A REVIVAL OF THE GARDEN CITY FOR A NEW PURPOSE

THE CASE FOR EXOPLANNING ON MARS

A Record of Study

By

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ABSTRACT

Elon Musk wants to go to Mars. Besides getting there, the new issue becomes "what is Point B going to look like and how will it function with regard to its location or proximity to resources"? Using Ebenezer Howard's Garden City to accomplish this task is highly recommended. This land use design would easily fit under a climate controlled dome offering plenty of living space and green space for producing oxygen, food, water, and maintaining the internal environment. Since Howard's self-contained city design is also hexagonal, it offers access to any direction without giving up useful land. This design also attempts to create a closed-system city that has a minimum of two important facilities such as water plants or Thorium fueled power plants, which in turn creates redundancy and resilient systems. These systems are very important keys to most if not all current technologies used in space. With that being said, Howard's Garden City will be modernized and brought up to today's standards. Also certain infrastructure assets will be added to the design to adjust the city to its new environment. With that being said, the paper will explore the background of the garden city and show case studies to prove it provided a higher quality of life to its citizens. The second focus of this paper will be the zoning and land use within the structure. The third focus will be based on the suitability of a site and its proximity to natural resources such as water or iron ore deposits. Furthermore, this paper will only be focusing on the Phase I city structure out of the four total phase structures, which is the smallest and least complex of the four preliminary designs for each higher density phase. Essentially this Phase I variant is scaled down to be compact and simple to understand, but more importantly, to be realistic.

DEDICATION

To my ancestors, from the coal mines and farm fields to the office towers and beyond. I am grateful for all the opportunities given to me by my loving family.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Van Zandt, and my committee members, Dr. Chamitoff, and Dr. Bright, for their guidance, support throughout the course of this research, and for putting up with this, literally, out of this world idea.

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Last but definitely not least, thanks to my Mother, Father, and Aunt Alison for their encouragement and patience. I also cannot forget the other family members such as my Nana & Papaw who partially funded this two year venture from their hard earned money. Money well spent I say.

NOMENCLATURE

CANDU-SCWR	Canadian Deuterium Uranium Supercritical Water Reactor
DEM	Digital Elevation Model
ESA	European Space Agency
GIS	Geographic Information Systems
GRS	Gamma Ray Spectrometer
HVAC	Heating Ventilation/Air Conditioning
LSA	Land Suitability Analysis
MAG/ER	Magnetometer and Electron Reflectometer
MCS	Mars Climate Sounder
MGS	Mars Global Surveyor
MOLA	Mars Orbiter Laser Altimeter
MRO	Mars Reconnaissance Orbiter
NASA	National Aeronautics and Space Administration
PIGWAD	Planetary Interactive GIS Web Analyzable Database
PDS	NASA Planetary Data System
TES	Thermal Emission Spectrometer
USGS	United States Geological Survey
USP	Unified Settlement Planning

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1. INTRODUCTION: EXOPLANNING

1.1 THE RATIONALE ("EMERGING MARKET")

As of 2016 there have been no real vigorous attempts to bring together the two fields of urban planning and aerospace engineering at this scale. Thus the word "Exoplanning" was born. To clarify, it is a verb and is closely based off the word Exoplanet (planet outside our own solar system). The meaning is basically urban planning on other worlds such as exoplanets. Since the beginning of written history, everything we have ever known, have known, or will know (for now) has been on one "pale blue dot". The bottom line is if humanity is to avoid total disaster or extinction, humanity must diversify their locations instead of remaining on one planet where it will eventually run out of some resources. Earth is essentially the basket with all of our eggs in it, and it would be better to have insurance by having multiple planets under our control than just one. This course of action must be carried out carefully over time and step by step.

