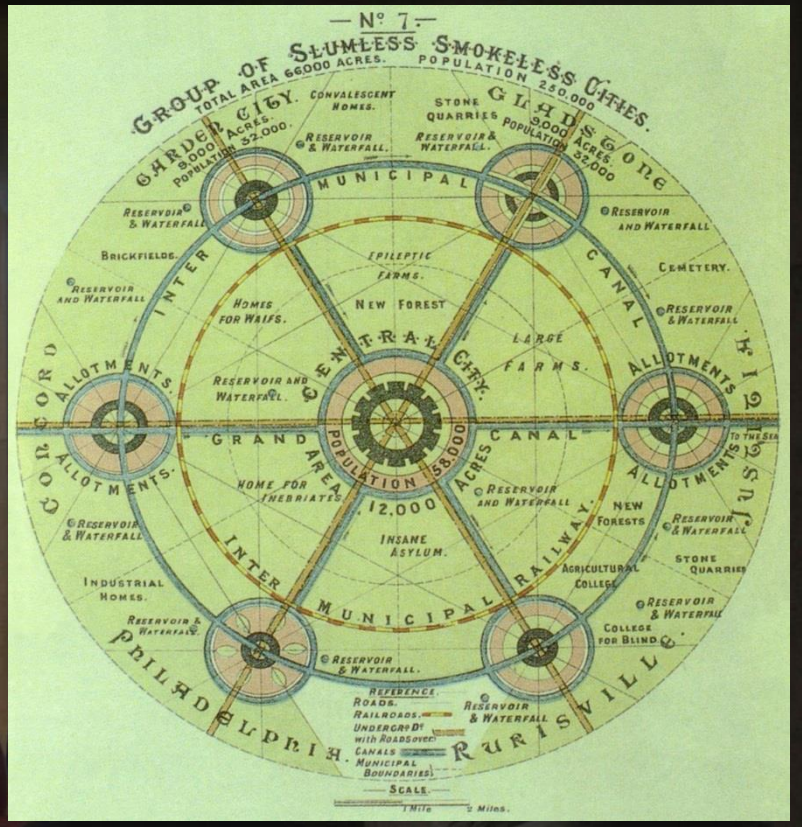
A Revival of The Garden City for a New Purpose

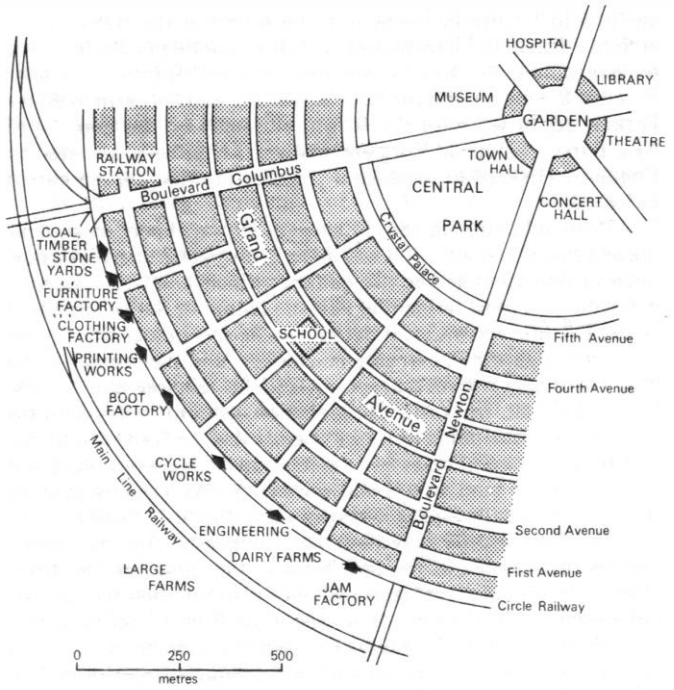


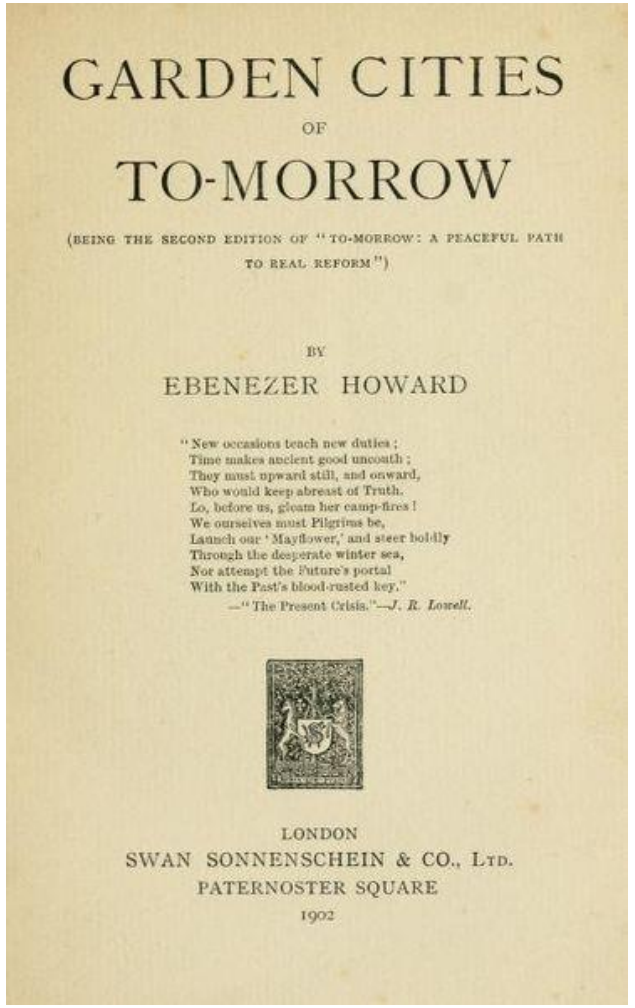
Jeffrey C. English
Master of Urban Planning
March 29, 2016

Setting the Stage…

- Table of Contents
  - The Rationale
  - Ebenezer Howard's Garden City
    - Letchworth, UK Case Study
  - Revival of the Garden City
    - Modified/Modernized Garden City Design
  - The Design Specifics
    - Land Use
  - The New Environment
    - Land Suitability Analysis
  - Population/Resource Simulations
    - 1,000 to 10,000

Howard, E. 1920s.




GARDEN CITIES
OF
TO-MORROW

(BEING THE SECOND EDITION OF "TO-MORROW: A PEACEFUL PATH TO REAL REFORM")

BY

EBENEZER HOWARD

"New occasions teach new duties;
Time makes ancient good uncouth;
They must upward still, and onward,
Who would keep abreast of Truth.
Lo, before us, gleam her camp-fires!
We ourselves must Pilgrims be,
Launch our 'Mayflower,' and steer boldly
Through the desperate winter sea,
Nor attempt the Future's portal
With the Past's blood-rusted key."
—"The Present Crisis."—*J. R. Lowell.*

LONDON
SWAN SONNENSCHEIN & CO., LTD.
PATERNOSTER SQUARE
1902

Both Images: Swan Sonnenschein & Co. 1902.

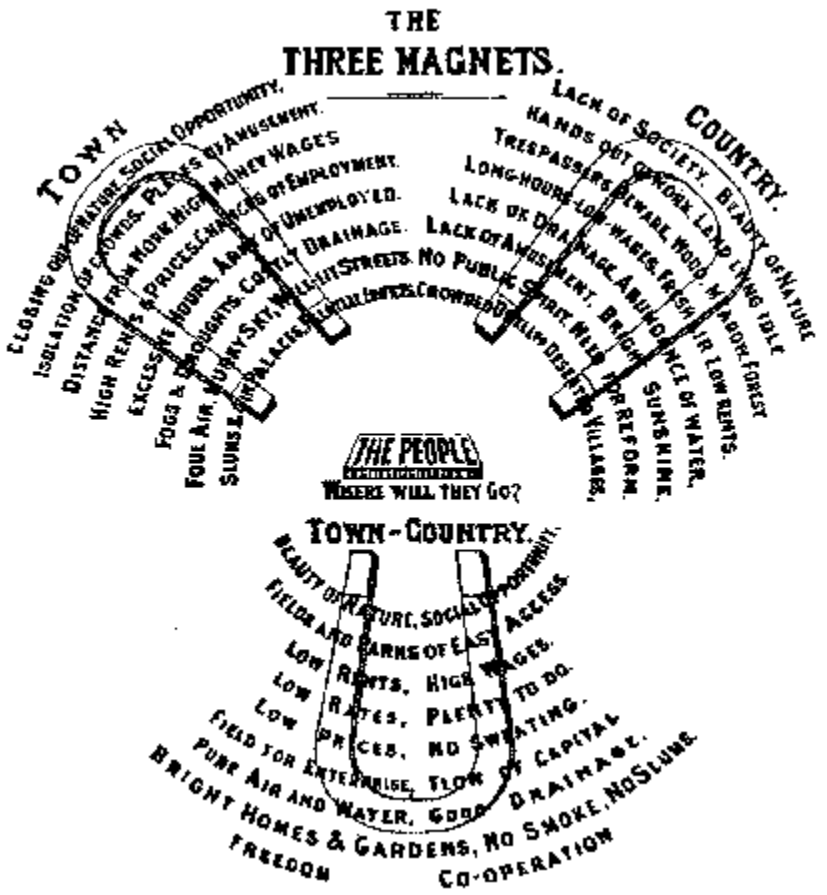
The Rationale OR “Emerging Market”

- Elon Musk has stated he would like to have a city on Mars
  - But does not specify how he wants it to look or function or where it will even be located
    - Most of the dirty work is done.
  - A step closer: Will Announce and Reveal Launch Vehicles to Mars in Late September 2016
- Unsustainable Natural Resource Use
- Insurance Policy (Will not have all our eggs in one basket)
- Don’t put off tomorrow what you can do today

Musk, Elon. 2015. Instagram. https://www.instagram.com/p/7oIOmKwEbl/?hl=en

Ebenezer Howard's Garden City

- Written in 1898: *To-morrow: A Peaceful Path to Real Reform*
  - Wanted a Higher Quality of Life for People
- Full City Diagram published in 1902: *Garden Cities of To-Morrow*
  - As seen on Title Slide
- Focused on the Best of both worlds for his City (Town-Country)
  - Rural Living (Country)
  - Urban Living (Town)
- Built 2 Garden Cities in England
  - Letchworth: 1904
  - Welwyn: 1920

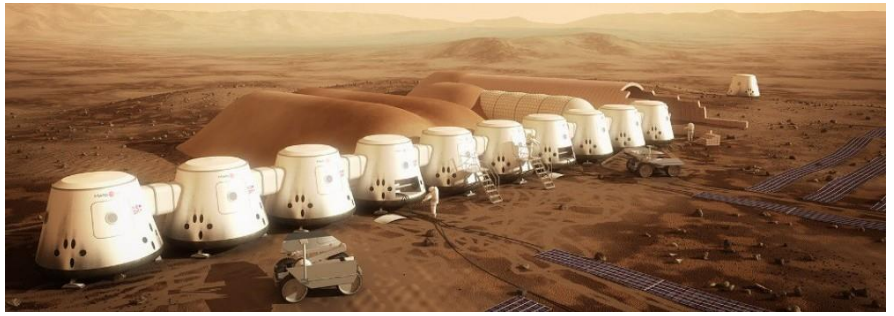


Howard, E. 1898.

Letchworth Garden City Case Study

- Letchworth GC has a spaced out design compared to other nearby cities
  - Higher quality health according to MacFadyen (1935)'s study
  - Welwyn GC had higher quality health too (The British Medical Journal, 1930).
- Cramped conditions lead to unhealthier citizens
  - Most Habitats to begin with on Mars will be small confined spaces
    - Bigelow Aerospace Inflatable Habitats
    - MarsOne Capsules
  - This city will be a huge upgrade from those small habitats

1933 England and Wales Vital Statistics	County Borough's	Urban Districts	Rural Districts
Death Rate	13.1	12.4	12.1
Infant Mortality	75	62	56
Scarlet Fever Attack Rate	3.4	2.98	1.93
Diphtheria Attack Rate	1.48	0.84	0.64
Puerperal Fever and Pyrexia Attack Rate per 1,000 births	15.5	10.9	9.0



Left Image from: MarsOne. 2011.

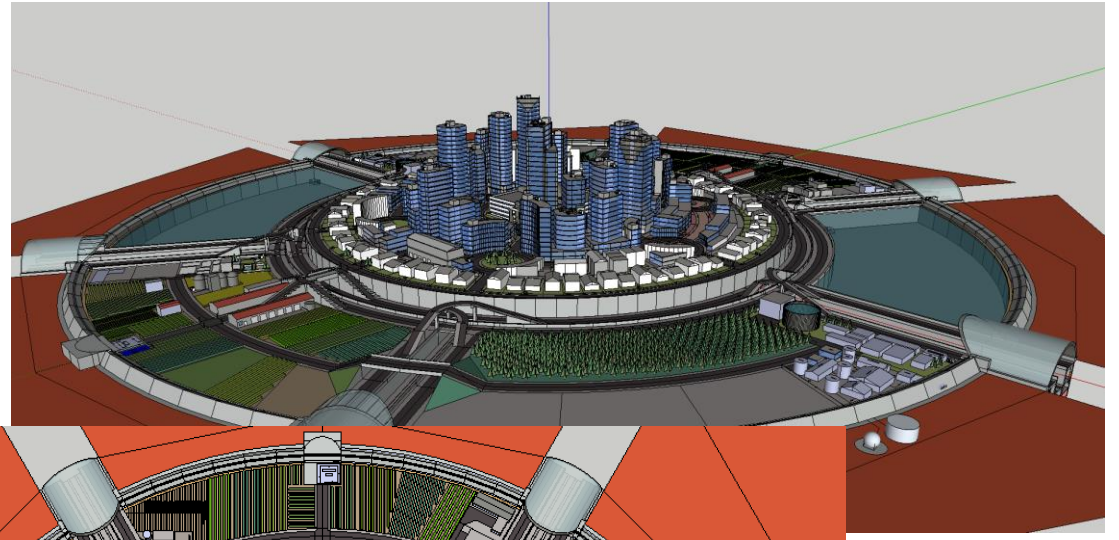
Standard of Public Health

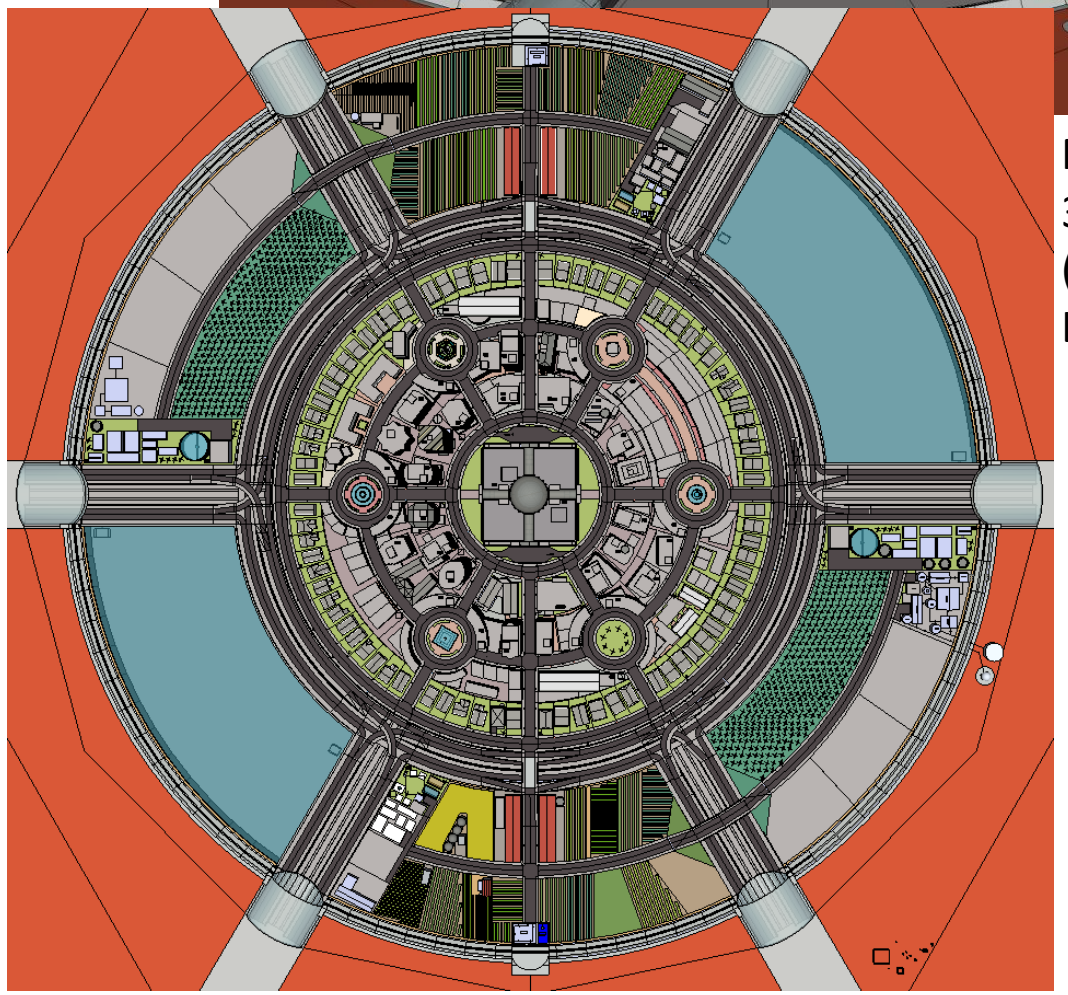
Year	Letchworth	County	England & Wales
General Death Rate			
1930	7.1	10.2	11.4
1931	7.2	10.3	12.3
1932	8.1	10.6	12.0
1933	9.9	10.8	12.3
1934	8.7	10.4	11.8
1930	*20*	*42*	*60*
1931	*41*	*46*	*66*
Infant Mortality			
1932	62	50	65
1933	30	42	64
1934	20	37	59
Death Rate from Pulmonary Tuberculosis			
1930	0.4	0.5	0.7
1931	0.3	0.4	0.7
1932	0.4	0.5	1.1
1933	0.4	0.5	0.6
1934	0.4	0.4	n/a

Right Image from: Ingalls, Bill. 2011. *NASA*.

Actual Garden Cities of Tomorrow

- The Garden Cities New Purpose:
  - First Large Scale Colony on Mars
  - A Land Use pattern that introduces to Mars:
    - Redundancy
    - Resiliency
    - Efficiency
    - Functionality
    - …that could all fit under one dome.

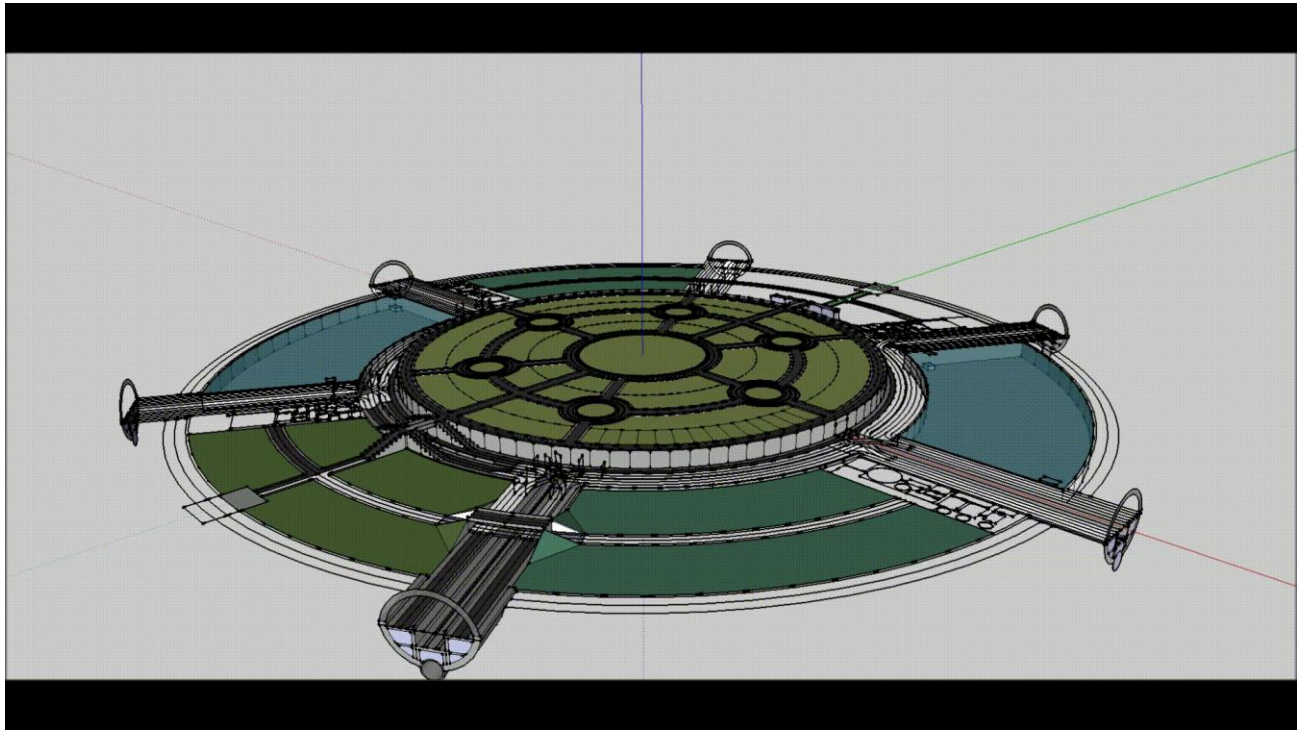




Model as of 3/22/2016 (Dome Layer: Off)

Overall Phase I Design

- Design Softwares Utilized
  - AutoCAD 2015 & 2016
  - SketchUp 2014 & 2015
- GIF Image of Mid June 2015 to Early February 2016
  - 3D Model Edited and Proper Adjustments were made over time, not construction procedures
- Living Areas (Residential Totals)
  - Center Elevated Circle (Raised 30 Ft)
  - 509,461.48 Square Feet
  - 0.0183 Square Miles



The Dome

- One of the main reasons why Howard's Garden City was modified and scaled down.
  - Make it more realistic.
- **Design:**
  - **Dome Diameter:**
    - 2,000 Ft/609.6 m
    - 710 Ft longer than Arches at AT&T Stadium in Arlington, TX (Near Dallas)
      - (Seen Right at 1,290 Ft Long)
    - Arch Abutments (Red Circle)
      - Foundation of Dome
  - **Apex Height:**
    - 400 Ft/121.9 m
  - **Dome Volume**
    - 425,365,333 Ft^3 or 12,045,004 m^3
  - **Internal Surface Area:**
    - 3,017,185.5 Sq Ft
  - **Materials (In Progress):**
    - Polyethylene (C_2H_4)
    - Transparent Aluminum (AlON)
  - **Internal Atmospheric Supply:**
    - Sabatier Reactors & Some Vegetation

Images from: Aniol, Dowd, & Platten. 2010. *Civil Engineering*.

