarios on freshwater resources
  - Potential for Nature-based Solutions to climate adaptation
  - Scale and decision making
  - Upload to HAWQS for use

Reforestation Priority



In review: Nature Communications

THANK YOU!