One concept within urban planning or in any field for that matter is to have diversity. Whether it is planting a variety of vegetables rather than just one type within a farm or multiple types of industry sectors in your stock portfolio, diversity is a type of backup plan to avoid total losses. This first step should be Mars since it is the closest planet to Earth and very similar (in regard to the other planets in the solar system) in composition, as will be shown later. This of course is in line with Elon Musk's plan to colonize Mars from Earth (Point A), but as of now he has no actual public plans of how Point B is going to function or how it will appear; this paper is a first step toward that plan or maybe even Elon's personal goal. The reasoning behind the choice for Ebenezer Howard's land use design pattern was to concentrate or centralize everything, including up to community facilities and dwelling units, within the city that it requires to function regularly such as a city on Earth. Another small reason was restricting developments from sprawling outward which would end up increasing construction/maintenance costs of the city structure, but more on Ebenezer Howard's design will be discussed below in the next section of this paper.

The first section goes into the history and background of Ebenezer Howard's garden city, the design inspiration of the city on Mars. This same section will give a case study to show that cramped conditions in other British cities compared to garden cities are unhealthy, this can also be in reference to the Biosphere 2 research station in Arizona where individuals were cramped together in a 3.14 acre facility, most of which was reserved for studying biomes in closed loop systems (Avise, 1994). The second section moves into the city's land use densities and land use patterns along with the city's design with regard to its new environment. The latter half of this section goes into the site selection process on Mars and the methods executed to find the right location. The third section is a simulation based on the design of the city and per person daily usages of resources to show how long the city would last if supply sources were cut off or depleted. The last section is a summary and conclusion of the whole paper with a segment on ideas of what to do next and how it can become a reality.