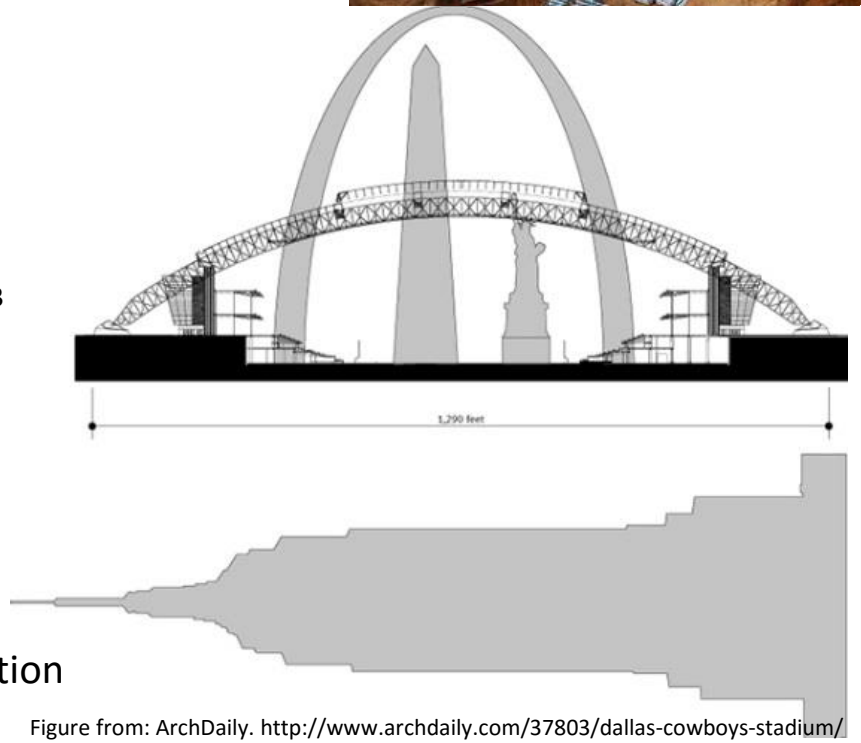
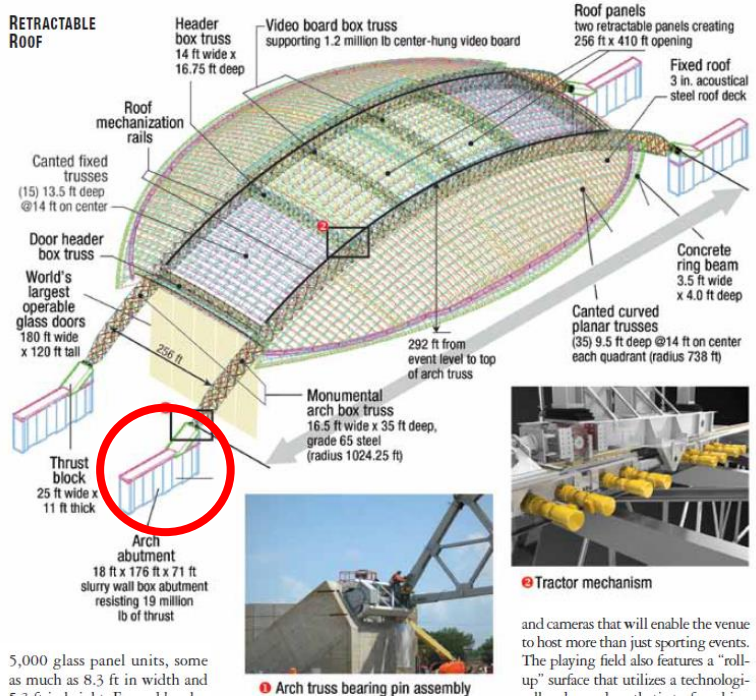


Figure from: ArchDaily. http://www.archdaily.com/37803/dallas-cowboys-stadium/



Transect Planning Densities

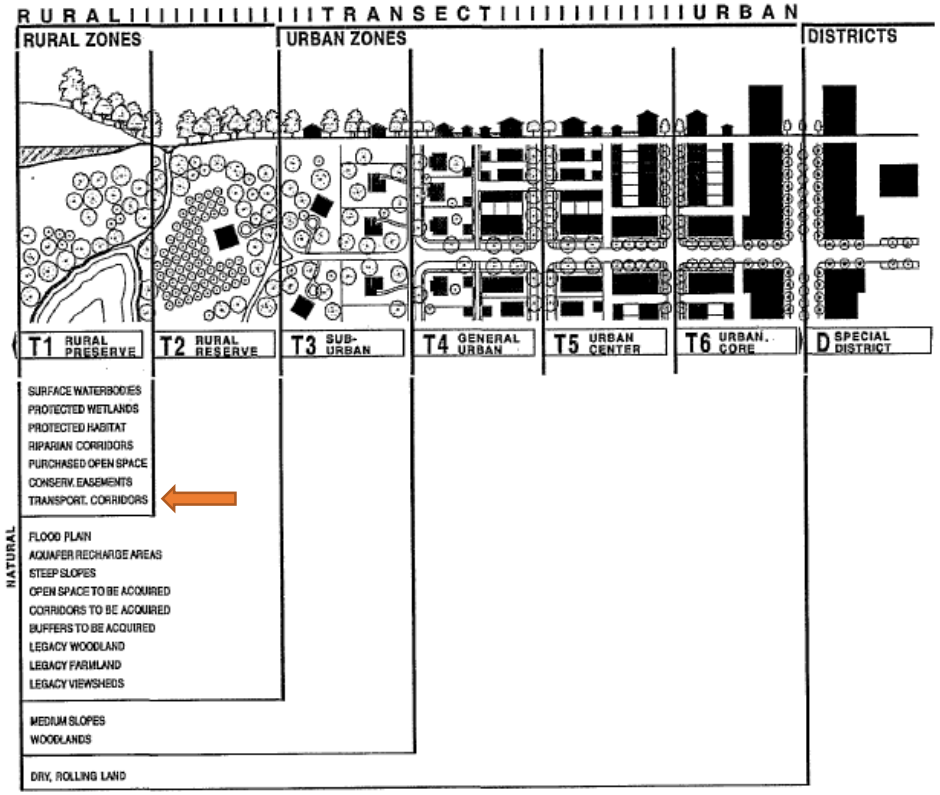
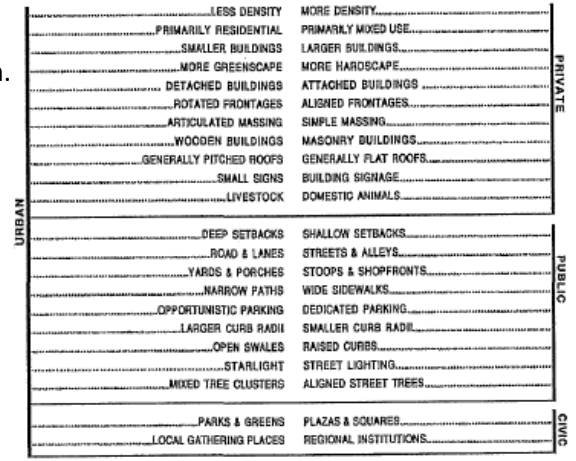
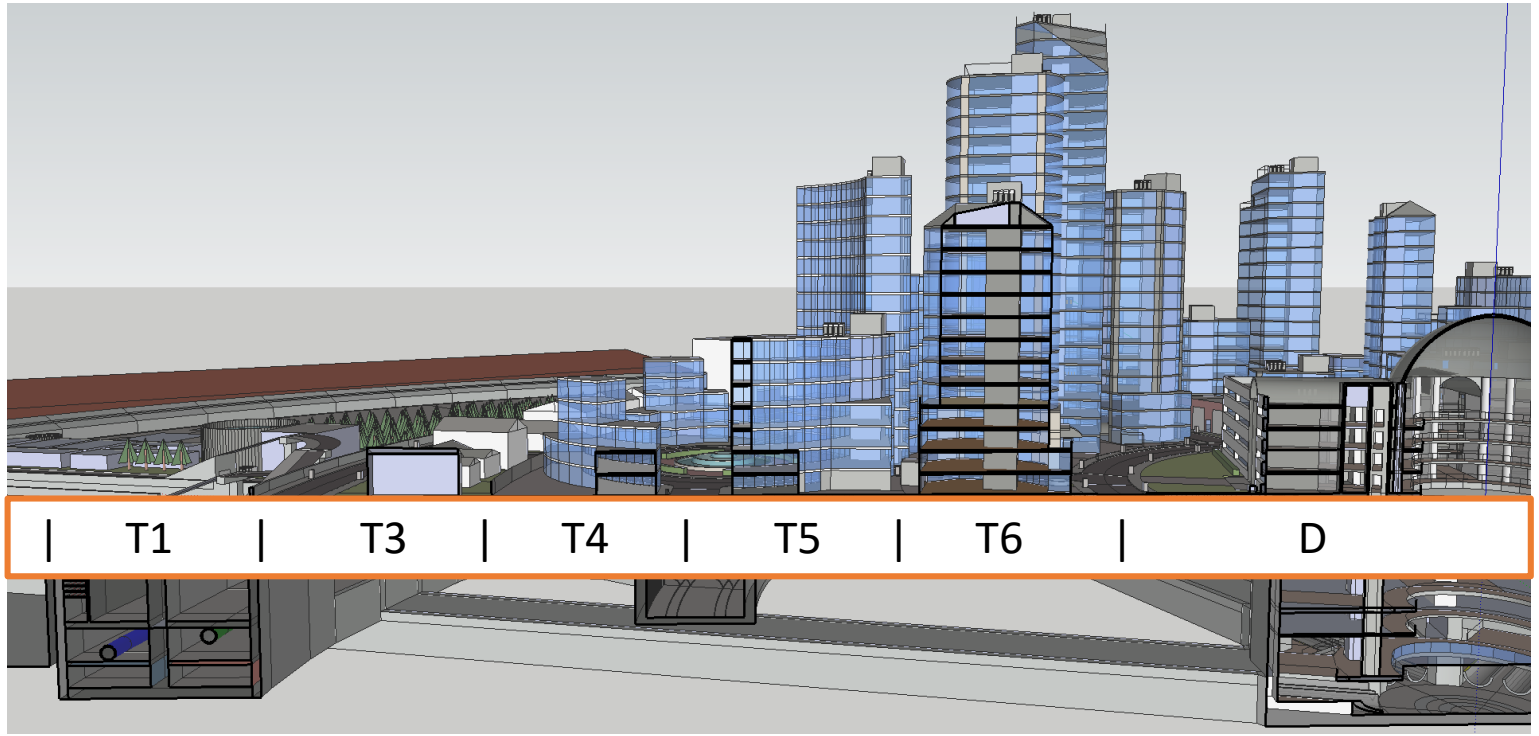
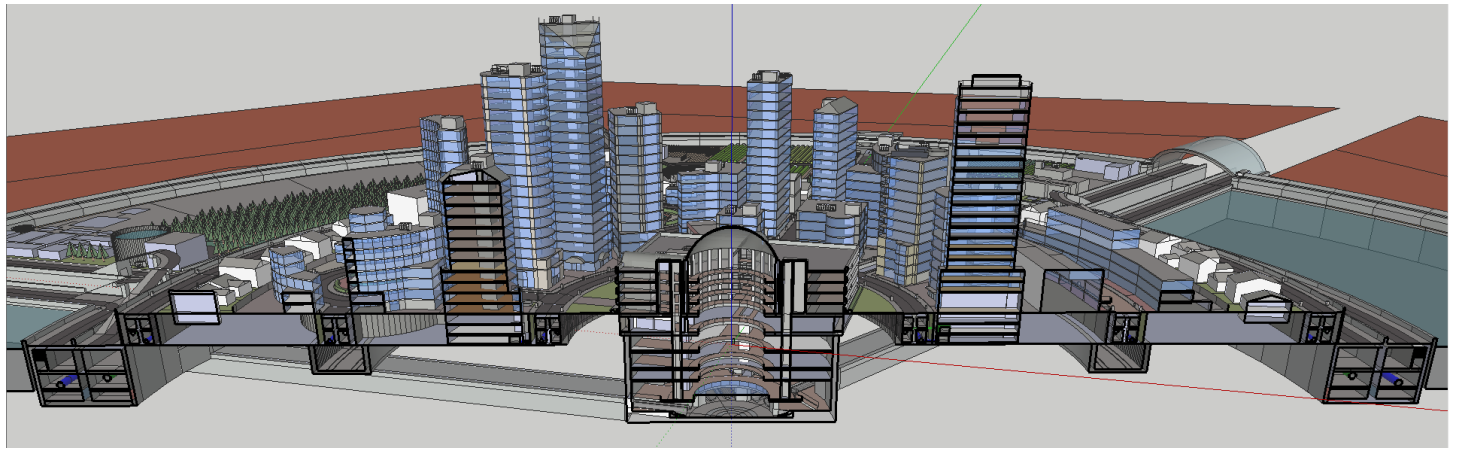


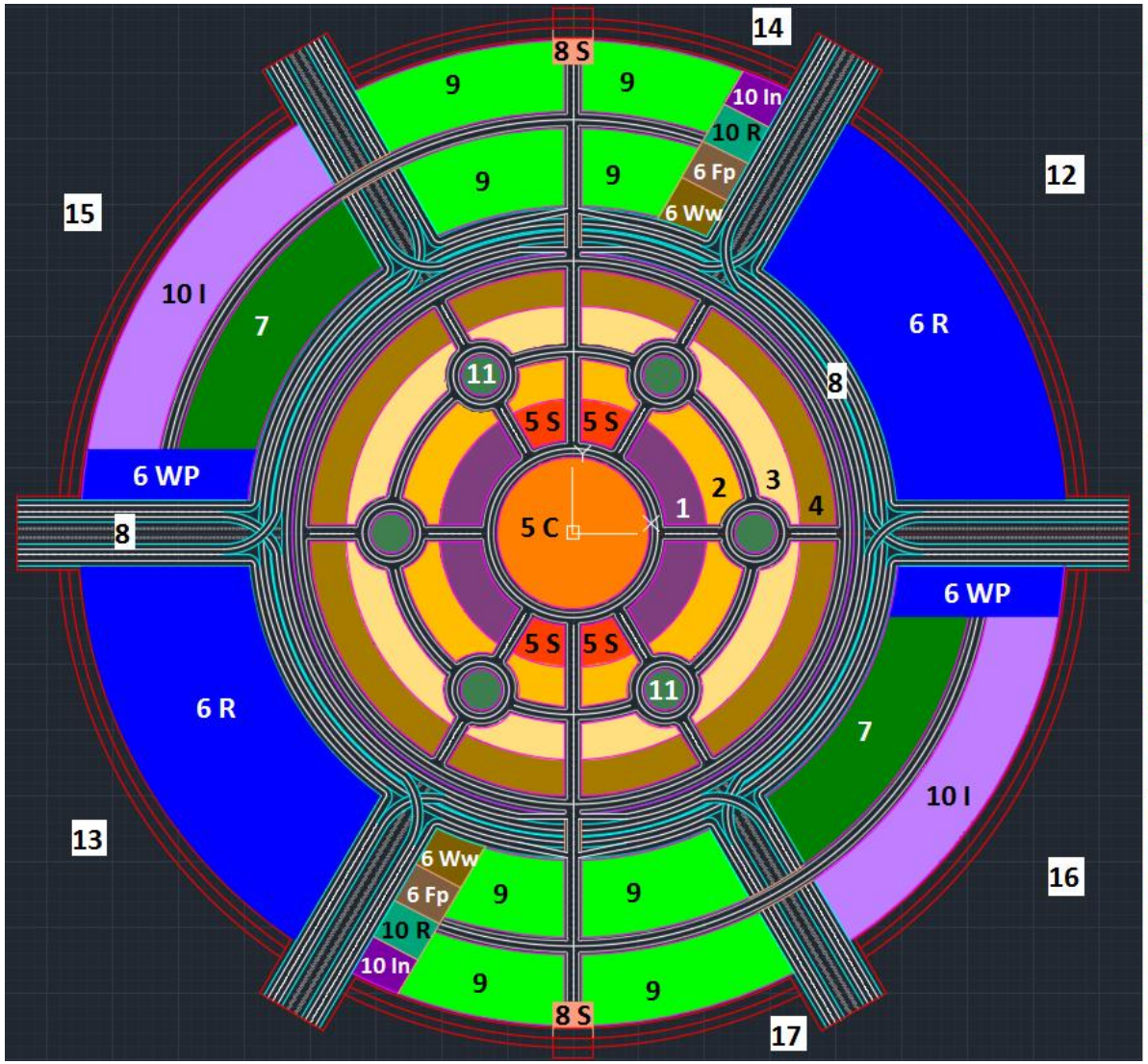
Figure from Duany & Talen. 2002.







Land Use Pattern

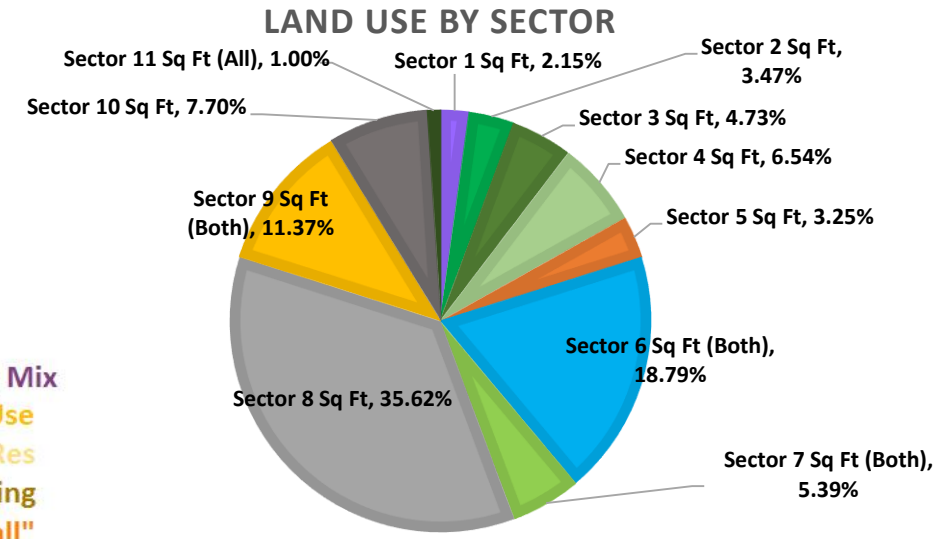


Interior

- 1 : Ultra High Density Mix
- 2 : High Density MixUse
- 3 : Medium Density Res
- 4 : Low Density Housing
- 5 C : Sector 5 "City Hall"
- 5 S : Sector 5 Civil Serv.
- 6 R : Reservoir
- 6 WP : Water Plant
- 6 Ww : Wastewater Pl.
- 6 Fp : Fertilizer Plant
- 7 : Forest
- 8: Utility/Transport
- 8 S : Sabatier/HVAC
- 9 : Agriculture
- 10 I : Industry
- 10 R: Recycling
- 10 In : Incinerator
- 11 : Parks/Green Space

Exterior

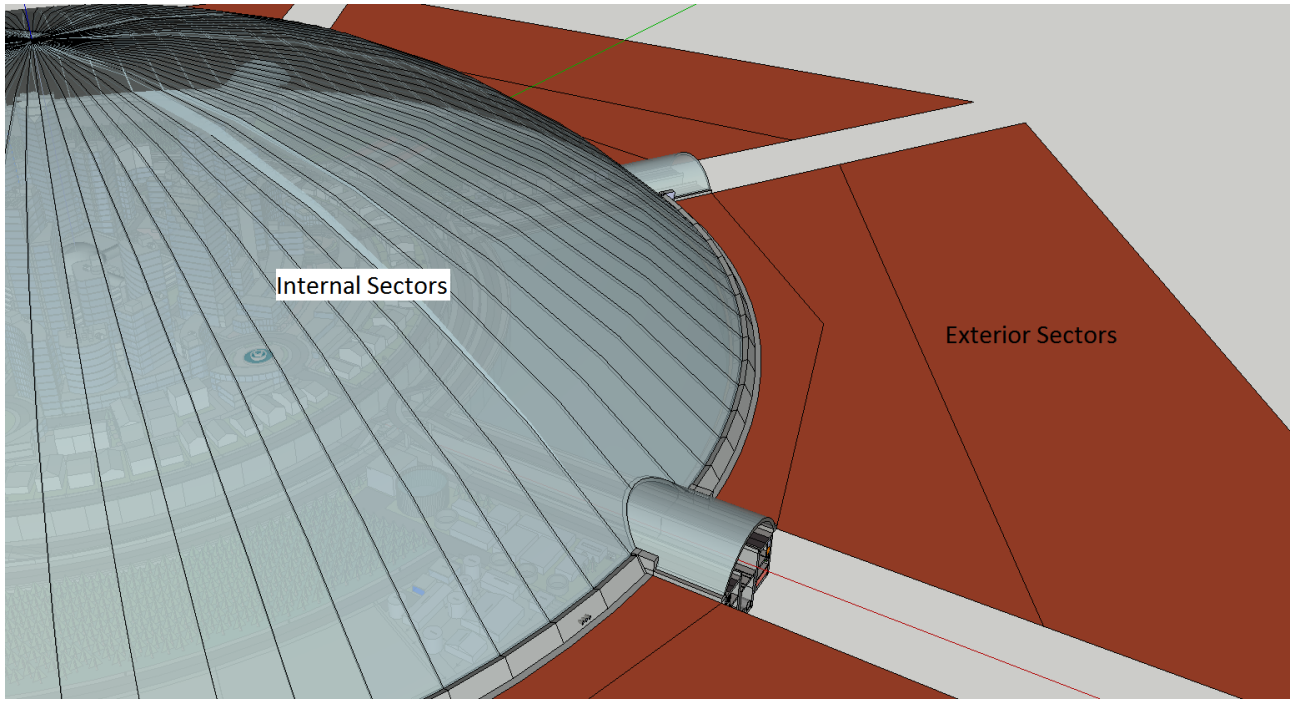
- 12: Launching Pads
- 13: Receiving Fields
- 14: Antenna Fields
- 15: Power Plant Slot
- 16: Landing Areas
- 17: Extraction Fields