1.2 EBENEZER HOWARD'S GARDEN CITY

1.2.1 BACKGROUND & HISTORY

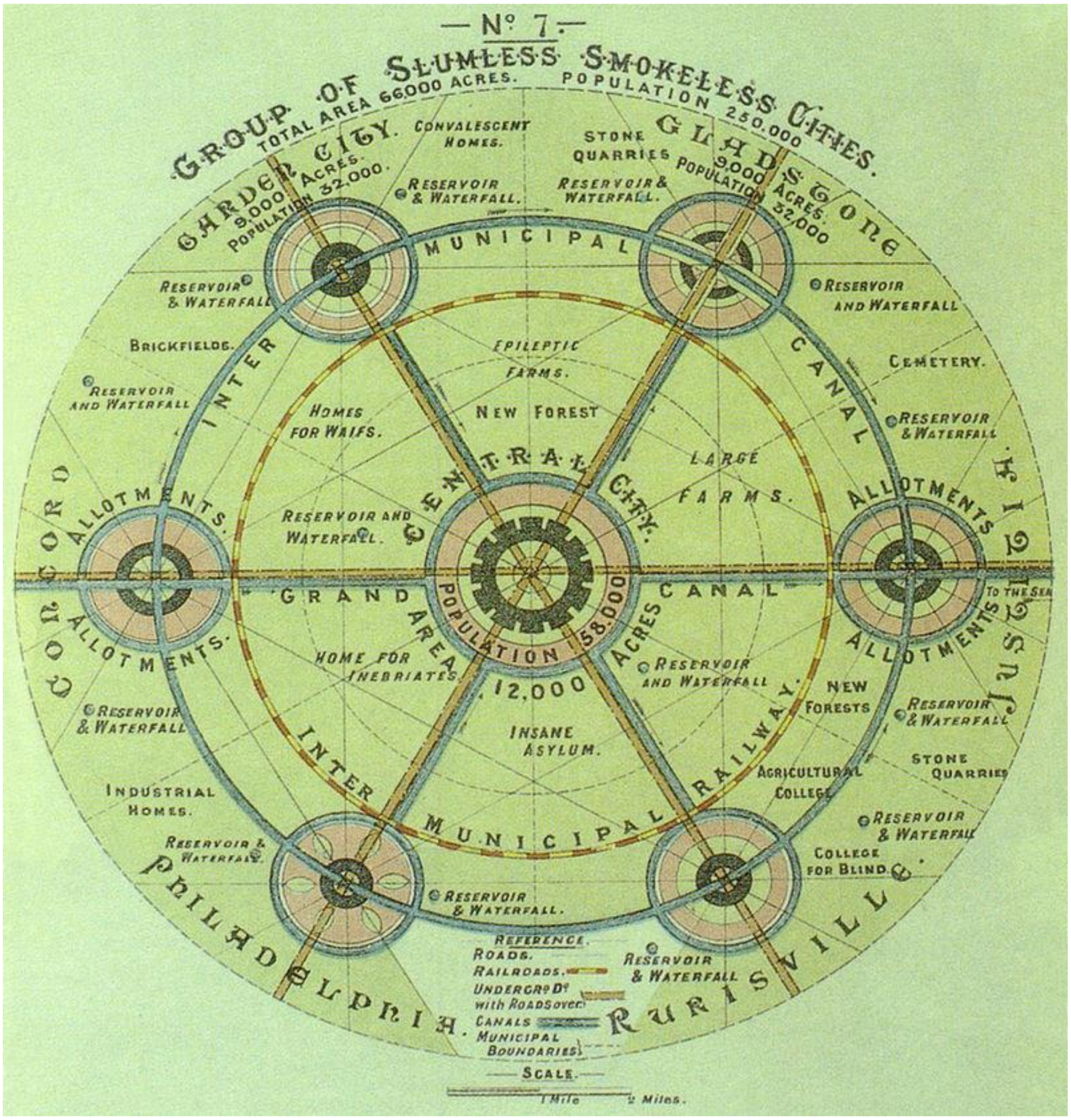
In 1898, a man by the name of Ebenezer Howard wrote a book called *To-morrow: A Peaceful Path to Real Reform*. In this book he discussed how the conditions of cities at the time were dismal and dirty but a better future awaited. He created the idea of a city that would provide a higher quality of life (health wise and environmental wise) and decent employment opportunities for its citizens. This ideal city included the best of both (two) worlds, rural (Country) and urban (Town). These two make up part of the Three Magnets which represent the pull for how or why people would locate to a garden city and the categories included Town, Country, and Town-Country. The Town magnet represented the "closing out of nature, social opportunity, isolation of crowds, places of amusement, distance from work, high money wages, high rent rates, high prices, high chances of employment, excessive work hours, army of unemployed, fogs & droughts, costly drainage, foul air, murky skies, well-lit streets, slums, gin palaces, and palatial edifices" (Howard, 1898) The second magnet was Country which included "the lack of society, beauty of nature, hands out of work, land lying idle, trespassers beware, woods & meadow forests, long hours & low wages, fresh air, low rents, lack of drainage, abundance of water, lack of amusement, bright sunshine, no public spirit, need for reform, crowding dwellings, and deserted villages" (Howard, 1898). The third and last magnet is a combination of the best features of the latter two magnets. This magnet is labelled Town-Country, which includes "the beauty of nature, social opportunity, fields & parks of easy access, low rents, high wages, low rates, plenty amusement options, low prices, no sweating, field for enterprise & opportunity, flow of capital, pure air & water, good drainage, bright homes & gardens, no smoke, no slums, freedom, and co-operation" (Howard, 1898).

These magnets formed the basis for his garden city, which is made up of six satellite towns that were to be 6,000 acres (2,400 ha) and house up to 32,000 people each with one central city of 58,000 people grand totaling out to 250,000 people within a 66,000 acre area (shown in Figure 1). Each city was to be self-sufficient and when fully developed would expand to a new already planned garden city nearby. Howard went on to discuss people and markets within the garden city and how goods would move from point A to point B. Mainly, this is about manufacturing or growing to buy locally. Next he went on discuss revenues from the garden city and how it would fund the operation and maintenance of the garden city. The majority if not all of the revenues generated from the town and country sections would come from rents. Howard then went on to break revenue sources down into residential, agricultural, and industrial sectors. After that the general expenditures of the garden city were discussed and the majority of that reading was based on capital expenditures for facilities such as the town hall or sewerage services. The last part of the book discussed the separation of public and private work within the garden city as to avoid government or corporate monopolies, which was an issue discussed in the difficulties section. In the back of the book Howard did manage to discuss the water production system of the garden city relying on underground reservoirs for production and the storage facilities for the excess such as the canals between cities (Light Blue lines shown in Figure 1). Lastly his book was the realization of a utopian society that strived to grow smarter and create a better environment for its citizens who were well acquainted to polluted industrial cities in England. This first book was such a success that he wrote a second edition a few years later.

In his second book called *Garden Cities of To-morrow*, which was a republish of the 1898 book in 1902, he further pushed for his idea of a better city. In this somewhat updated edition there were very little differences between the two. The reader however was given visual aids this time to see how the garden city looked at different viewpoints. Howard's most famous picture can be seen in Figure 1 (Howard, Garden Cities of To-Morrow, 1902). This is the same exact city, slightly modified and scaled down, that will be intended for use on Mars. This garden city represents the best a city has to offer such as a green environment with ample job opportunities while providing room for smart growth. These self-contained garden cities leave much to be desired with its open green spaces, which on Mars could be turned into self-sufficient zones that can strive to make this Martian city a closed loop system. This will be explored further later in the paper.

His garden city idea was so enchanting that he was able to convince investors into helping him build one. His books essentially started the Garden City movement, which led to the creation of two garden cities named Letchworth, formed in 1903, and Welwyn in 1919 both are technically now suburbs of London, England (United Kingdom).

FIGURE 1: Ebenezer Howard's Garden City Diagram



Howard, Ebenezer. 1902. *Garden Cities of To-Morrow*.

1.2.2 LETCHWORTH CASE STUDY

This new 3,818 acre community was first formed in 1903 by Sir Ebenezer Howard's First Garden City, Ltd., a company that was formed in September 1903 (Lewis, 2015). Letchworth was small hamlet of 60 to 90 people in the 19th century according to local censuses before it was labeled a Garden City in 1903. Raymond Unwin and Barry Parker became the architects of the town after they won a design competition hosted by First Garden City, Ltd in 1904. The design was based off of Howard's ideas but the architects were given the responsibility of housing design and building control, which sometimes went against what Howard wanted. The goal of the company through the eyes of the shareholders was to make money, thus every time a construction contract was secured it provided confidence for investors in the long term future of the city. Along these same lines, the company's offensive drive to bring more construction contracts in faster saw the quality of designs suffer and was sometimes seen as a secondary importance next to the rate the company wanted to see development break ground. An issue for the city was trying to lure in businesses and industry to make the city viable for more businesses and potential future residents that could work locally as promised by the company. This forced the company to enact a competitive pricing strategy on rent for land. This worked by bringing in numerous businesses and factories such as the Spirella Company. Attracting businesses and industry to Mars besides the transportation issue would probably be relatively easy, the businesses that locate there would most likely be monopolies and control their markets for some time. Labor force and skillsets will be difficult to find at first but over time will be corrected.

Letchworth from the outset was not planned like other traditional cities at the turn of the 20th century. This city was about "creating a place that could support the physical, social, and psychological well-being of the people who were to live and work there" (Lewis, 2015). After the *Sociology Effects of Garden Cities* study from Dugald Macfadyen in 1935 was published, it appears this quote was correct of Letchworth. In the first part of this study, they measured key characteristics of a healthy community such as death rates, infant mortality, scarlet fever rates, diphtheria rates, puerperal fever and pyrexia attack rate per 1,000 births. They used this data and compared it to other county boroughs, urban districts, and rural districts.

TABLE 1.1 1933 England and Wales Vital Statistics

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

The second part of the study measured the death rate of pulmonary tuberculosis and infant mortality rate. It used these characteristics to compare them to the county, which Letchworth was located in along with England and Wales.

TABLE 1.2 Standard of Public Health (Macfadyen. P.253)

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
Infant Mortality			
1930	20	42	60
1931	41	46	66
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