Internal Land Uses	Square Footage	Percentage
Sector 1 Mix Use	64,895.61	2.15%
Sector 2 Mix Use	104,679.87	3.47%
Sector 3 Residential	142,618.28	4.73%
Sector 4 Residential	197,267.69	6.54%
Sector 5	97,992.97	3.25%
Sector 6	566,979.08	18.79%
Sector 7	162,521.46	5.38%
Sector 8	1,074,573.43	35.62%
Sector 9	343,194.62	11.37%
Sector 10	232,303.23	7.70%
Sector 11	30,159.28	1.00%
Total Phase I Land	**3,017,185.59**	**100.00%**

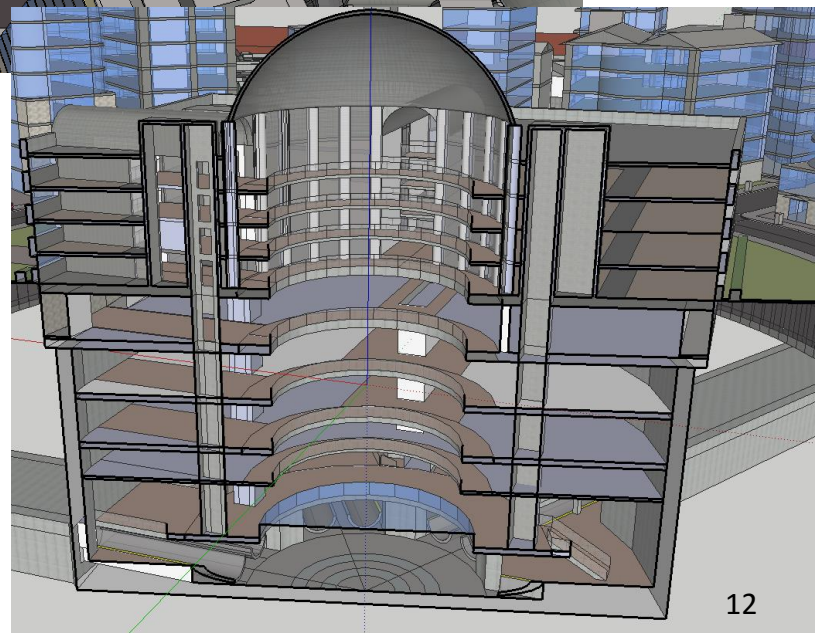
Individual Land Uses/Sectors

- Sectors 1-11 are within the Dome
  - Called Internal/Interior
    - Pressurized Atmosphere
    - Heated/Climate Controlled
    - Monitored Oxygen/CO2 Levels
    - Lower Radiation Levels
- Sectors 12-17 are outside the Dome
  - Called External/Exterior
    - Lower Atmospheric Pressure
    - Freezing
    - Abundant Carbon Dioxide (Toxic)
    - Higher Radiation Levels
    - Dust storms



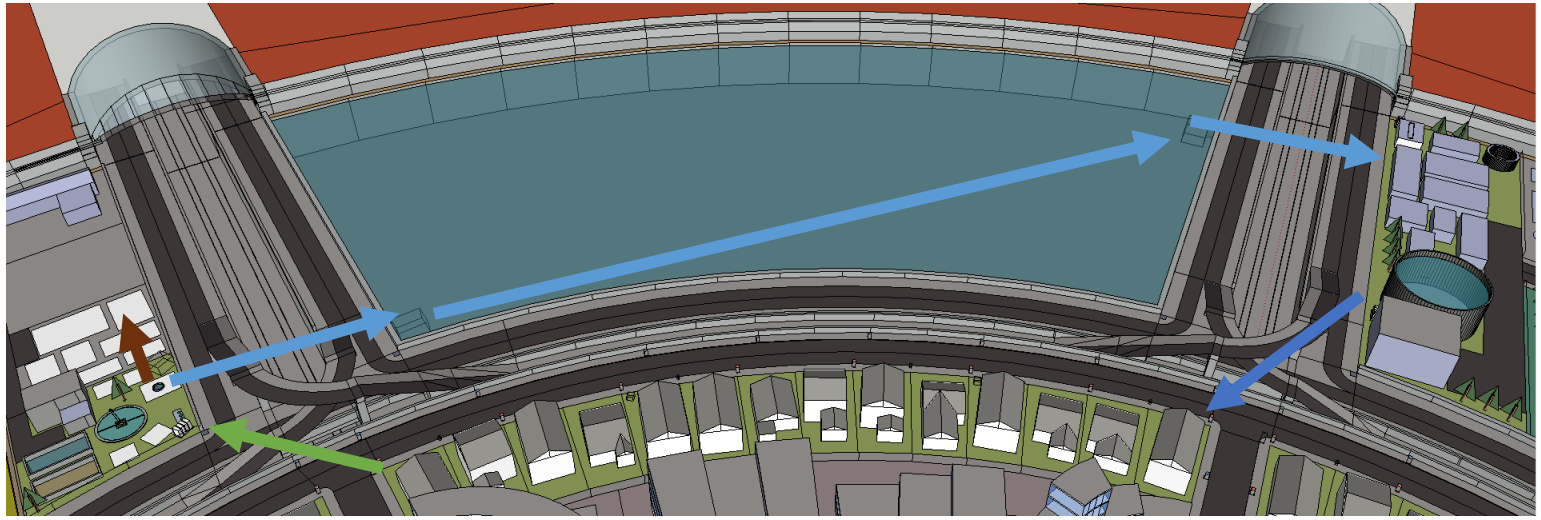
Sectors 1-5

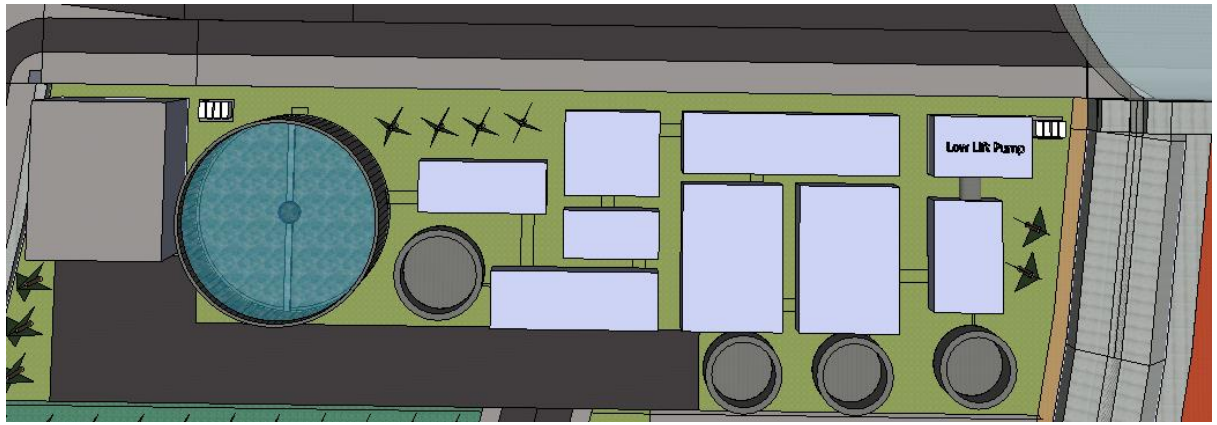
- Sector 1
  - High Density Mixed Use
    - Residential
    - Retail
    - Office/Lab
- Sector 2
  - High Density Residential
    - Sparce Retail Allowed
- Sector 3
  - Medium Density Residential
- Sector 4
  - Low Density Residential
- Sector 5
  - Two Levels
    - Above Ground: City Hall/Administration Center
    - Below Ground: Transportation Hub

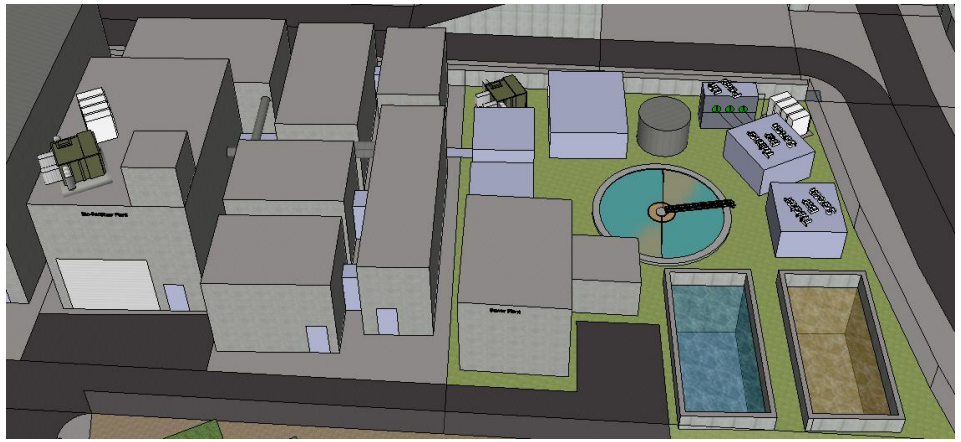


Sector 6

- Water
  - Reservoirs (2)
    - 231,881.78 Square Feet Each
    - Each 45 Feet Deep
    - 156,112,439 Gallons or 590,949,896 kg
  - Water Treatment Plants (2)
    - UV Light Treatment = Less Imported Chemicals
- Sewer
  - Wastewater Treatment Plants (2)
  - Bio-Fertilizer Plants (2)
- Both Systems are pressurized
  - Gravity Based Systems will not work

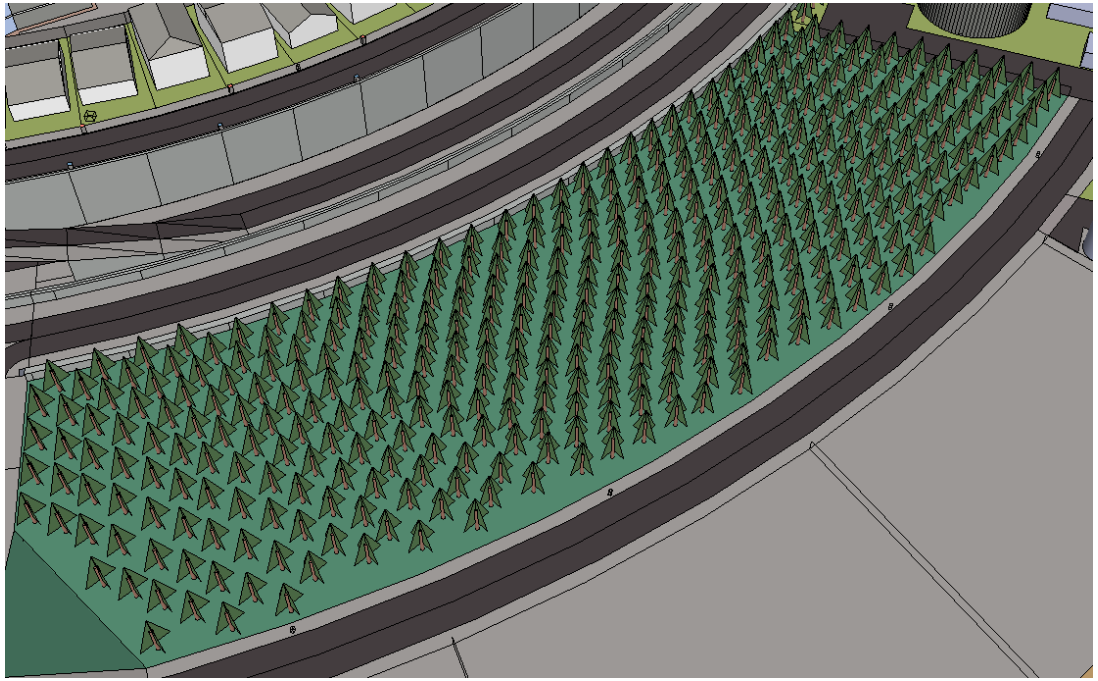






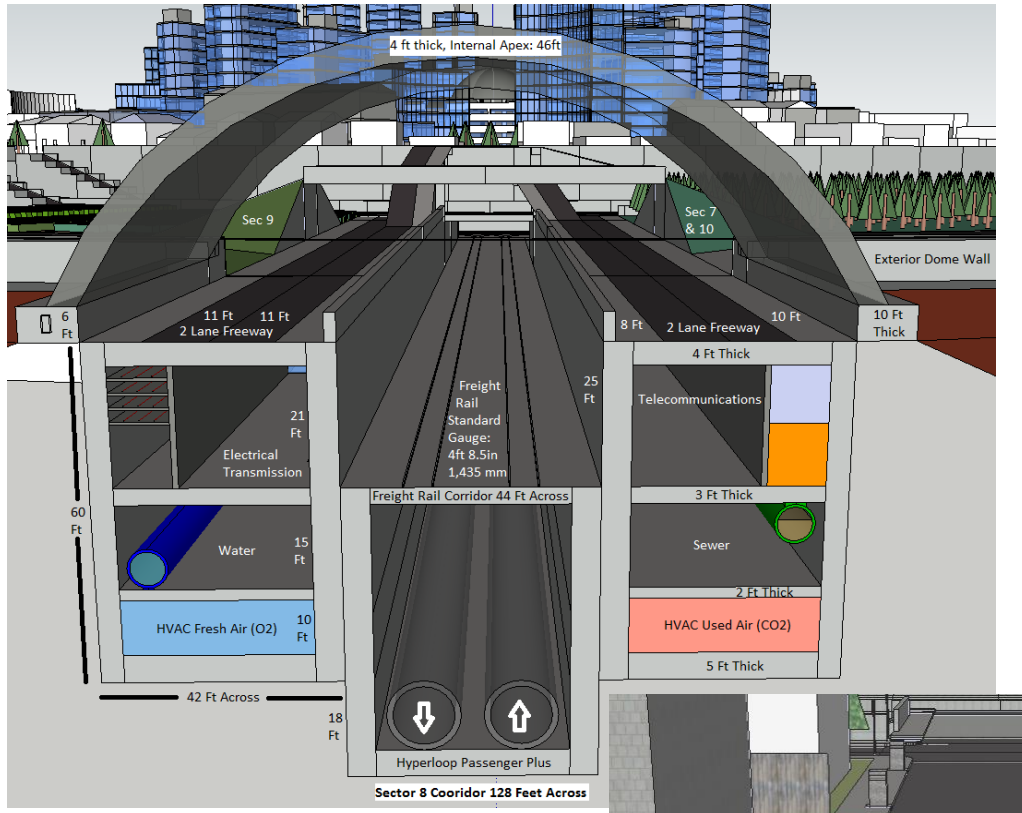
Sector 7

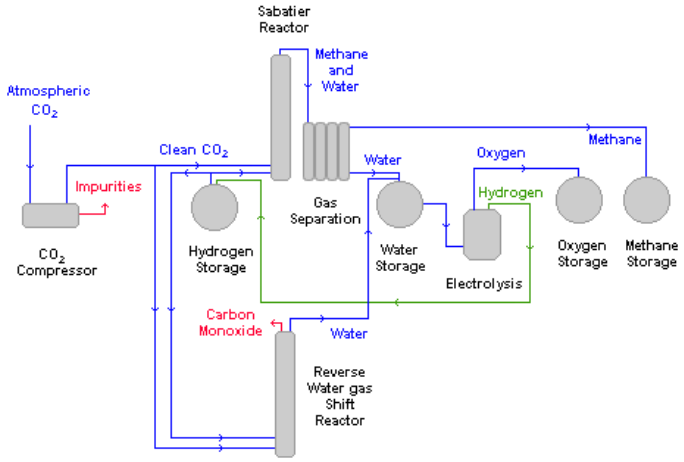
- Vegetation (Trees)
  - Provide Oxygen & Remove Carbon Dioxide
- Mixed with Sector 9
  - Fruit Trees
- Sector could be Eliminated by Sabatier Reactors (Sec 8/10)
  - Difficulty of measuring Oxygen outputs and amount of carbon dioxide removed or water inputs into trees
  - Might be a Machine City after all



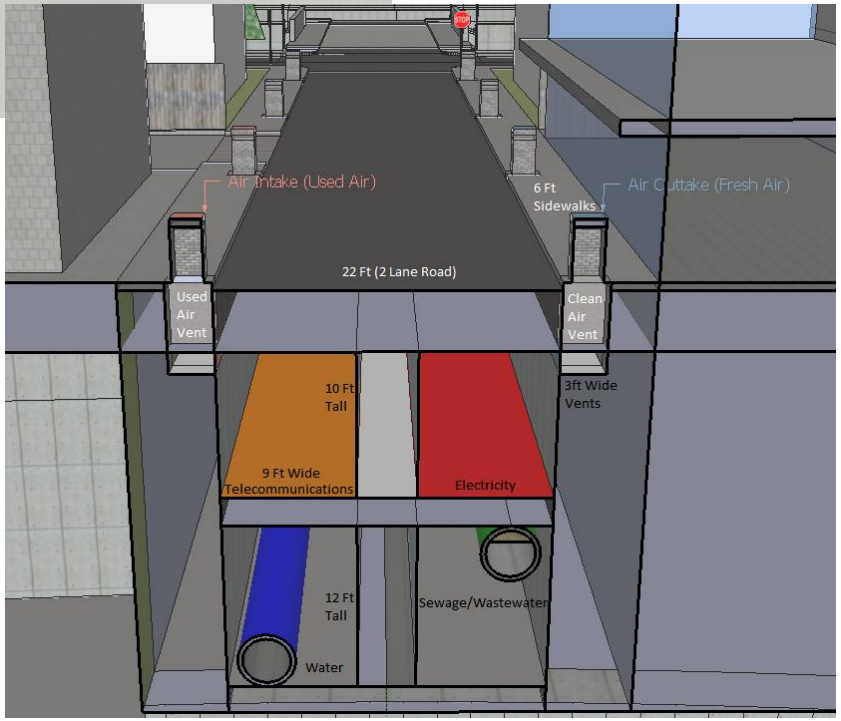
Sector 8 Corridors

- **Transmission Corridors (City to City)**
  - Utilities
    - Water Mains
    - Sewer Trunk Lines
    - Electrical Transmission/Distribution Lines
    - Telecommunications
    - HVAC System (Sabatier/Fresh & Used Air)
      - $CO_2 + 4H_2 ==> CH_4 + 2H_2O$
  - Transportation
    - Rail Freight
    - 4 Lane Freeway
    - 2 Hyperloop Passenger Plus Tubes
  - Safety
    - Airlocks between Dome and Corridors (Not Shown Upper Right)
    - 4ft thick Dome along routes
- **Distribution Corridors (Within City)**
  - Utilities
    - Same as above
  - Transportation
    - Two Lane Roads OR Four Bike Lanes
    - Sidewalks



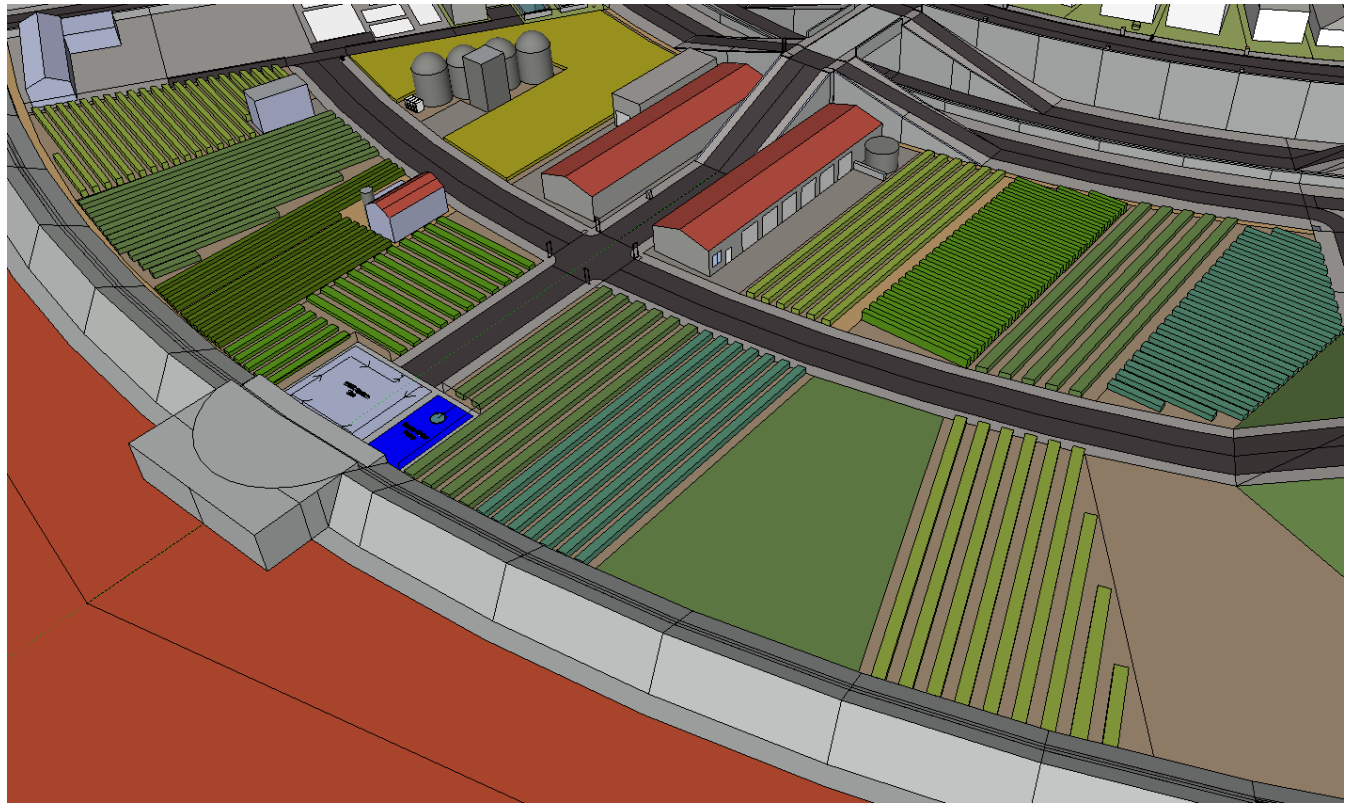


The closed-loop Sabatier and reverse water gas shift reaction system. Dice, David. 2009. Digipac.