This shows that the design of the Letchworth Garden City provides a cleaner environment and a higher quality of life to its citizens. Even Welwyn Garden City had a higher quality of health than their surrounding nearby cities (The British Medical Journal, 1930). The reason for this could be the garden city redesigned the city's once narrow streets and relocated industry, which before presented health issues to local residents. Moving citizens away from pollution sources or vice versa such as factories and putting those citizens closer to agricultural belts seemed to have paid dividends. It also shows Letchworth's citizens condition to be greater than average of the nearby cities or counties. During Macfadyen's study he noticed that most of the tuberculosis cases were imported from outside Letchworth. He also noted that "there is evidence that in Garden Cities the spring of 'interest' (vital capacity or youth) remains active much longer than in large cities, that people who moved here to die twenty years ago have not succeeded in doing it yet" (Macfadyen, 1935). The levels of intellectuals in the city were also higher than average according to the city's librarians, to the point that "the young people, used all their time and mental energy to keep up with the increasing variety, individuality, and specialization of our older readers' interests" (Macfadyen, 1935). Perhaps the most interesting part of the study was the garden city's strong bias against alcohol. Many of the original "settlers" of the city were well aware of the havoc drunkenness associated with most industrial cities at the time, thus they issued no license to sell alcohol within the city. This allowed the garden city to have a feeling of cleanness and "up-lift". This contributed to the natural vitality of the city and generated expectations to its residents, which made for a self-respected, responsible, and healthy individual.

These design characteristics will be vital to having a self-sufficient and long term sustaining city on Mars. The design of the city also contributes to the health and well-being of the citizen living in it. Separating dirty uses from living quarters is important as well as not having buildings not being too crowded together. The main reason is that the first habitats on Mars will be small and certainly cramped, but this will be discussed later.

2. NEW PROPOSAL FOR THE GARDEN CITY

2.1 PHASES & SECTORS

2.1.1 ORIGINS OF PHASES

Walter Christaller came up with a geographical theory known as Central Place Theory, in this theory he explains the number, size, and location of human settlements in an urban hierarchy. This hierarchy stretches from small Hamlets to fully grown Cities. Hamlet will be called Phase I for this paper while the other categories later will be Phases II, III, and finally Phase IV that will be labeled as Cities. This same hierarchy is how these Martian cities will be broken up into phases (As seen on Page 51, Figure 2). To a get a better sense of the overall system, Unified Settlement Planning (USP) brings together Ebenezer Howard's Garden Cities, Walter Christaller's Central Place Theory, and the work of August Lösch into the regional scale, or in other words bulk planning, which is used to support development on a massive scale. This type of unified planning system was first thought up in the Soviet Union (Khodzhayev & Khorev, 1972) during the Khrushchev era and recently started gaining traction in India. USP in India seeks to avoid destroying already existing communities and taking advantage of emptier spaces in rural areas to meet increasing population demands for livable spaces. This same approach will be used on Mars to expand the different Phases around, thus over time introducing resiliency to this urban pattern in case one of the Phases is damaged or compromised.

2.1.2 TRANSECT PLANNING & SECTORS

Within each Phase there are different land uses and sectors. Each Phase has a total set amount of internal square footage that is under the atmospheric and climate controlled dome. Sectors 1-5 will be set up almost exactly like Transect planning calls for in zones T1 – D (Duany

& Talen, 2002). These sectors or zones will be defined in Table 2.1, which are the sectors broken down by land use types and activities. Also see Appendix A13 for the cross section to better understand the similarities between Transect planning and this new city.

TABLE 2.1: Interior Sectors and Transect Zoning Equivalent Definitions

Sector # Transect #	**Land Use**	**Activities**
Sector 1 Zone T6	High Density Mix Use	Includes Office, Hotel, Retail, and Residential
Sector 2 Zone T5	High Density Residential	Includes Small Retail and Multi-Family Residential
Sector 3 Zone T4	Medium Density Residential	Includes Small Retail and Multi-Family, Duplexes Residential
Sector 4 Zone T3	Low Density Residential	Includes Single family Residential units
Sector 5 Zone D	Community Facilities	Includes "Town Hall", Police, Fire, Health, Educational Centers, and Regional Transportation Hub
Sector 6 Zone T2	Water & Wastewater Facilities	Includes Water production, Wastewater Treatment plants, and Both Reservoirs
Sector 7 Zone T1	Forestry & Agroforestry	Includes Some Oxygen production and CO_2 removal
Sector 8 Zone T1	Transportation & Utilities	Includes Freeways, Freight Rail, Utilities corridors, Sabatier/HVAC system, and Underground Regional Hyperloop system
Sector 9 Zone T2	Agriculture	Includes fruits, grains, and vegetable production
Sector 10 Zone T2	Industrial & Solid Waste	Light Industrial operations, Sabatier Reactors, and Recycling & Incineration Facilities
Sector 11 Zone T3	Parks & Recreation	Includes Green Spaces and Plazas