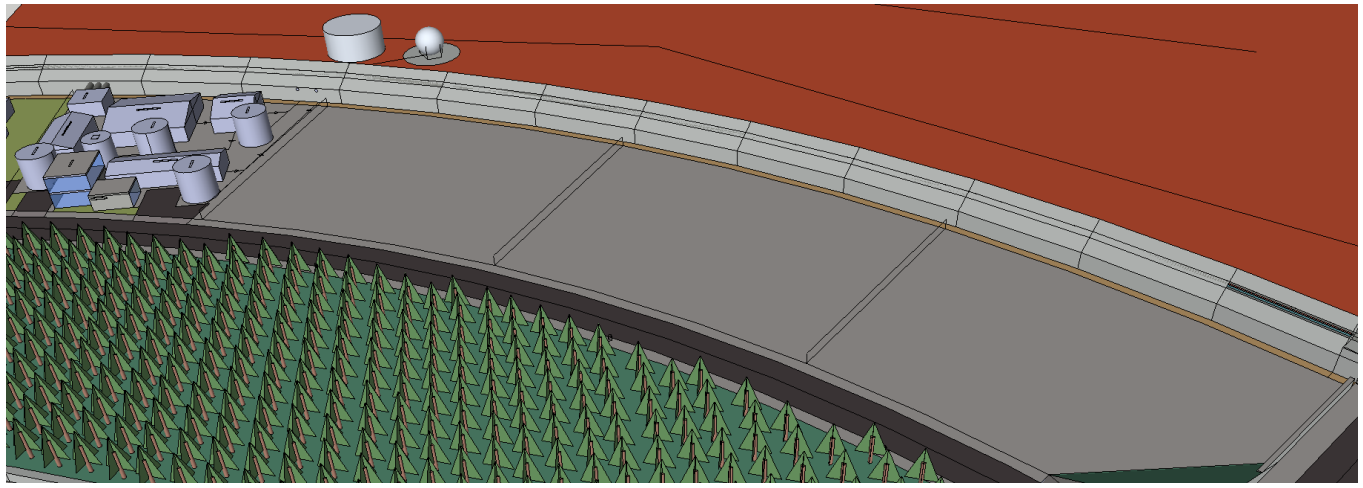


Sector 9

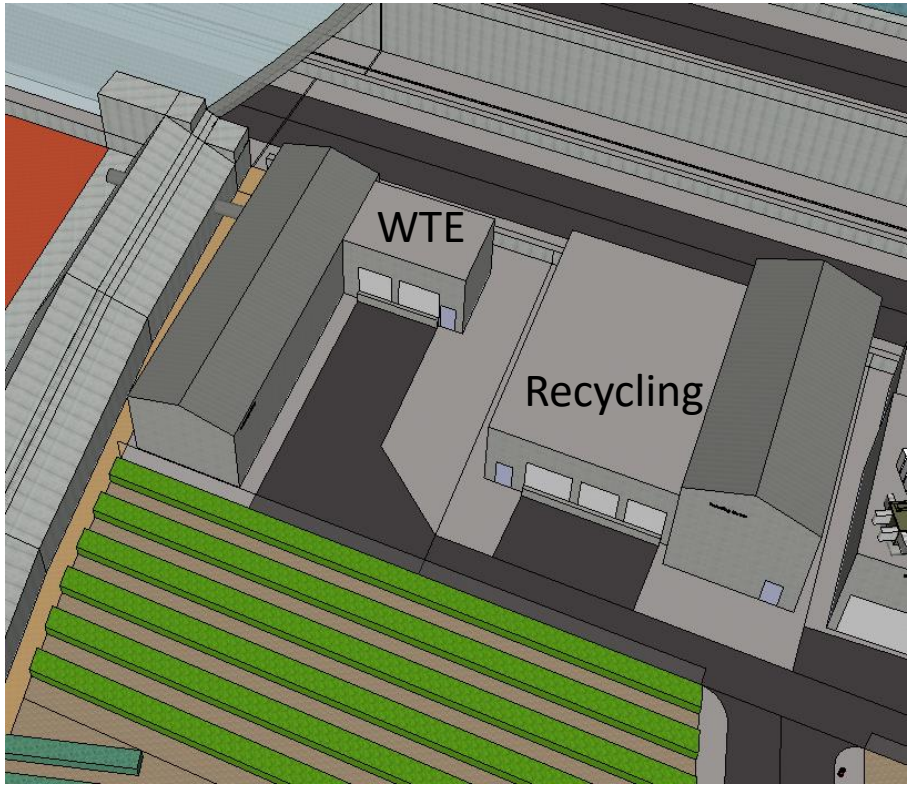
- Agriculture (Crops Only)
  - Possible Crop Types on Mars (Wamelink, 2014)
    - Tomatoes
    - Wheat
    - Carrots
    - Field Mustard
  - Some Oxygen Production
    - Until Harvest
  - No Herding of any animals
    - Easier to Import Refrigerated Meats than whole live cows, at least for now.



Sector 10

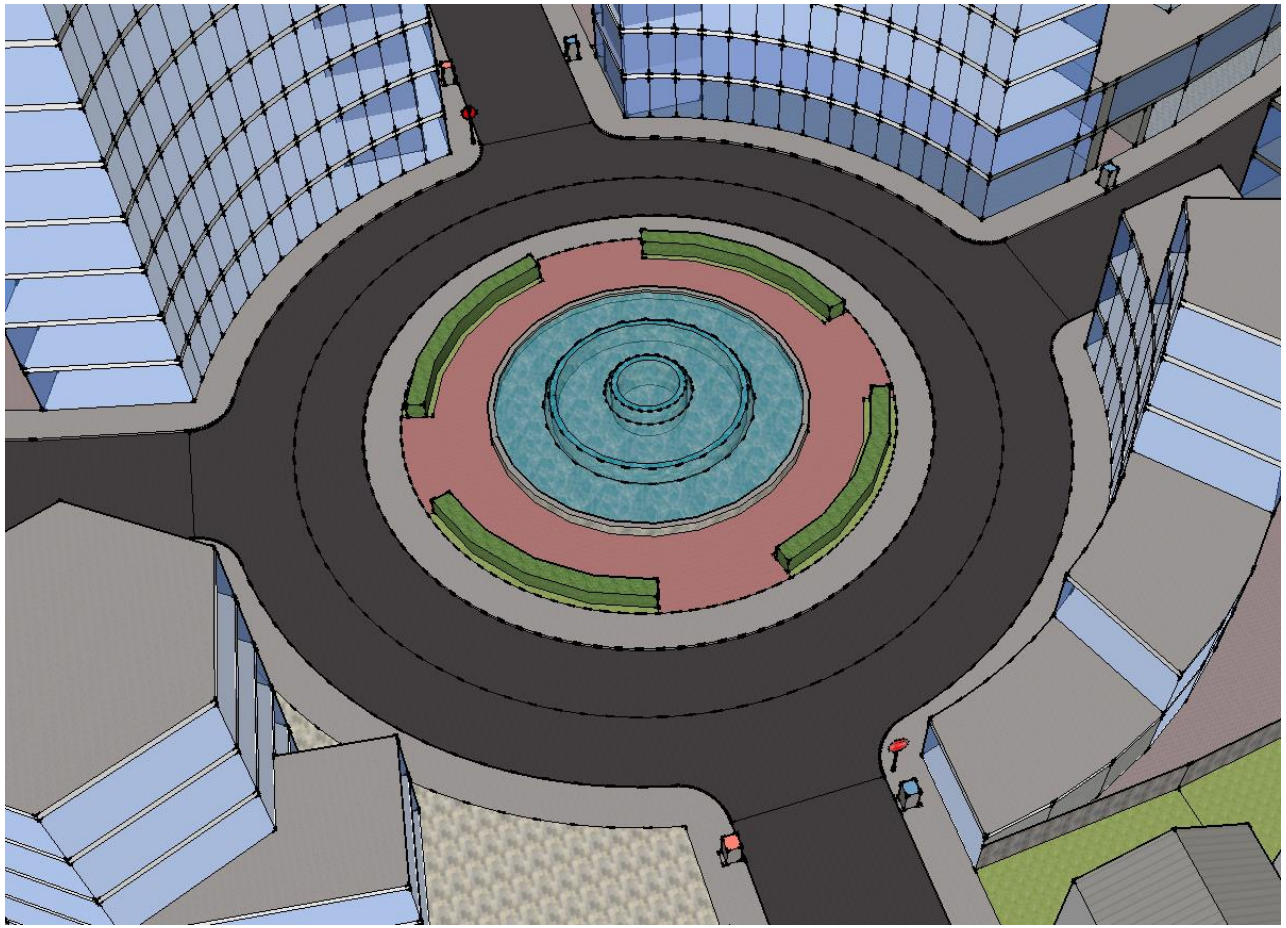


- Industrial Operations
  - Examples Include:
    - Sabatier Refinery (Methane Production)
    - Steel Mills
    - Thorium Processing
    - Silicon Chip Manufacturing
    - Food Processing (i.e. Wheat to Bread)
    - Cement Plant
    - Glass (Polyethylene) Factory
- Solid Waste Management
  - Placed under this section because the APA's Land Based Classification Standards (LBCS) Codes put waste management with industrial uses.
  - Includes:
    - 2 Recycling Plants
    - 2 Incineration Plants (Waste-to-Energy [WTE])



Sector 11

- Parks & Rec
  - Phase I
    - Plazas and small green spaces
  - Future Phases
    - Larger Green spaces that will offer more options & amenities
    - Could be used as Cemeteries
- Phase Size dictates the amount of green space
  - More Recreational Options



External Land Uses/Sectors

Sector 13

Bartz, Richard. 2008. Bavaria, Germany.

Sector 14

Unknown. 2005. Rugby VLF Transmitter, England.

- Sectors
  - 12: Launching Pads
  - 13: Antenna Fields (Receiving)
    - Communications FROM Earth
  - 14: Antenna Fields (Sending)
    - Communications TO Earth
    - Local Broadcasting (Radio, 5G, etc.)
  - 15: Power Generation Slot
    - Nuclear
      - CANDU Reactor Type
    - Solar
    - Wind
  - 16: Landing Zones
  - 17: Extraction/Mining Fields
    - Related to Elements in LSA

Sector 15

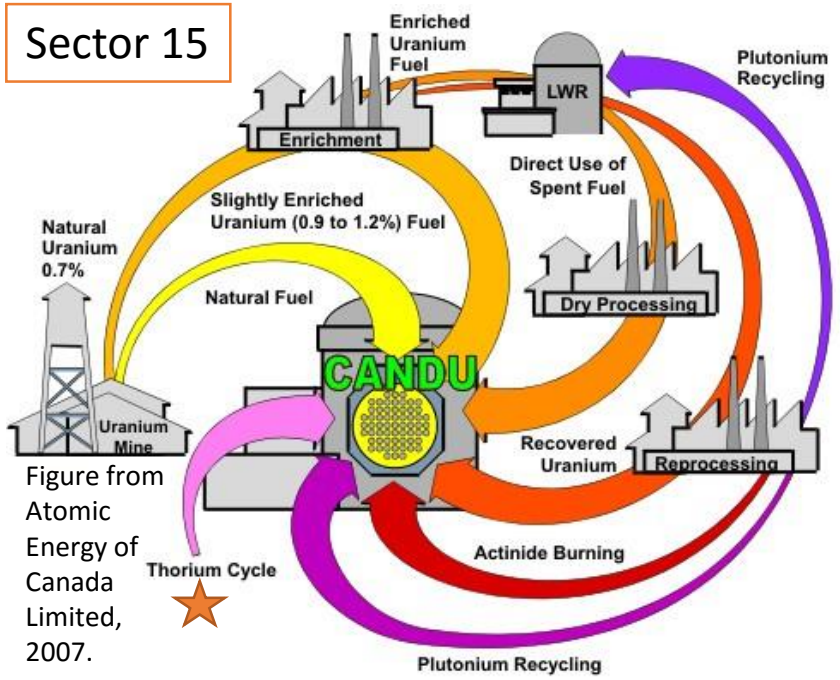


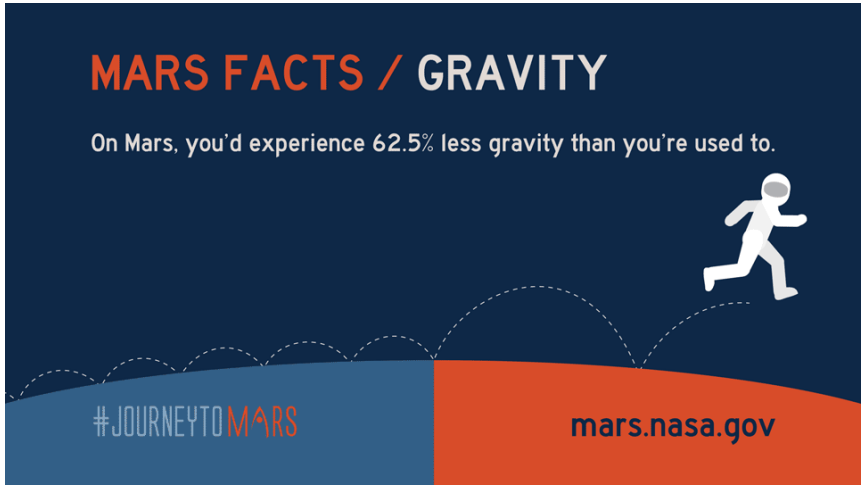
Figure from Atomic Energy of Canada Limited, 2007.

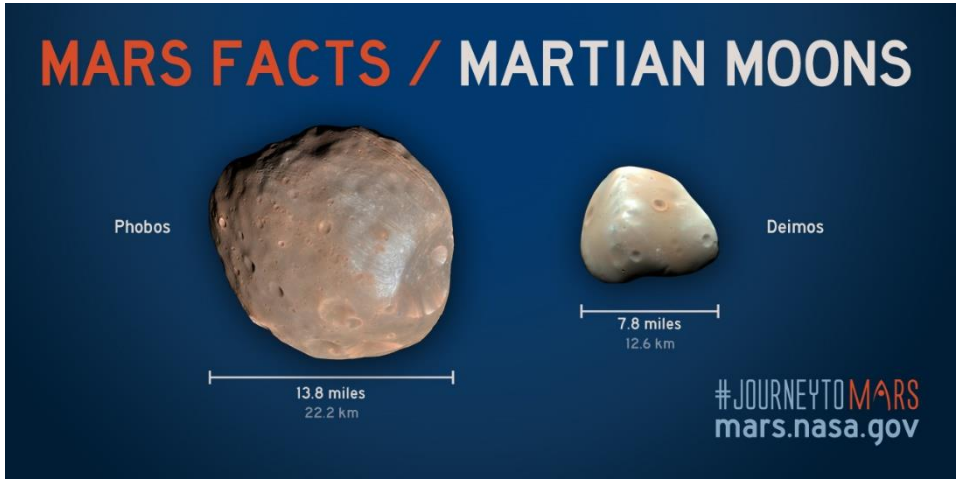
Sector 16

SpaceX. 22 December 2015. https://www.flickr.com/photos/spacex/23271687254/

Mars & Earth Comparison

- Conditions on Mars to lay the groundwork for the Land Suitability Analysis

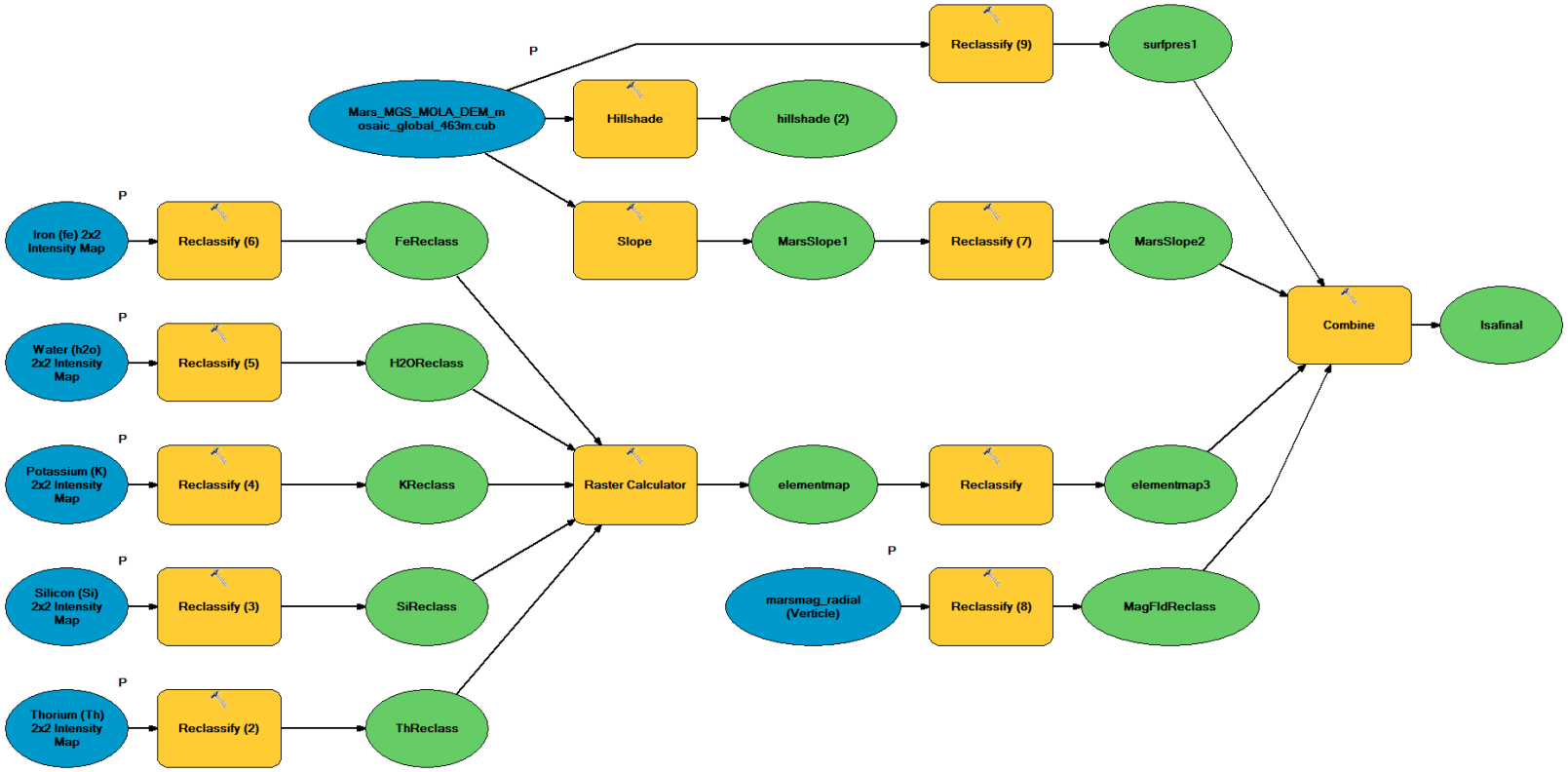




Category	Earth	Mars
Distance from Sun	93 Million Miles (1 AU)	142 Million Miles (1.5 AU)
Planet Diameter	7,926 Miles	4,220 Miles
Planet Tilt Angle	23.5 Degrees	25 Degrees
Planet Density	5.5 g/cm^3	3.9 g/cm^3
Length of Year	365.25 Days	687 Earth Days
Length of Day	24 Hours	24.4 Hours
Gravity	2.66 times Mars	0.375 of Earth
Weight (100 Lbs.)	100 Lbs.	38 Lbs.
Temperature (Range)	57 F (-126 F to 136 F)	-81 F (-284 F to 86 F)
Atmos. Pressure (Avg)	101.325 kPa (Sea Level)	0.60 kPa
Number of Moons	1	2
Atmosphere Composition	Nitrogen, Oxygen, Argon, & Others	Mostly Carbon Dioxide & Some water vapor
Source:	**mars.nasa.gov/allaboutmars/facts/**	

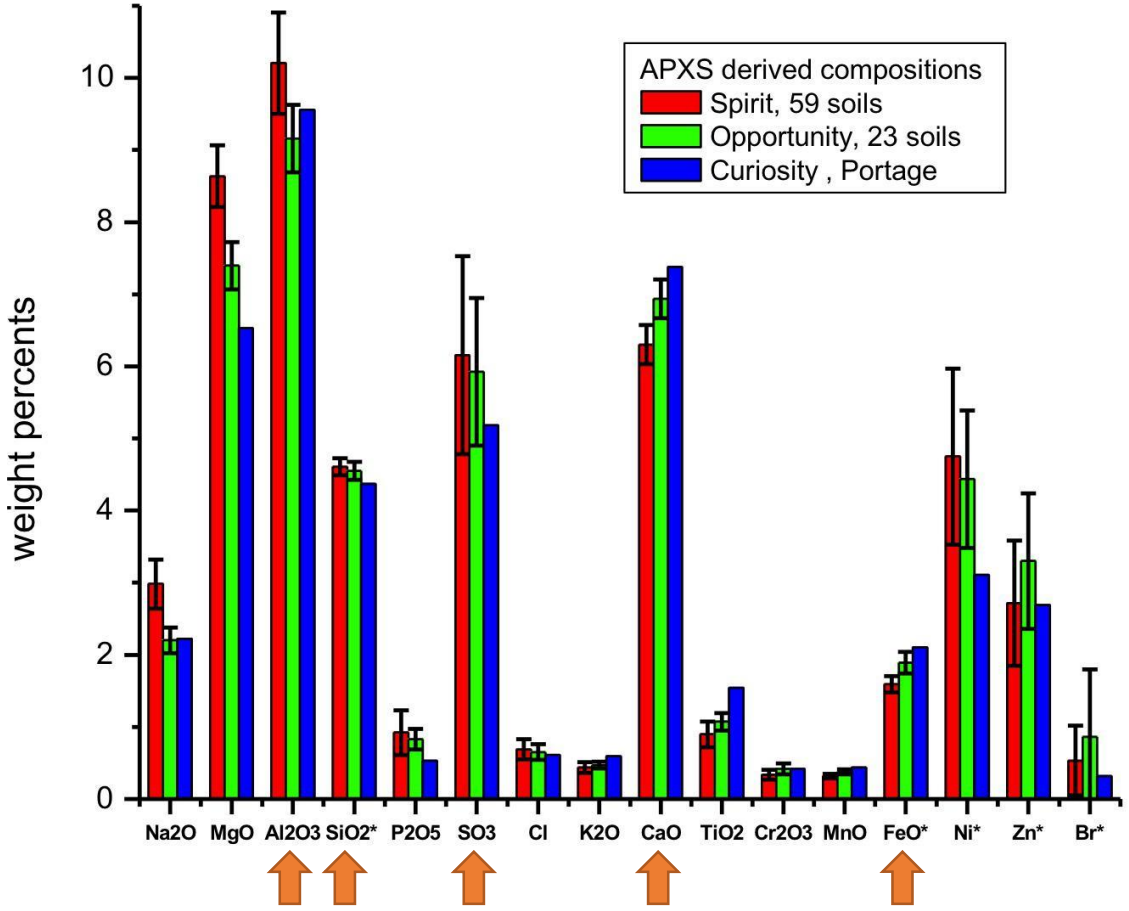
Land Suitability Analysis (LSA)