Sectors 1 – 4 will provide living and office work spaces for the inhabitants along with shopping options. Sector 5 will provide civil services and will later house the regional underground transit hub. Sector 6 will produce potable water and treat wastewater by "recycling" liquids while distributing solids to a bio-fertilizer factory located nearby to use on

Sector 9. Sector 7, a forest section, was to be the main source of oxygen and carbon dioxide removal within the structure before I stumbled upon the Sabatier Process (Zubrin, Muscatello, & Berggren, 2013), which allowed for half of Sector 7 to be converted over to Sector 10 for light industrial uses, but the deeper reasoning for the switch will be discussed later. Sector 8 is the transportation, freight, and utilities transmission corridors located inside and outside the structure, these will be critical to future regional growth. Sector 8 is also the location for the equivalent of an internal HVAC (Heating, Ventilation, and Air Conditioning) system and smaller Sabatier Reactors, this Sabatier Process creates a byproduct of oxygen from external atmospheric carbon dioxide from Mars whose atmosphere is 95% carbon dioxide (Zubrin, Muscatello, & Berggren, 2013). Sector 9 is the agricultural section of the design. Sector 10 is the industrial section, and it also home to solid waste facilities that recycle or incinerate. This section could also be the location for larger Sabatier "Refinery" facilities in the future, to be discussed later in the paper. Lastly, Sector 11 is located within Sectors 1 – 4 to provide open plazas or green spaces for very dense sections of the city to provide citizens with relaxation time.

TABLE 2.2: External Sectors Definitions

Sector #	Land Use	Activities
Sector 12	Launching Pads	Rockets & Freight TO Space
Sector 13	Receiving Fields	Receiving Signals from Space
Sector 14	Antenna Fields	Broadcasting Signals (Radio, Emergency, etc.
Sector 15	Power Plant	Nuclear, Wind, or Solar
Sector 16	Landing Pads & Runways	Rockets & Freight FROM Space
Sector 17	Extraction Fields	Mining & Excavation

External sectors as defined above are activities outside the city structure. Sector 12 is the land use restricted to an airport equivalent of departure traffic, it will be used to export goods or even put communication satellites in orbit around Mars to have uninterrupted service to/from Earth. Sector 13 is a receiving point for any communications coming from beyond the ground on Mars. Sector 14 is a broadcasting field, it will house antennas of varying designs for sending signals out such as AM/FM radio or Wi-Fi internet. Sector 15 is energy generation plant slot, this slot is highly important to power the city and keep it functioning daily. Sector 16 is the land use restricted to an airport equivalent of arrival traffic. Sector 17 is reserved for mining and excavation of raw resources or other heavy industrial activities. But before this paper dives deeper into the details of these new zones and site designs, the next section will focus on the exploration of the origins within these designs.

2.2 PHASE I: LARGE-SCALE DESIGN & LONG-TERM COLONY

2.2.1 NOT A TEMPORARY CITY

When humans first arrive on Mars this city will not be there to welcome them, it will most likely be smaller abodes such as light weight inflatable Bigelow Aerospace habitats. These habitats are expandable units, which are made of lighter weight material that is easier to launch than conventional habitats could take up more space, weigh more, and therefore harder to launch.

FIGURE 2 Bigelow Aerospace Inflatable Habitats

Ingalls, Bill. 2011. *NASA*. https://www.flickr.com/photos/nasahqphoto/5417056094/

This is where the inhabitants will carry out less intensive activities compared to what the city requires to be fully operational. The differences between Ebenezer Howard's Garden city and this new proposal can be broken down into modernizations with current technologies along with new strategies and modifications. These topics will show how to bring Howard's city into the 21st century, which makes it unique that it is building off the past with his design in the present for the future on Mars and possibly other planetary systems.