- "LSA aims at identifying the most appropriate spatial pattern for future land uses according to specified requirements, preferences, or predictors of some activity" (Malczewski, 2004).
- Created within ArcGIS 10.3.1
  - Raster Calculator Weights
    - Water 50%
    - Iron 30%
    - Thorium 10%
    - Silicon 5%
    - Potassium 5%
- LSA only uses Integers, not Float Numbers (Decimals)
  - Reclassify Tool



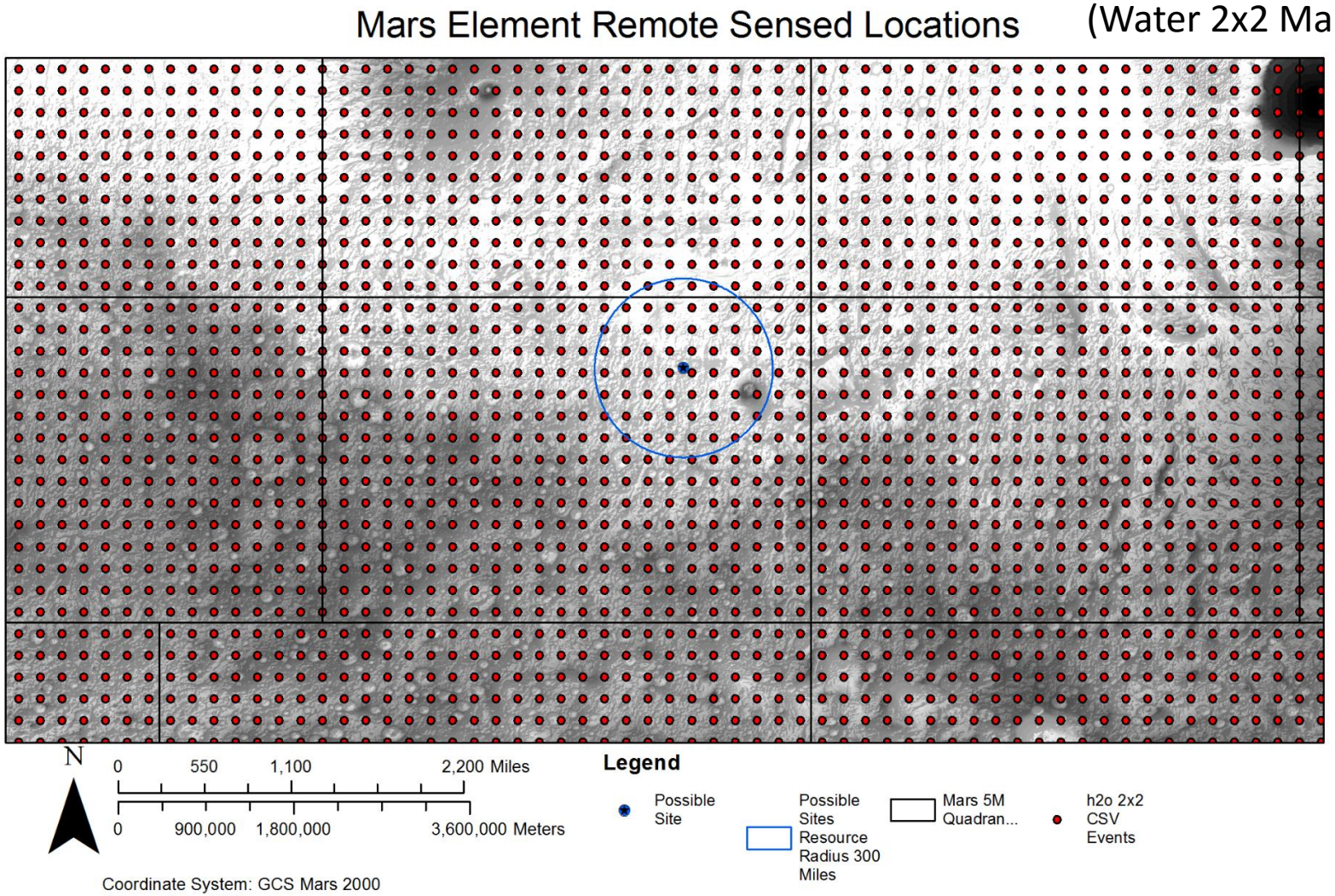
Importance of Elements Mentioned in LSA

- Frozen Water Deposits
  - Drinking, Industrial processes, etc.
  - (Electrolysis) Hydrogen for making Polyethylene (C_2H_4) Radiation Shielding used on the Dome
- Iron Ore Reserves
  - Construction Purposes, Piping, etc.
- Silicon & Associated Dusts Not in LSA
  - Portland Cement (CaO, SiO_2, Al_2O_3, Fe_2O_3, and Sulfate [SO_4^{2-}])
  - Glass, Gypsum, etc.
- Thorium Ores
  - Processed into usable Nuclear Fuel Rods
- (Extra) Atmospheric Carbon Dioxide
  - Convert to Oxygen and Methane Fuel via Sabatier Reactors

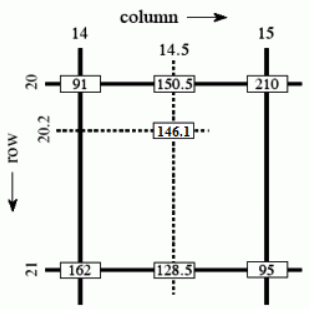


Source: NASA/JPL, 2012.

How the Element Maps were Generated

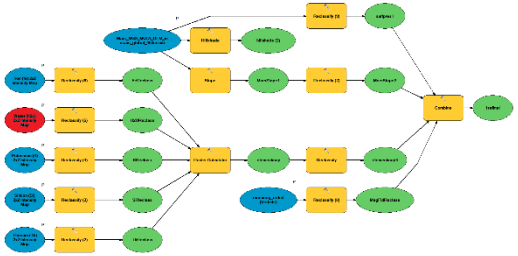


- Remote Sensing
  - Every Periodic Element reflects visible light (R,G,B) differently.
  - Satellite Orbiting Mars
    - 2001 Mars Odyssey
    - Tool: Gamma Ray Spectrometer (GRS)
- 2x2 Dot Maps
  - Each Dot had a Z value
    - Concentration Value
- ArcGIS
  - Bilinear Interpolation was used on each dot to create Element Maps



Kostelyk, Jayson. 2011. Grayscale B.I. Example

Mars Water (H2O) Concentrations Map



Mare Boreum
Mare Boreum
Ismenius Lacus
Casius
Cebrenia
Diacria
Arcadia
Mare Acidalium
Arabia
Syrtis Major
Amenthes
Elysium
Amazonis
Tharsis
Lunae Palus
Oxia Palus
Sinus Sabaeus
Iapygia
Mare Tyrrhenum
Aeolis
Memnonia
Phoenicis Lacus
Coprates
Margaritifer Sinus
Noachis
Hellas
Eridania
Phaethontis
Thaumasia
Argyre
Mare Australe
Mare Australe

N

0 2,150 4,300 8,600 Miles

0 3,200,000 6,400,000 12,800,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

Mars 5M Quadrangles

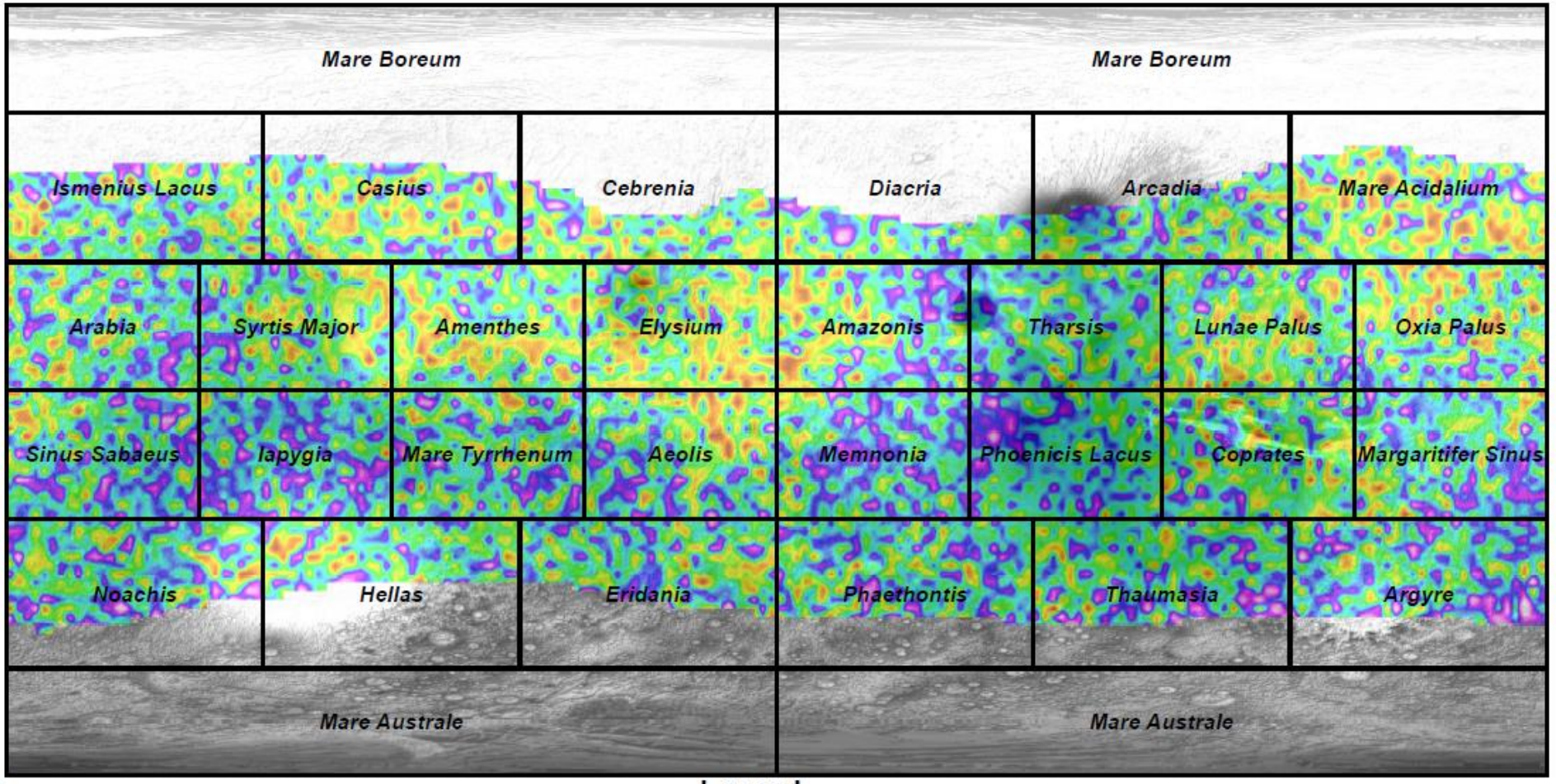
Water (h2o) 2x2 Intensity Map

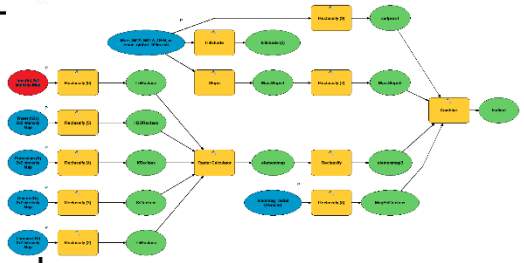
-2.64 - -1.64	2.23 - 2.62	5.3 - 5.73	10.2 - 11.1
-1.63 - -0.862	2.63 - 3	5.74 - 6.19	11.2 - 12.3
-0.861 - -0.22	3.01 - 3.36	6.2 - 6.66	12.4 - 14.3
-0.219 - 0.348	3.37 - 3.71	6.67 - 7.19	14.4 - 18.1
0.349 - 0.886	3.72 - 4.08	7.2 - 7.79	18.2 - 27.3
0.887 - 1.37	4.09 - 4.45	7.8 - 8.48	
1.38 - 1.79	4.46 - 4.86	8.49 - 9.27	
1.8 - 2.22	4.87 - 5.29	9.28 - 10.1	

Soil Weight %

-10.8 - -6.59
-6.58 - -4.08
-4.07 - -2.65

Mars Iron (Fe) Concentrations Map





N

0 2,150 4,300 8,600 Miles

0 3,200,000 6,400,000 12,800,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

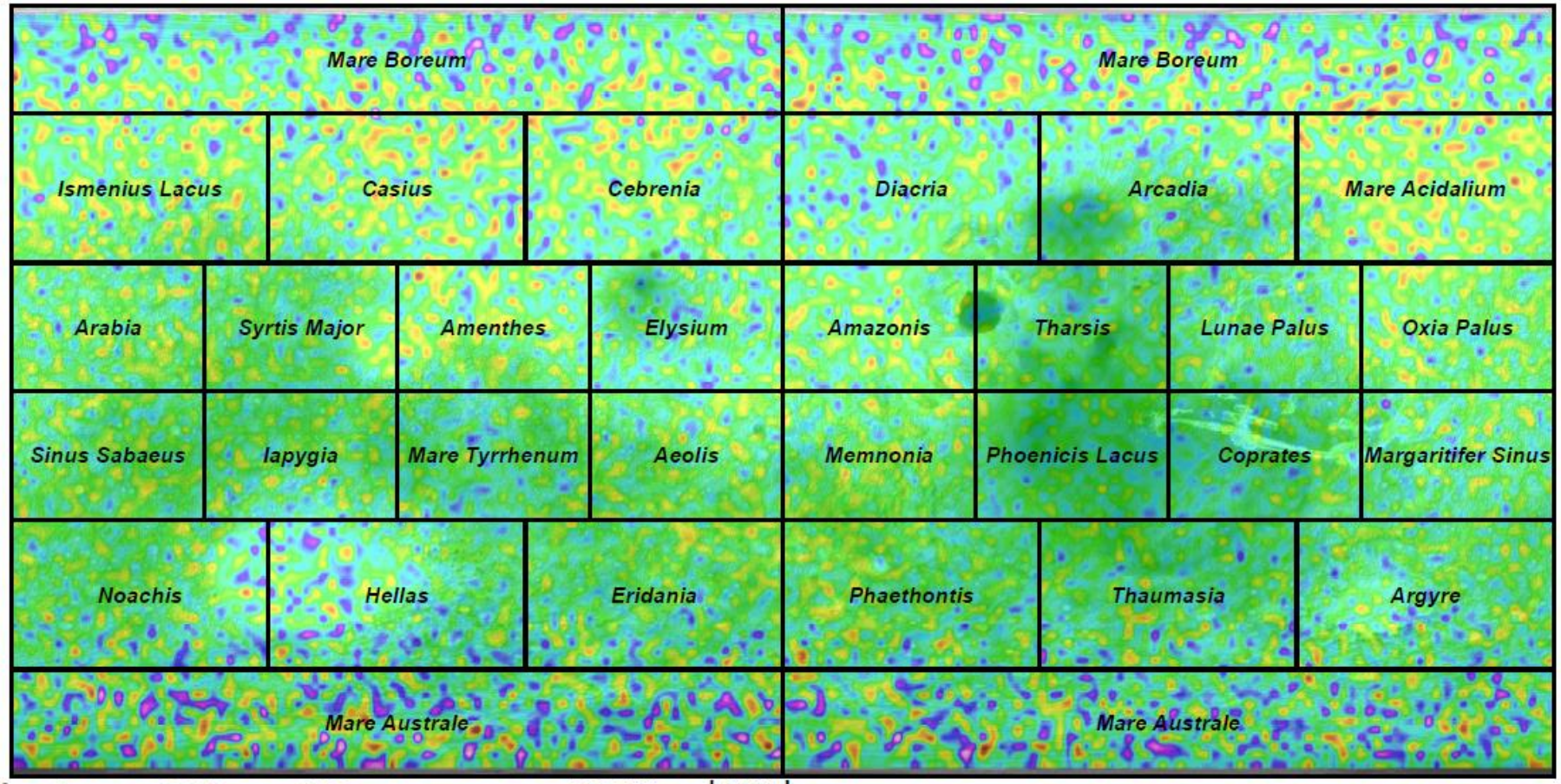
Mars 5M Quadrangles

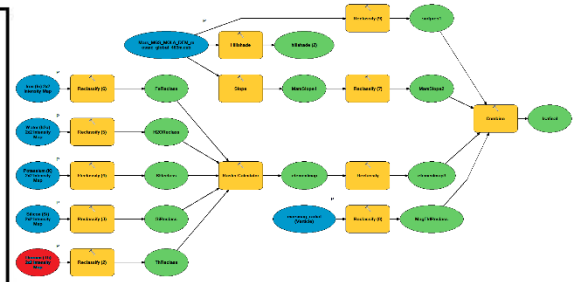
Iron (fe) 2x2 Intensity Map

Soil Weight (%)

- -9.35 - -1.98
- -1.97 - 1.46
- 1.47 - 3.39
- 3.4 - 4.82
- 4.83 - 6.01
- 6.02 - 7.03
- 7.04 - 7.94
- 7.95 - 8.8
- 8.81 - 9.67
- 9.68 - 10.5
- 10.6 - 11.3
- 11.4 - 12
- 12.1 - 12.7
- 12.8 - 13.4
- 13.5 - 14
- 14.1 - 14.6
- 14.7 - 15.3
- 15.4 - 16
- 16.1 - 16.7
- 16.8 - 17.4
- 17.5 - 18.2
- 18.3 - 18.9
- 19 - 19.8
- 19.9 - 20.7
- 20.8 - 21.8
- 21.9 - 22.9
- 23 - 24.2
- 24.3 - 25.8
- 25.9 - 28
- 28.1 - 31.2
- 31.3 - 44.5
- 44.6 - 50

Mars Thorium (Th) Concentrations Map





N

0 2,150 4,300 8,600 Miles

0 3,200,000 6,400,000 12,800,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

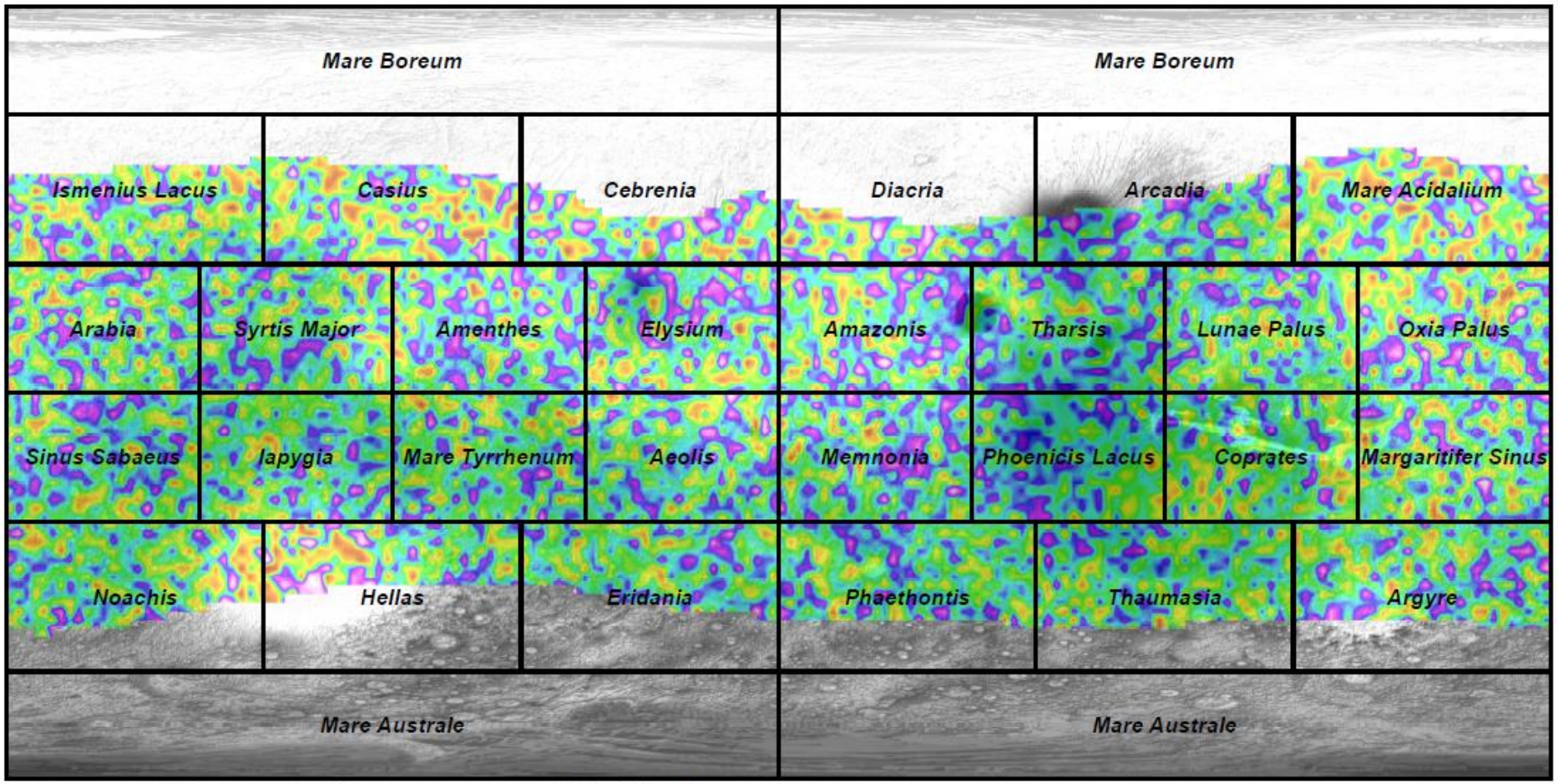
Mars 5M Quadrangles

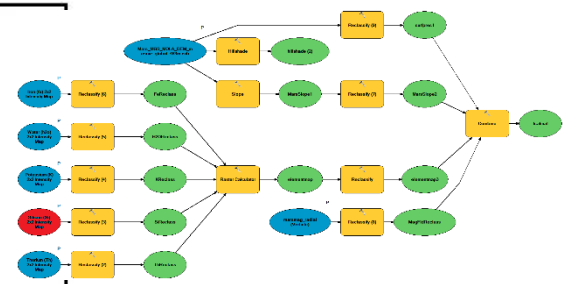
Thorium (Th) 2x2 Intensity Map

Parts Per Million (ppm)

-0.000361 - - 0.000305	-0.000181 - - 0.00016	-0.00003 - - 0.000012	0.000115 - 0.000133	0.000267 - 0.000287
-0.000304 - - 0.000253	-0.000159 - - 0.000142	-0.000011 - 0.000006	0.000134 - 0.000151	0.000288 - 0.000318
-0.000252 - - 0.000207	-0.000141 - - 0.000123	0.000007 - 0.000025	0.000152 - 0.00017	0.000319 - 0.000352
-0.000206 - - 0.000182	-0.000122 - - 0.000105	0.000026 - 0.00004	0.000171 - 0.000188	0.000353 - 0.000426
	-0.000104 - - 0.000086	0.000041 - 0.000059	0.000189 - 0.000207	
	-0.000085 - - 0.000068	0.00006 - 0.000077	0.000208 - 0.000225	
	-0.000067 - - 0.000049	0.000078 - 0.000096	0.000226 - 0.000244	
	-0.000048 - - 0.000031	0.000097 - 0.000114	0.000245 - 0.000266	

Mars Silicon (Si) Concentrations Map





N

0 2,150 4,300 8,600 Miles

0 3,200,000 6,400,000 12,800,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

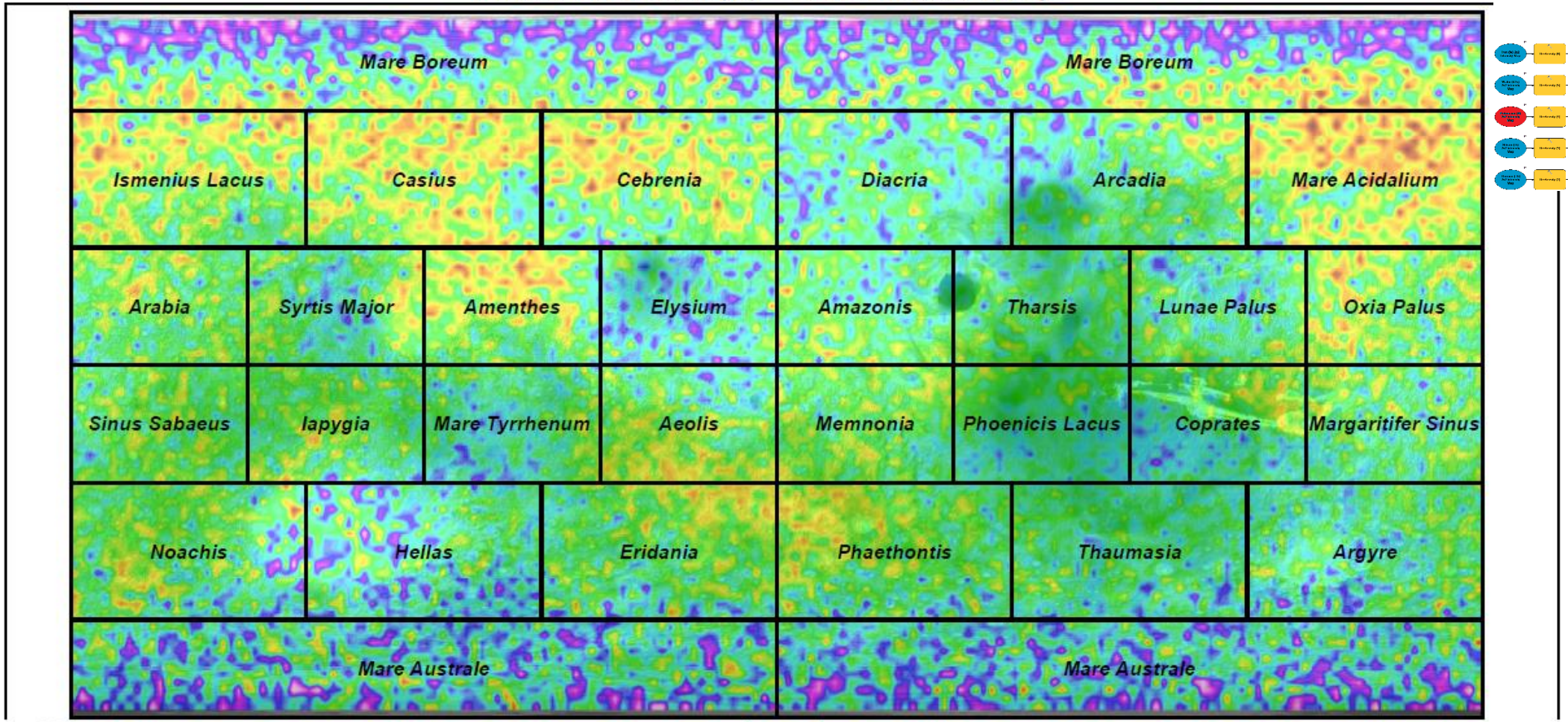
Mars 5M Quadrangles

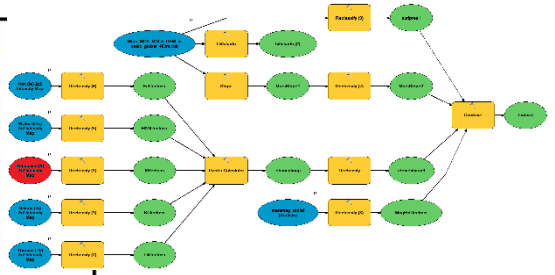
Silicon (Si) 2x2 Intensity Map

Soil Weight (%)

-5.16 - 1.05	5.67 - 8.43	17 - 17.6	22.2 - 22.8	29.8 - 31.2
1.06 - 5.66	8.44 - 10.4	17.7 - 18.3	22.9 - 23.7	31.3 - 33.3
	10.5 - 12	18.4 - 18.9	23.8 - 24.5	33.4 - 36.1
	12.1 - 13.2	19 - 19.5	24.6 - 25.4	36.2 - 41.4
	13.3 - 14.3	19.6 - 20.1	25.5 - 26.3	41.5 - 48.9
	14.4 - 15.3	20.2 - 20.7	26.4 - 27.3	49 - 50
	15.4 - 16.2	20.8 - 21.4	27.4 - 28.4	
	16.3 - 16.9	21.5 - 22.1	28.5 - 29.7	

Mars Potassium (K) Concentrations Map





N

0 2,150 4,300 8,600 Miles

0 3,200,000 6,400,000 12,800,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

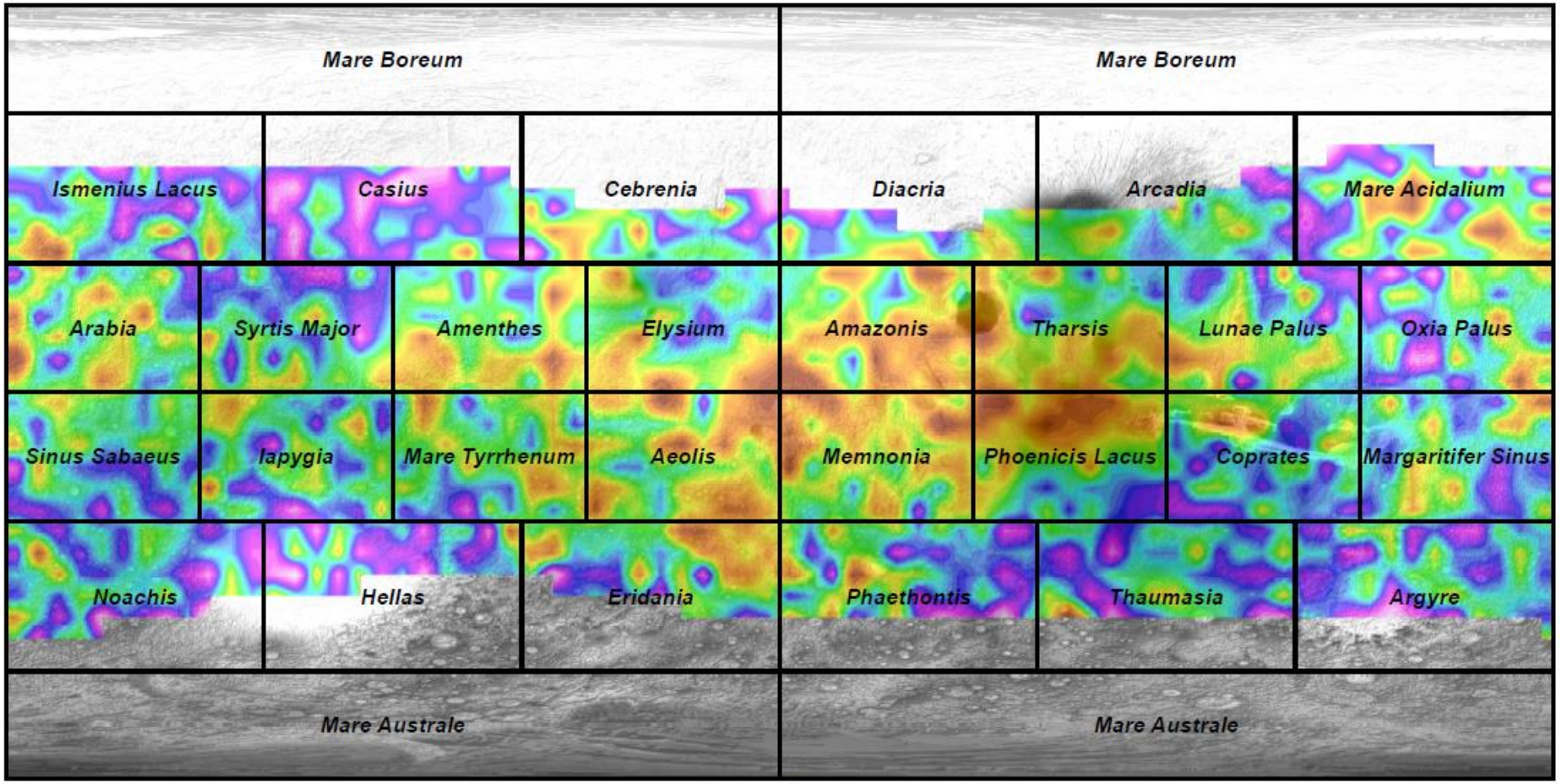
Mars 5M Quadrangles

Potassium (K) 2x2 Intensity Map

Soil Weight (%)

-0.399 - -0.312	-0.137 - -0.088	0.122 - 0.149	0.335 - 0.361	0.567 - 0.599
-0.311 - -0.208	-0.0879 - -0.047	0.15 - 0.176	0.362 - 0.388	0.6 - 0.633
-0.207 - -0.138	-0.0469 - -0.01	0.177 - 0.203	0.389 - 0.415	0.634 - 0.678
	-0.0099 - 0.026	0.204 - 0.229	0.416 - 0.443	0.679 - 0.736
	0.0261 - 0.06	0.23 - 0.255	0.444 - 0.472	0.737 - 0.823
	0.0601 - 0.091	0.256 - 0.28	0.473 - 0.501	0.824 - 0.985
	0.0911 - 0.121	0.281 - 0.306	0.502 - 0.533	
		0.307 - 0.334	0.534 - 0.566	

Mars Chlorine (Cl) Concentrations Map



N

0 2,150 4,300 8,600 Miles

0 3,200,000 6,400,000 12,800,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

PDS Note: "We do not calculate Chlorine data at a 2-degree latitude by 2-degree longitude bin side. This is because there are insufficient counts in a 2x2 bin size for the peak fitting to be statistically meaningful."

Legend

Mars 5M Quadrangles

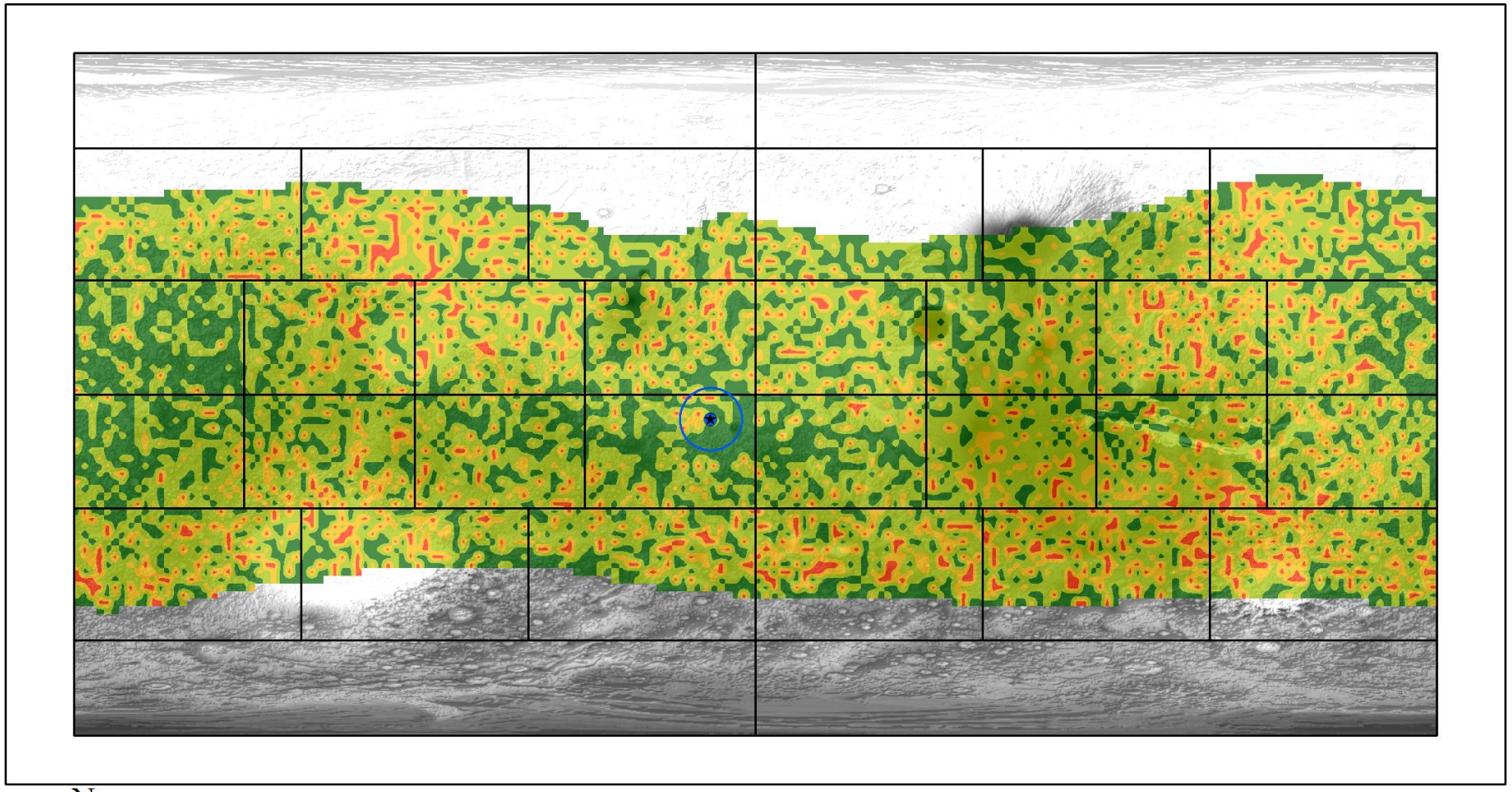
Chlorine (Cl) 5x5 Intensity Map

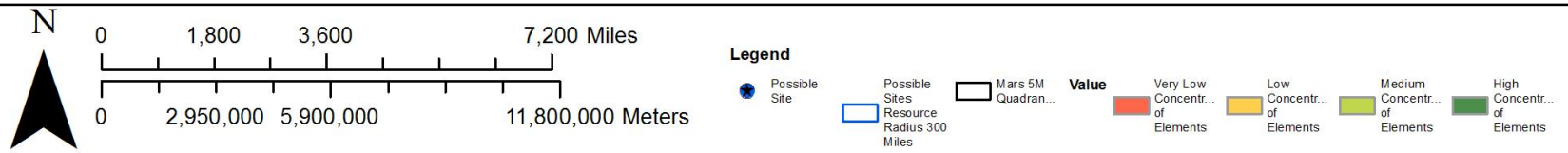
Soil Weight (%)

-0.263 - -0.246
-0.245 - 0.026
0.0261 - 0.104
0.105 - 0.156
0.157 - 0.202
0.203 - 0.243
0.244 - 0.276
0.277 - 0.305
0.306 - 0.332
0.333 - 0.355
0.356 - 0.378
0.379 - 0.4
0.401 - 0.421
0.422 - 0.439
0.44 - 0.457
0.458 - 0.476
0.477 - 0.495
0.496 - 0.516
0.517 - 0.537
0.538 - 0.557
0.558 - 0.578
0.579 - 0.598
0.599 - 0.617
0.618 - 0.636
0.637 - 0.661
0.662 - 0.692
0.693 - 0.726
0.727 - 0.761
0.762 - 0.8
0.801 - 0.857
0.858 - 1.04
1.05 - 5

- Left out of LSA
  - 5x5 distorted the Final 2x2 Elements Map
- Better for Manual LSA than ArcGIS Tool

Mars Weighted Elements Map

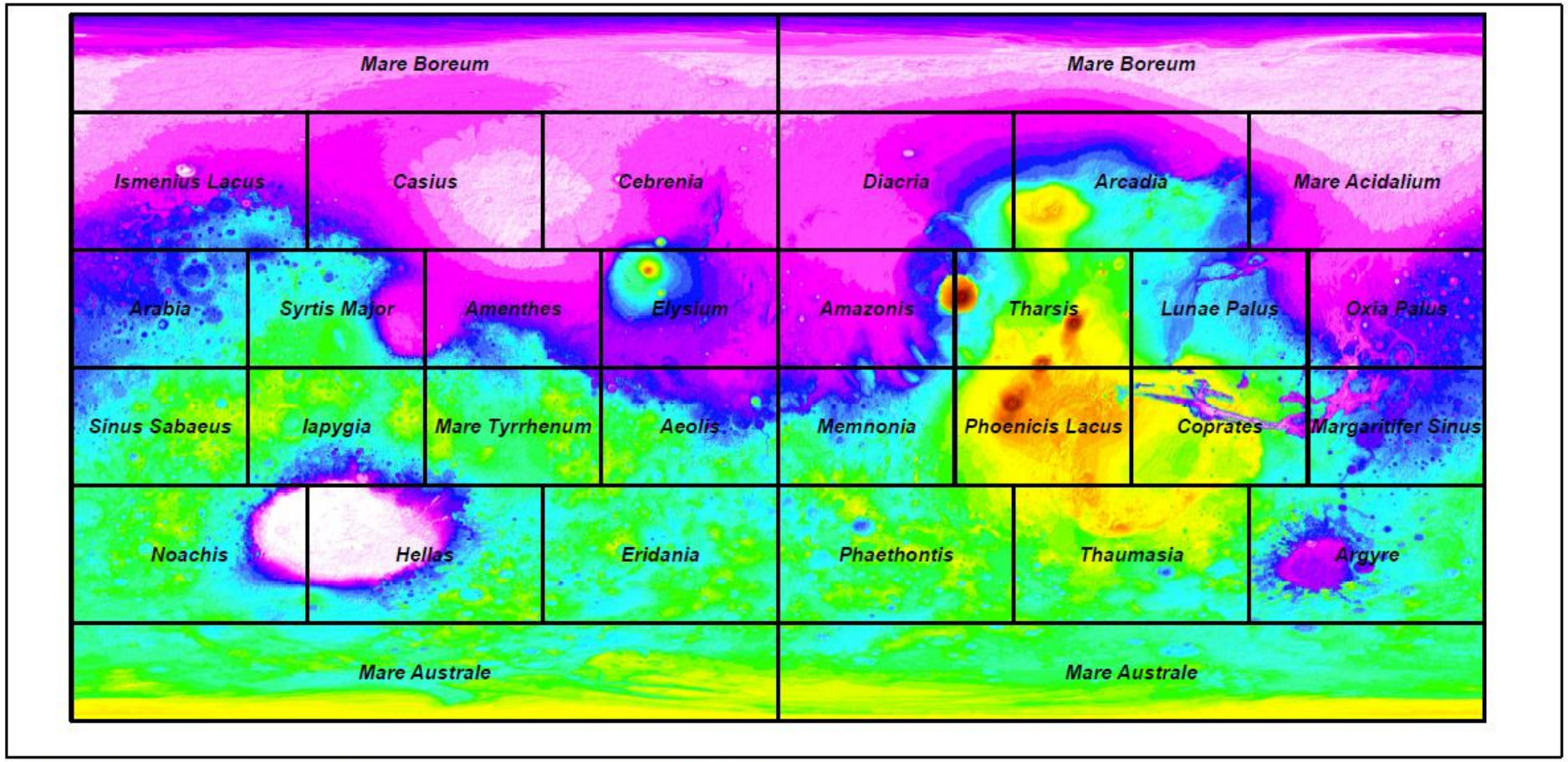


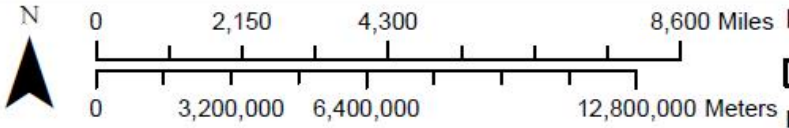


Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

- The Map is heavily influenced by Water
- High
  - All Elements Present with High Concentrations
- Medium
  - Elements Present with Moderate Concentrations
- Low
  - Elements Present with Medium/Low Concentrations
- Very Low
  - Elements Present with Low Concentrations

Mars DEM Map





Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

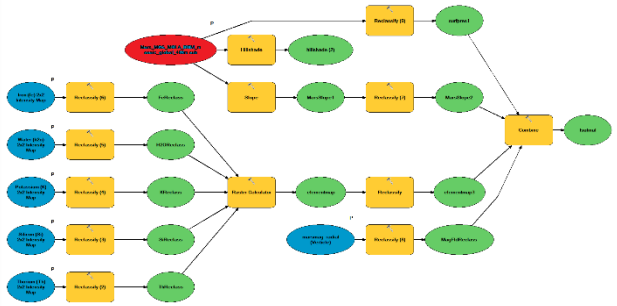
Legend

Mars 5M Quadrangles

Mars_USGS_D...