First, modernization will bring his city up to today's standards such as the additions of bike lanes or automated pressurized water/sewer treatment systems while modifying it for its new environment off Earth. These modifications are to ensure the necessary functions of the city will continue despite being located in a hostile environment located extremely far from Earth. One step of this is to make everything as closed loop or recyclable as possible, lowering transportation costs and the number supplies that have to be imported to keep the city consistently functioning properly.

One long term issue that must be addressed is a breathable atmosphere within the city, which is the life support systems that will include multiple large scale Sabatier reactors that can create water (sabatier process only) or liquid oxygen (sabatier with electrolysis component) from imported/recycled hydrogen and atmospheric carbon dioxide from Mars (Zubrin, Muscatello, & Berggren, 2013). This process also creates liquid methane, a fuel resource used by eventual reusable rockets such as SpaceX's Raptor Engines (Office of Communications at NASA-SSC, 2015). To clarify from earlier, the Sabatier reaction is a process that uses carbon dioxide from Mars and imported/recycled hydrogen to produce oxygen along with liquid methane that can be used as rocket fuel later on. Refocusing back to the city, these Sabatier reactors will be split up between Sector 8 (mainly for oxygen production) and Sector 10 (mainly for liquid methane production). There will also be a forest section located within the city structure in Sector 7. The types of trees to be used within the sector are still being determined but the section will use large amounts of water in the growing phase before the trees mature. Agricultural uses in Sector 9 will also contribute to oxygen production to a small degree before being harvested but to what degree will need to be studied further.

Another facet to make this a long term and self-sufficient city would be food production. Agricultural land uses should be a high priority if the city is to succeed. Howard's city had one section between the central city and a suburb devoted for large farms but not multiple devoted sections to increase production and diversify crop types. Howard's books do not go into detail about what is to be grown on their farms, but he does however discuss how farmers cannot afford to compete with grain farmers in the United States or in Ukraine so they should grow something else, but not much further. In the new proposal, the Sector 9 segments are subdivided into farm plots of varying sizes depending on nutritional demands by inhabitants and a nearby bio-fertilizer plant to supply the farms with nutrients. Bottom line, food production will be based on several factors. These factors include seeds, soil content/fertilizers, water/humidity levels, atmospheric conditions, and sunlight. There are no seeds on Mars, these will need to be imported. The effects on "seeds during space travel appear to make the seeds have a better chance at budding and growing faster than seeds on Earth" (Grigsby & Ehrlich, 1991). Soil (regolith) content on the Mars surface is made up of "Silicon dioxide [51.4%], Iron(III) Oxides [19.4%], Aluminum Oxide [7.1%], Sulfur Trioxide [0.2%], Magnesium Oxide [9.3%], Calcium Oxide [10.0%], Sodium Oxide [1.3%], Chlorine [0.01%], Titanium dioxide [0.87%], and Potassium Oxide [0.16%]" (James, Chamitoff, & Barker, 1998). Also see Appendix A11 for additional soil figures. Artificial fertilizers will become extremely useful for two reasons, aiding growth in agriculture where soil is weaker while recycling human sewage bio-solids.

Water is a requirement for this agriculture sector to function properly and being located next to the Sector 6 reservoir should improve the chance of seeds germinating. Water demand for this sector will depend on the growing seasons for each different type of fruit or vegetable. Inside temperatures will be at a level where plants will not freeze/fry and humidity levels will be maintained. Sunlight is another requirement in this sector to function properly, the dome over the whole city will dim the sunlight slightly from the already reduced amount it gets compared to Earth on a daily basis but how much is still unknown at this time. Essentially, to make this city a long term outpost it will come down to oxygen, water, electricity, food, and how waste is managed. Not only are these five the essential building blocks to developing a successful city, they along with shelter (the dome) are the pillars of life.