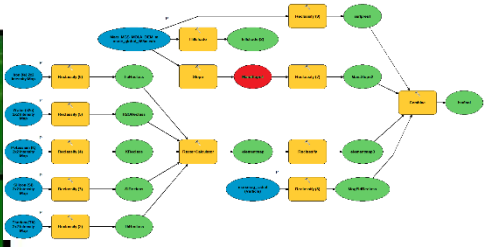
Meters

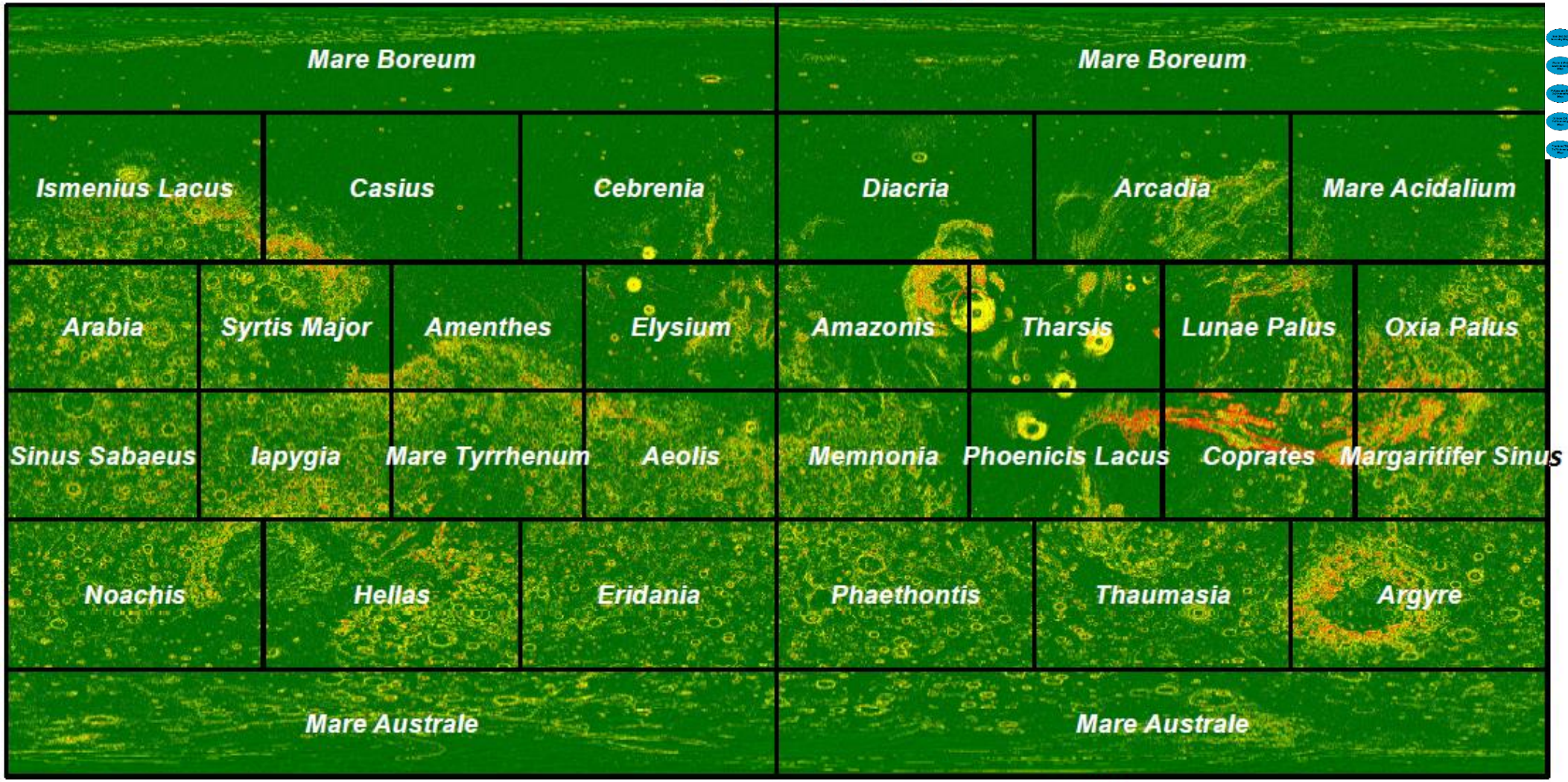
-8,201 - -6,376	-3,827.999999 - -3,378	28.00000001 - 469	3,067.000001 - 3,597	11,659.00001 - 14,541
-6,375.999999 - -5,468	-3,377.999999 - -2,881	469.0000001 - 854	3,597.000001 - 4,176	14,541.00001 - 17,670
-5,467.999999 - -4,682	-2,880.999999 - -2,379	854.0000001 - 1,197	4,176.000001 - 4,860	17,670.00001 - 21,241
-4,681.999999 - -4,239	-2,378.999999 - -1,901	1,197.000001 - 1,516	4,860.000001 - 5,666	
-4,238.999999 - -3,828	-1,900.999999 - -1,439	1,516.000001 - 1,840	5,666.000001 - 6,566	
	-1,438.999999 - -953	1,840.000001 - 2,195	6,566.000001 - 7,723	
	-952.9999999 - -456	2,195.000001 - 2,598	7,723.000001 - 9,393	
	-455.9999999 - 28	2,598.000001 - 3,067	9,393.000001 - 11,659	

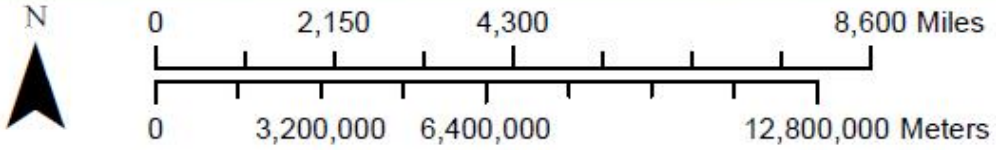


- DEM: Digital Elevation Model
- Created from the MOLA Tool on the Mars Global Surveyor (MGS) Satellite
- Retrieved from the USGS

Mars Slope Map (Unclassified Slope Map)







Legend

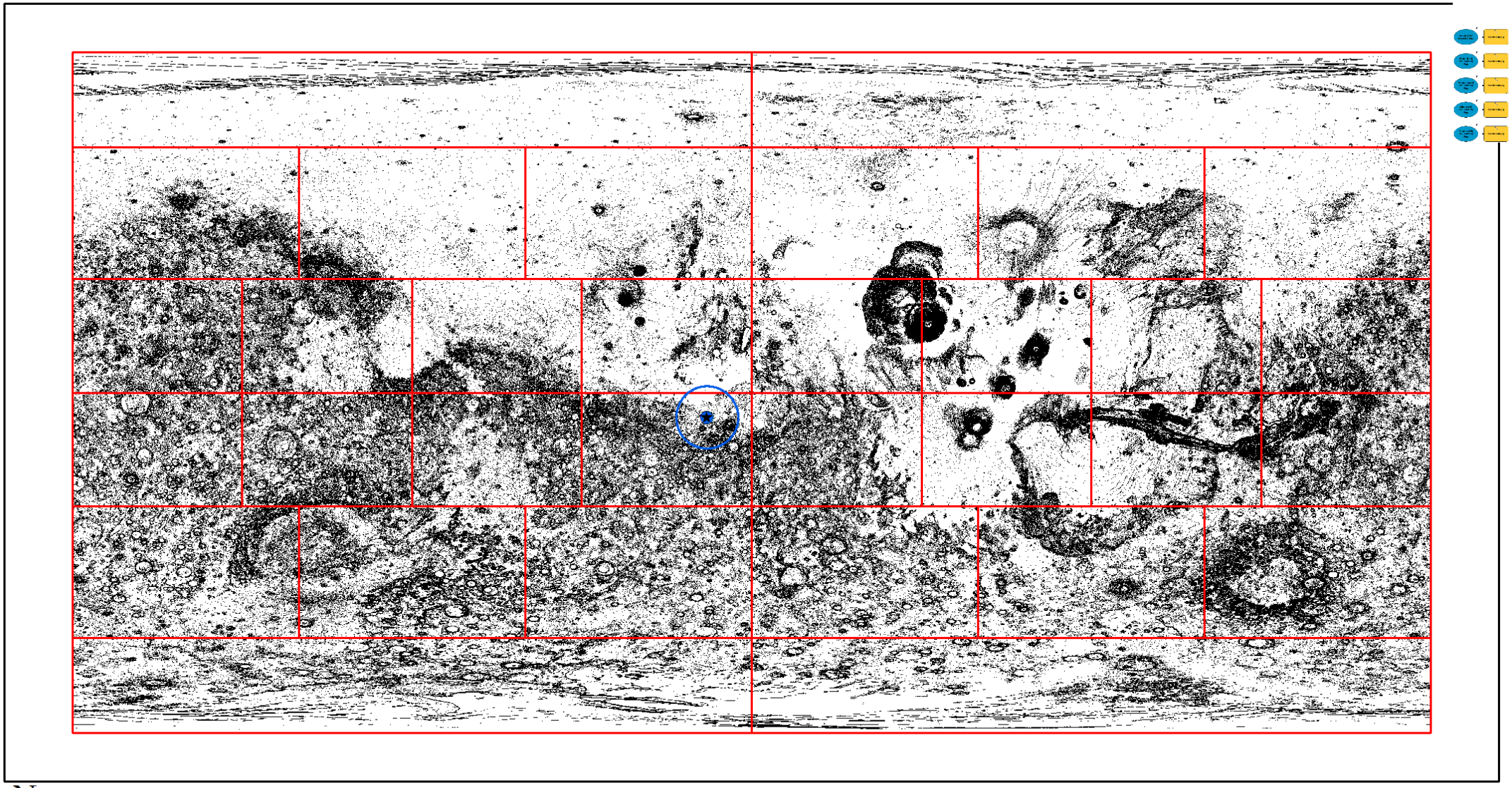
Mars 5M Quadrangles

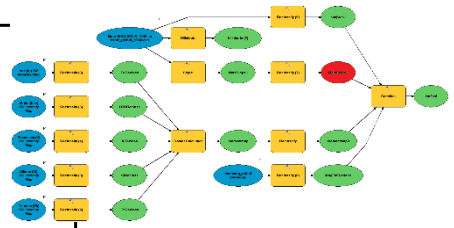
Mars Slope Map

Degrees

- 0 - 2.814774278
- 2.814774279 - 10.00808632
- 10.00808633 - 79.75193787

Mars Slope Map (Classified Slope)





- Green goes to White

N

0 1,800 3,600 7,200 Miles

0 2,950,000 5,900,000 11,800,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

Possible Site

Possible Sites Resource Radius 300 Miles

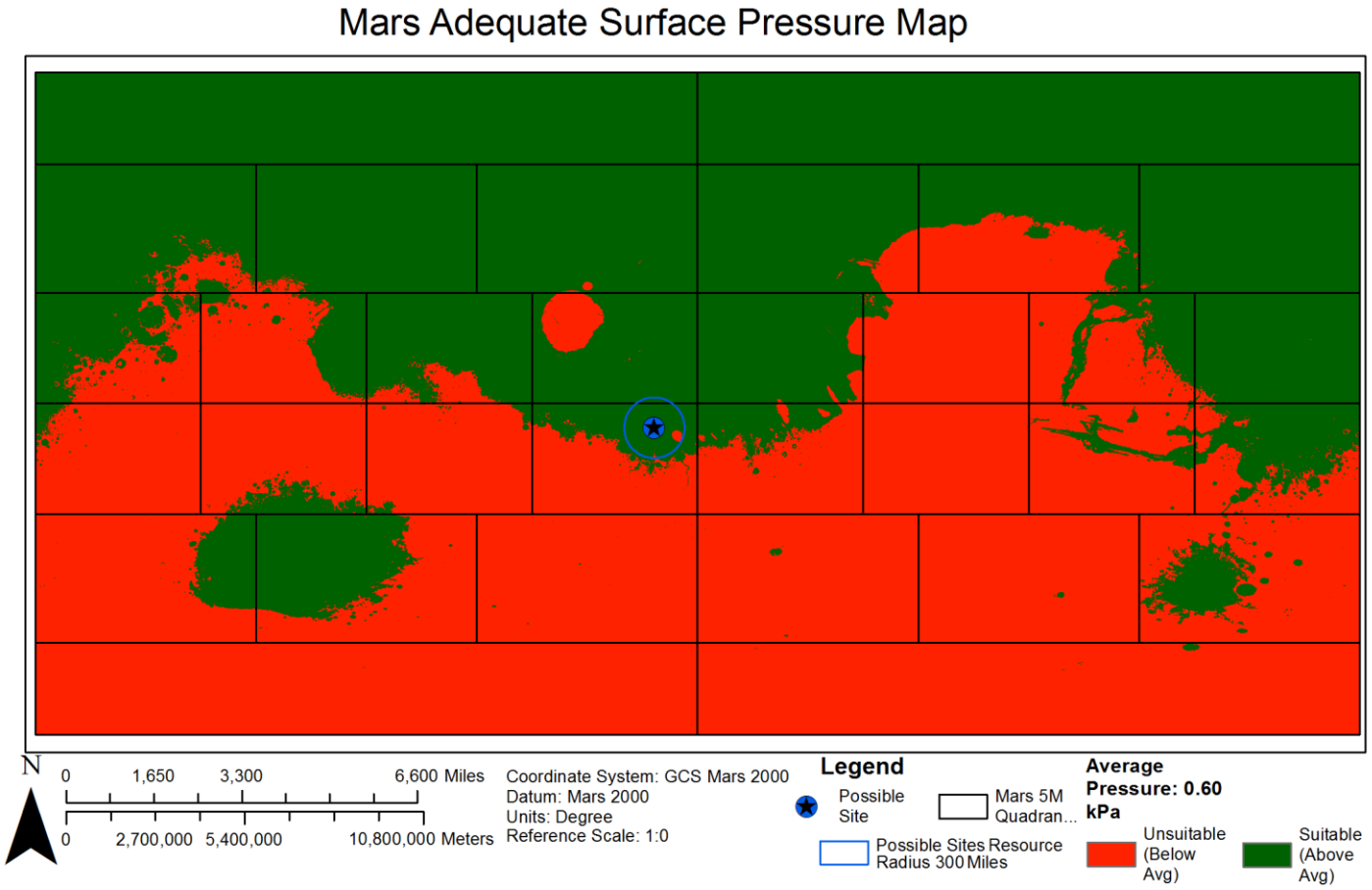
Mars 5M Quadran...

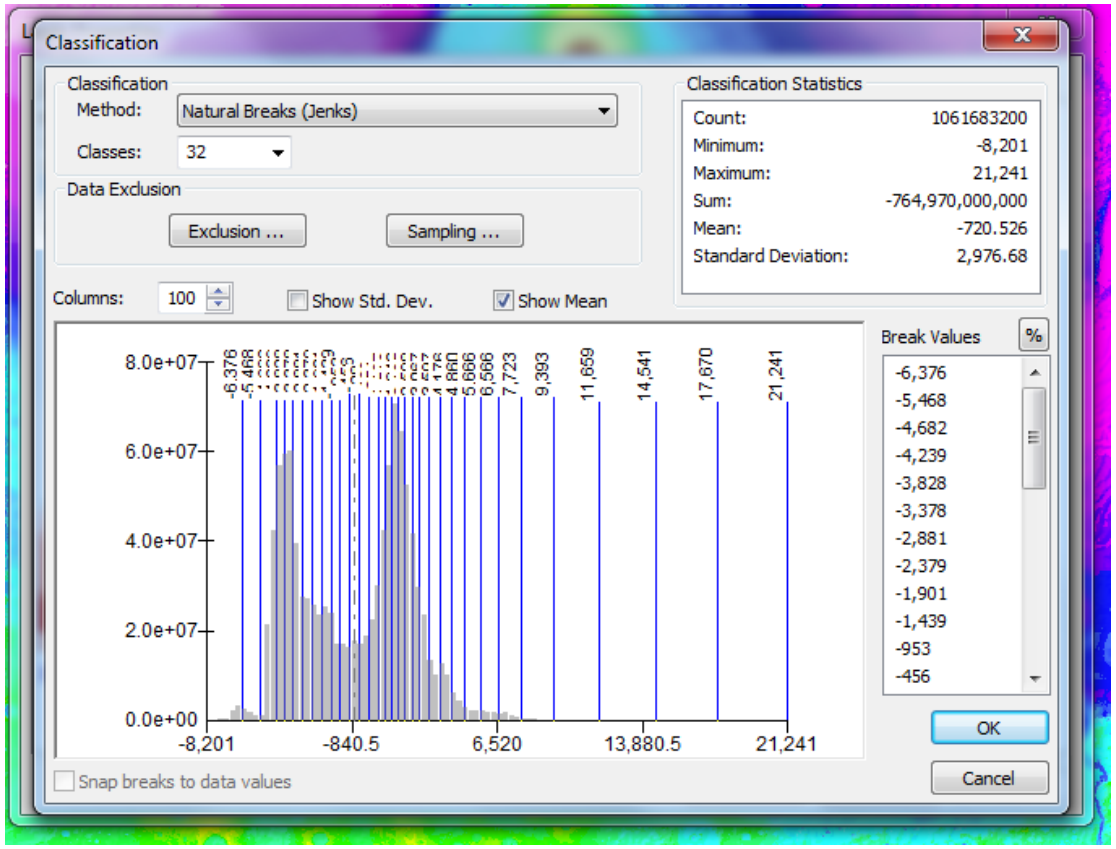
Degrees Slope

Unsuitable Sloped Land

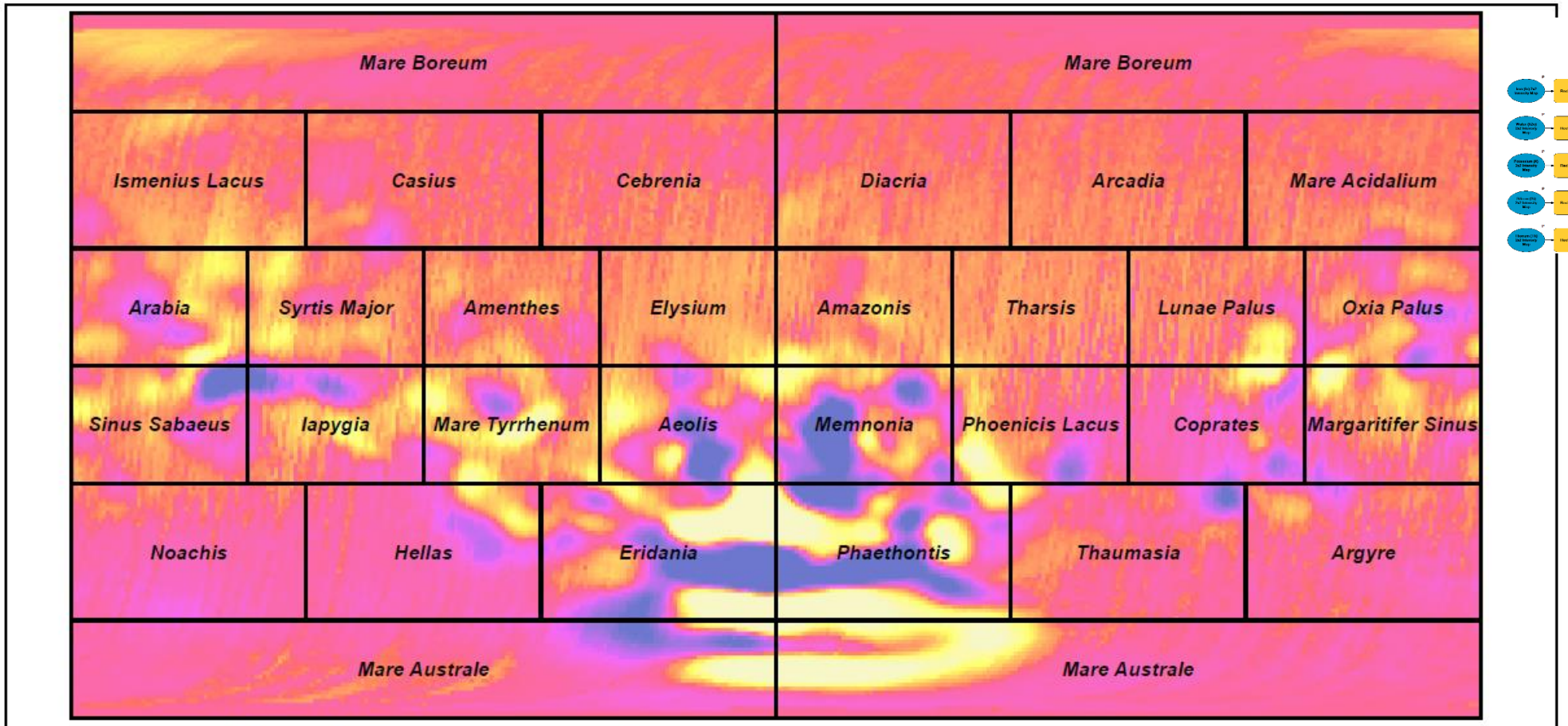
Suitable Smooth Land

Average Surface Pressure & Elevation Histogram





Mars Magnetic Field Map



N

0 2,150 4,300 8,600 Miles

0 3,200,000 6,400,000 12,800,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

Mars 5M Quadrangles

marsmag_radial (Verticle)

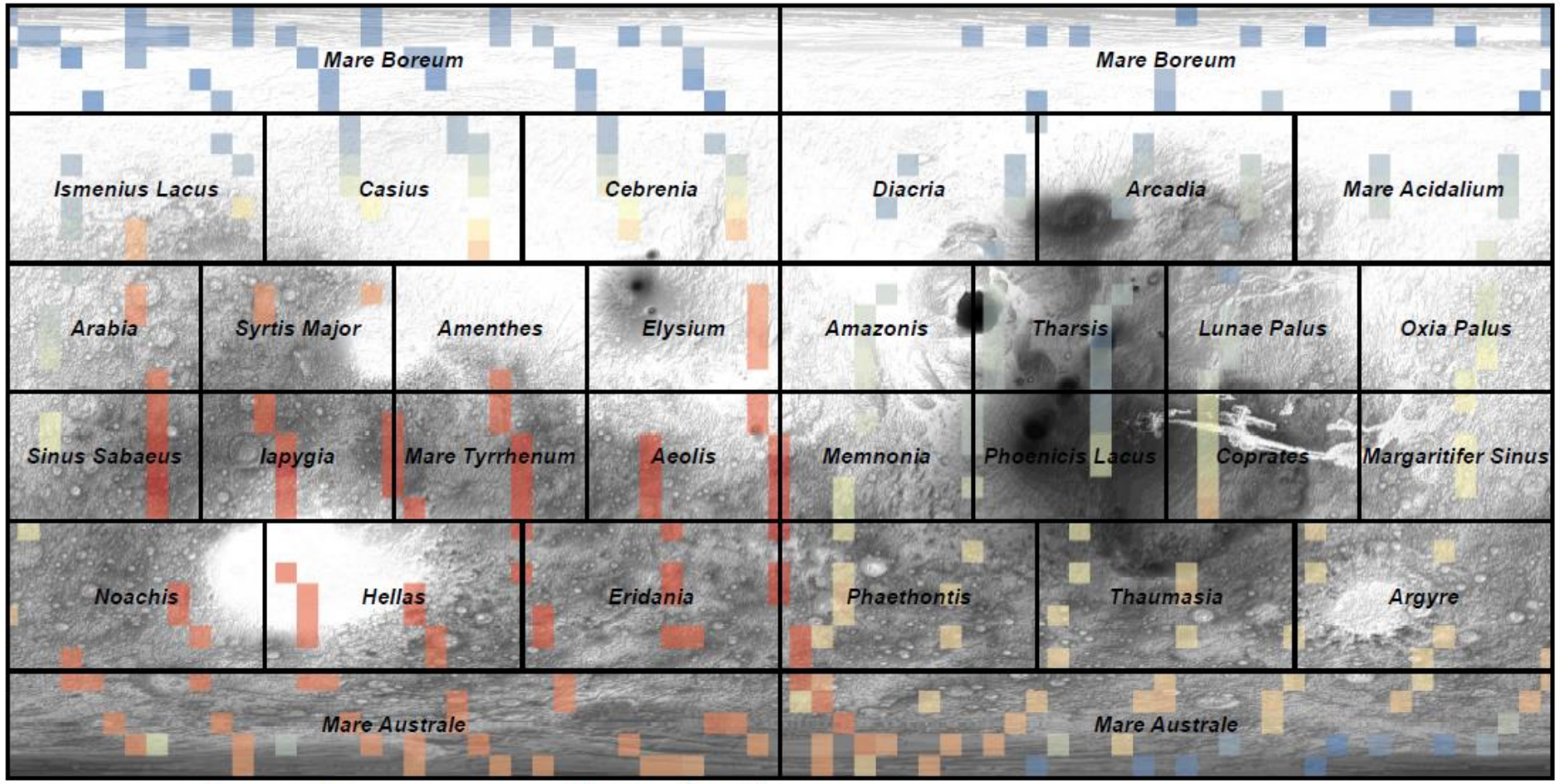
Nano-Teslas (nT)

High : 221.079

Low : -130.005

- Mars Highest Strength:
  - 211.079 nT
- Earth Lowest Strength:
  - 25,000 nT
- …And for that reason it was dropped from Mars LSA

Mars Northern Winter/Southern Summer (Daytime Western Hemisphere) Map



N

0 2,150 4,300 8,600 Miles

0 3,200,000 6,400,000 12,800,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

Mars 5M Quadrangles

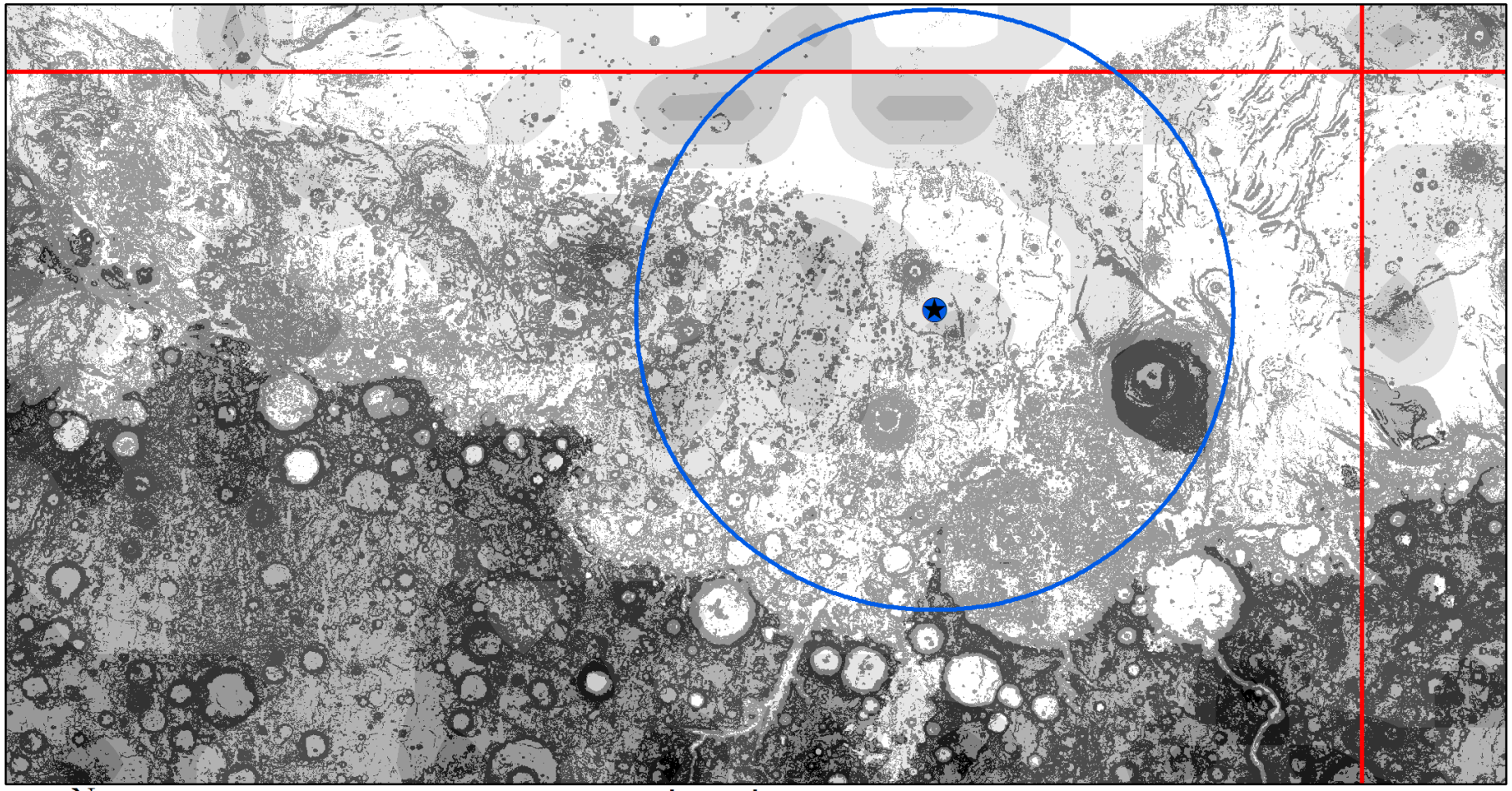
WestWinterDay

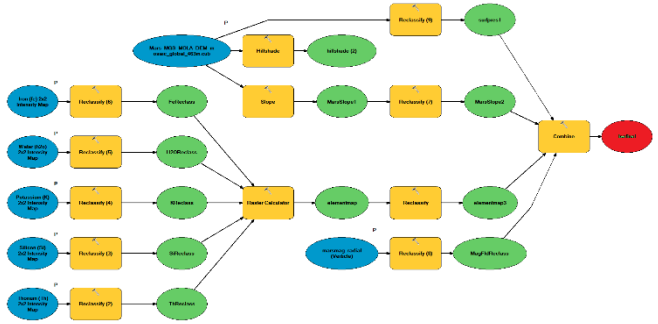
Temperature (Kelvin)

123.76 - 129.55	140.9 - 142.9	162.21 - 166.38	205.23 - 210.3	275.78 - 279.58
129.56 - 133.77	142.91 - 144.6	166.39 - 177.01	210.31 - 223.18	279.59 - 282.86
133.78 - 137.94	144.61 - 145.93	177.02 - 182.58	223.19 - 234.67	282.87 - 286.36
137.95 - 140.89	145.94 - 147.2	182.59 - 188.37	234.68 - 244.34	286.37 - 292.76
	147.21 - 149.4	188.38 - 193.93	244.35 - 252.69	
	149.41 - 152.28	193.94 - 198.49	252.7 - 262.01	
	152.29 - 156.78	198.5 - 202.2	262.02 - 270.25	
	156.79 - 162.2	202.21 - 205.22	270.26 - 275.77	

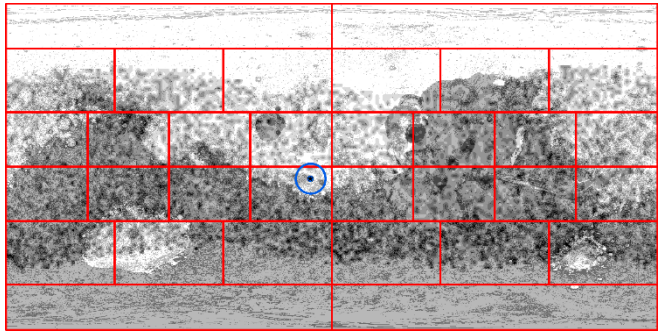
- Example Weather Map:
  - Winter Equinox
  - January 11, 2015
- Left out of LSA because it would distort final map since the data comes in strips/orbits
- Better for manual LSA, not ArcGIS tool

SiteOne: Suitability Map (Slope, Pressure, & Elements)





Mars Inset Map



N

0 190 380 760 Miles

0 312,500 625,000 1,250,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

- Possible Site
- Possible Sites Resource Radius 300 Miles
- Mars 5M Quadran...

Degrees Slope

- Unsuitable Sloped Land
- Suitable Smooth Land

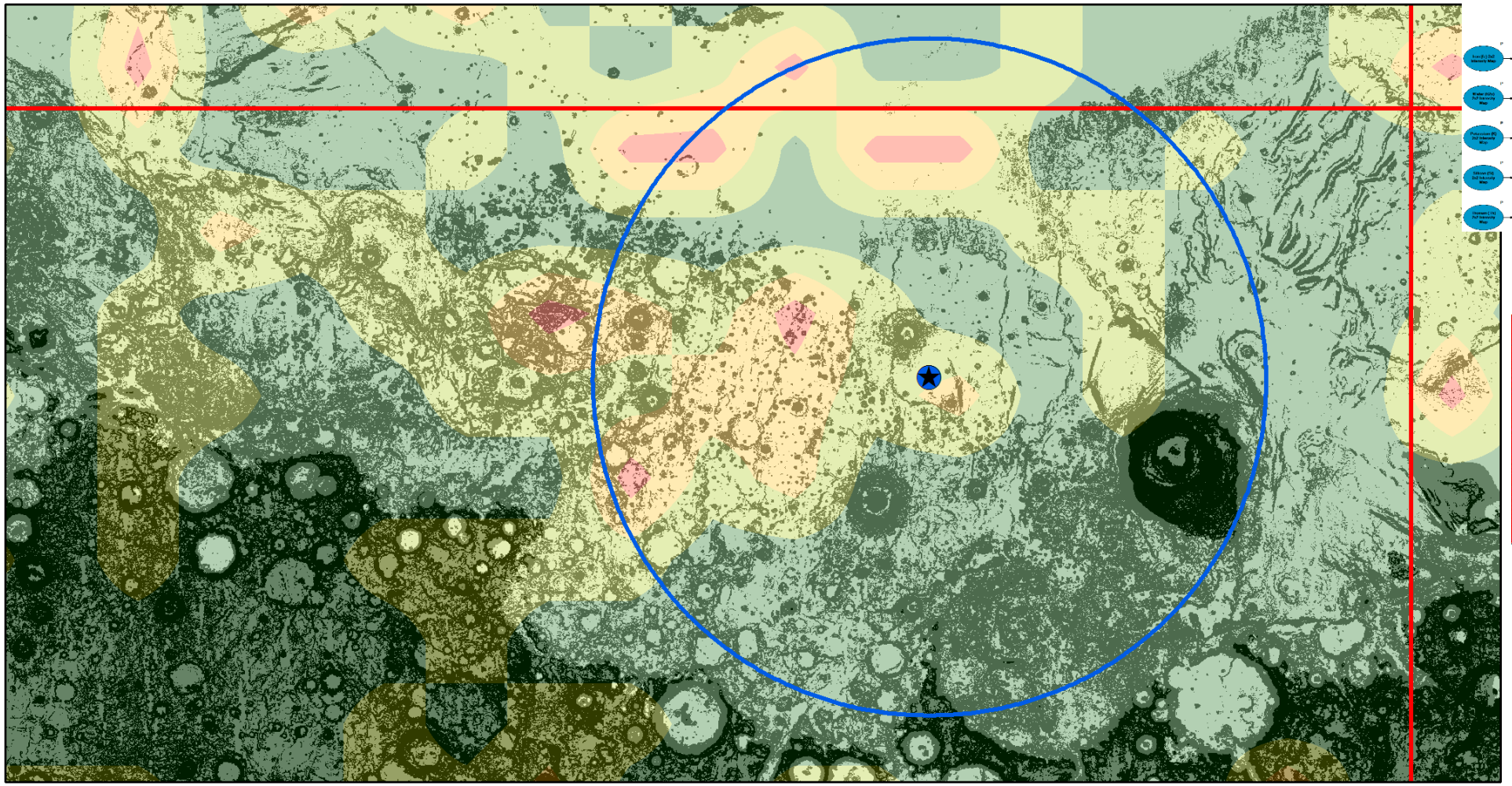
Value

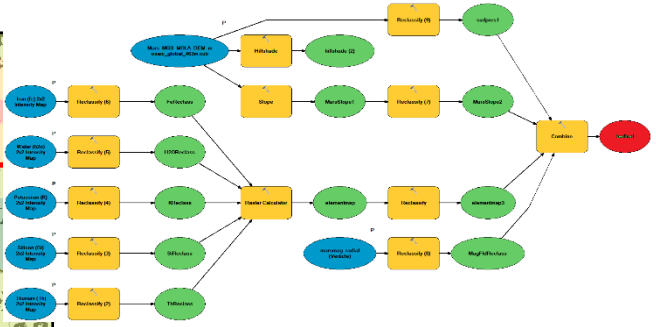
- Unsuitable (Below Avg)
- Suitable (Above Avg)

Value

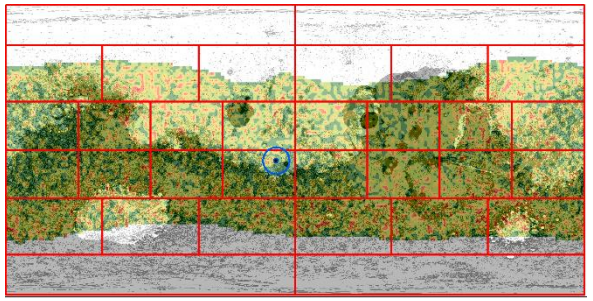
- Very Low Concentr... of Elements
- Low Concentr... of Elements
- Medium Concentr... of Elements
- High Concentr... of Elements

SiteOne: Suitability Map (Slope, Pressure, & Elements)





Mars Inset Map



N

0 170 340 680 Miles

0 275,000 550,000 1,100,000 Meters

Coordinate System: GCS Mars 2000
Datum: Mars 2000
Units: Degree
Reference Scale: 1:0

Legend

- Possible Site
- Possible Sites Resource Radius 300 Miles
- Mars 5M Quadran...

Degrees Slope

- Unsuitable Sloped Land
- Suitable Smooth Land

Average Pressure 0.60 kPa

- Unsuitable (Below Avg)
- Suitable (Above Avg)

Concentratio... of Elements

- Very Low Concentr... of Elements
- Low Concentr... of Elements
- Medium Concentr... of Elements
- High Concentr... of Elements

Simulations

Daily Uses per Person

Material Consumed	Amount Per Person Per Day	Sources:
Oxygen	0.9 kg (2 lbs)	Harding, 1989
Drinking Water	4.6 kg (10.1 lbs, 1.2 US Gal)	Rummel & Volk, 1987
Washing Water	18 kg (39.6 lbs, 4.75 US Gal)	Rummel & Volk, 1987
Food	2.5 kg (5.5 lbs)	James, Chamitoff, et al. 1998
Electricity	50 kW (*24 hours = 1200 kWh)	James, Chamitoff, et al. 1998
Material Produced	**Amount Per Person Per Day**	
Carbon Dioxide	1.1 kg (2.4 lbs)	Rummel & Volk, 1987
Waste Water	3.0 kg (6.6 lbs, 0.8 US Gal)	Rummel & Volk, 1987
Solid Waste (Trash)	0.2 kg (0.44 lbs)	James, Chamitoff, et al. 1998

Artificial Resource Capacities

Sector	Resource	Capacity (Units)	Source:
Sector 6	Water (Reservoirs)	156,112,439.83 Gal	AutoCAD Model
Sector 6	Sewer (Processing)	3.0 kg * Population	Rummel & Volk, 1987
Sector 9	Food (Farm Plots)	343,194.6208 Sq Ft	AutoCAD Model
Sector 15	Electricity	29,280,000 kWh	Torgerson, et al. 2006
Sectors 8/10	Oxygen (Production)	1 kg per CO2 Harvested	Zubrin, Et al. 2013
Sector 10	Trash (Processing)	0.2 kg * Population	James, et al. 1998

- Simulation Notes:
  - *Capacity / Daily Usage = Days Left*
    - 1 Mars Sol = 1.027491251 Earth Days
  - Each Individual Citizen will have their resources rationed (Flat Consumer Rate)
  - Oxygen Production based on Small Sabatier Reactor seen in Zubrin's 2013 paper.
  - Electric Capacity will be based on Backup battery storage if the Reactor(s) were to go offline
  - Water & Food Capacity based on Phase I AutoCAD model specifications & Accessible Literature
    - Food Based on: *Total Square Feet / (In Row Spacing Feet[Y axis] * Row Spacing[X axis])*
    - Accessible Literature
      - Only covered Wheat, Tomatoes, and Carrots
      - Thus Food Amount is smaller and Water remaining in storage is larger

Population: 1,000

- Phase I Population Density:
  - 0.0183 square miles or 509,461 square feet of Residential Areas
  - 54,721 People Per Square Mile

Material Day: 24 hrs.	Consumables Per Person Per Day	Total Consumables Per Day	Phase I Capacities	Earth Days Left	Mars Sols Left
Air (O_2)	0.9 kg 1.98 lbs.	900 kg 1,984.16 lbs.	8,800 kg 19,400.68 lbs.	10 Days	10.05 Sols
Water	10 kg 2.6 Gal	10,000 kg 2,641.72 Gal	590,952,369 kg 156,113,107 Gal	59,095 Days	60,719 Sols
Food	2.5 kg 5.5 lbs.	2,500 kg 5,511.56 lbs.	41,631 kg 91,780.644 lbs.	17 Days	17.11 Sols
Electricity	50 kW 1,200 kWh	50,000 kW 1,250,000 kWh	1,220,000 kW 29,280,220 kWh	25 Days	25.23 Sols
Material	**Waste Per Person Per Day**	**Total Waste Produced Per Day**	**Conversion Processes**	**Energy Used in Process**	**New Material**
Carbon Dioxide	1.1 kg 2.42 lbs.	1,100 kg 2,425.08 lbs.	Sector 8/10 Sabatier Reactors	190,080 kWh	Oxygen O_2
Wastewater (Sewage)	2.5 kg 0.66 Gal	2,500 kg 660.43 Gal	Sector 6 Sewer Plants	4 kWh	Water H_2O
Solid Waste (Trash)	0.2 kg 0.44 lbs.	200 kg 440.92 lbs.	Sector 10 Incineration (OR Recycling)	220 kWh	Power kWh

Population: 5,000

- Phase I Population Density:
  - 273,607 People Per Square Mile

Material Day: 24 hrs.	Consumables Per Person Per Day	Total Consumables Per Day	Phase I Capacities	Earth Days Left	Mars Sols Left
Air (O_2)	0.9 kg 1.98 lbs.	4,500 kg 9,920.80 lbs.	8,800 kg 19,400.68 lbs.	10 Days	10.05 Sols
Water	10 kg 2.6 Gal	50,000 kg 13,208.60 Gal	590,952,369 kg 156,113,107 Gal	11,819 Days	12,144 Sols
Food	2.5 kg 5.5 lbs.	12,500 kg 27,557.78 lbs.	41,631 kg 91,780.644 lbs.	3 Days	3.42 Sols
Electricity	50 kW 1,200 kWh	250,000 kW 6,250,000 kWh	1,220,000 kW 29,281,102 kWh	5 Days	5.17 Sols
Material	**Waste Per Person Per Day**	**Total Waste Produced Per Day**	**Conversion Processes**	**Energy Used in Process**	**New Material**
Carbon Dioxide	1.1 kg 2.42 lbs.	5,500 kg 12,125.42 lbs.	Sector 8/10 Sabatier Reactors	950,400 kWh	Oxygen O_2
Wastewater (Sewage)	2.5 kg 0.66 Gal	12,500 kg 3,302.15 Gal	Sector 6 Sewer Plants	22 kWh	Water H_2O
Solid Waste (Trash)	0.2 kg 0.44 lbs.	1,000 kg 2,204.62 lbs.	Sector 10 Incineration (OR Recycling)	1,102 kWh	Power kWh

Population: 10,000

- Phase I Population Density:
  - 547,213 People Per Square Mile
- More People = Higher Consumption Rates = Less Days left of Resource Capacity

Material Day: 24 hrs.	Consumables Per Person Per Day	Total Consumables Per Day	Phase I Capacities	Earth Days Left	Mars Sols Left
Air (O_2)	0.9 kg 1.98 lbs.	9,000 kg 19,841.60 lbs.	8,800 kg 19,400.68 lbs.	9.78 Days	10.05 Sols
Water	10 kg 2.6 Gal	100,000 kg 26,417.21 Gal	590,952,369 kg 156,113,107 Gal	5,909.75 Days	6,072.22 Sols
Food	2.5 kg 5.5 lbs.	25,000 kg 55,115.57 lbs.	41,631 kg 91,780.644 lbs.	1.67 Days	1.71 Sols
Electricity	50 kW 1,200 kWh	500,000 kW 12,500,000 kWh	1,220,000 kW 29,282,205 kWh	2.49 Days	2.56 Sols
Material	**Waste Per Person Per Day**	**Total Waste Produced Per Day**	**Conversion Processes**	**Energy Used in Process**	**New Material**
Carbon Dioxide	1.1 kg 2.42 lbs.	11,000 kg 24,250.84 lbs.	Sector 8/10 Sabatier Reactors	1,900,800 kWh	Oxygen O_2
Wastewater (Sewage)	2.5 kg 0.66 Gal	25,000 kg 6,604.30 Gal	Sector 6 Sewer Plants	43 kWh	Water H_2O
Solid Waste (Trash)	0.2 kg 0.44 lbs.	2,000 kg 4,409.24 lbs.	Sector 10 Incineration (OR Recycling)	2,205 kWh	Power kWh

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Questions and/or Comments?