2.2.2 DESIGN OF THE CITY

When I first starting designing this city in AutoCAD, I thought to myself what land use pattern can I use that includes redundancy/resiliency, efficiency, and functionality that could fit under a dome. I stumbled upon the Garden City in 2012 and it fit the system perfectly. This was before I even thought about the 3D design of the city. The only environmental aspect this city cannot combat or negate (right now) is gravity, which Mars has 1/3 less than Earth. One important aspect of the city's design was a requirement for the placement of all the civil infrastructure in twos but spaced far enough apart if one was to break or an accident to occur near it that the other one would continue to function without being effected. Another bonus of this modified design is having all the inhabitants live within a small 538 foot radius, which once the Sector 5 transit hub opens could classify it as a Transit Oriented Development. Everything in the city is certainly within walking or biking distance as well. I also needed a design that could store enough water and have enough room to produce food while producing enough oxygen to support the city. I did notice however one topic missing in Howard's books, which is the mention of the electricity supply to the city but this will be covered in detail later.

Centralization will also be another key to success. Unlike Howard's cities having to compete with nearby cities and resources, this new proposal will be a stand-alone city (for now) with no nearby competitors of any kind. If anything, people will want to build or locate nearby this city to begin with, this could jokingly be Howard's fourth magnet or better known as a monopoly. Utilities and transportation networks will be centralized and consolidated. This will lead to lower travel times for freight and commuters therefore lowering costs and resource uses. One difference is that Howard wanted to use canals as a mode of transportation between cities, this simply cannot be done because water will have a much higher importance to the city than a mode of transportation. It will be used for drinking and its other use of reducing radiation exposure by slowing down charged particles from space events such as cosmic rays or solar flares (NASA, 2002).

2.2.3 THE DOME

The most important structure for the city to be on Mars and hardest aspect to construct is the dome (Aniol, Dowd, & Platten, 2009). This type of structure was selected because it covers and protects the city beneath it from the hostile environment outside of it. It also creates opportunities for internal developments to expand upward. It also will be aerodynamic enough to not let possible high winds shift it too much or let sand from dust storms build up on it causing it to collapse from excessive weight.

This dome will have an external diameter of 2,020 feet and 1,980 feet internal diameter, this should leave more than enough space to support the dome's concrete foundation, which has a wall of 10 feet above ground level. To compare, this dome is about 710 feet longer than the dome stadium in Arlington, Texas (AT&T Stadium). The dome's radius is 980 feet in the interior and 1,020 feet on the exterior. These four figures along with the internal height of 400 feet were helpful in finding the interior volume of the dome using a spherical cap formula:

$$(\pi/3)*(Height)^2*(3*(Radius) - (Height)).$$

The answer turned out to be 445,365,788.1411 cubic feet or 12,611,354.7002 cubic meters. This volume number will eventually determine the amount of energy it will take to keep the HVAC system running and supplying adequate oxygen and carbon dioxide removal services. This dome will carry out many different jobs at once, such as radiation protection and keeping out super cold temperatures that come with lower pressures from the outside as well as the occasional dust storm.

This dome, to carry out its sole four purposes, will be layered. Starting with the exterior layer of 12 inches of Polyethylene (Made of Carbon and Hydrogen), this layer will insulate or keep the cold air away from the next layer that contains warm air. This warm air layer is to keep the purified water layer behind it (separated by another Polyethylene layer) at a liquid state rather than frozen chunks of ice. Purified water is the better option than ice because sunlight levels do not need to be reduced for the agricultural sectors. This water layer will be about one foot thick (Guetersloh, et al., 2006) to combat radiation events and reduce or negate harmful radiation from reaching inhabitants. The last layer, which will be facing the interior will have the function of holding the water that reduces radiation. However one or more of the layers of Polyethylene will need to have some tint to it to reduce Ultraviolent Light from going through but not tinted enough to affect the agricultural sectors. Transparent Aluminum (Aluminum Oxynitride, AlON) could also be used in one of the layers of the dome to support the structure while allowing sunlight through, however it does not reduce radiation levels as much. There must also be some sort of cleansing process on the exterior of the dome to reduce dust and sand build up which could reduce lighting for agriculture and put stress on the structure.

At one time during the theoretical design process, the dome had another use besides the ones mentioned above, this use was providing artificial rain to the whole city. This idea was scrapped because the water could be contaminated from outside radiation and create free radicals within the water, which would be harmful to humans or any biological entity causing cancer (U.S. Department of Energy, 1993). Other design considerations included interior noise levels (Connors, Harrison, & Akins, 1985), which recommends sound to be kept down around 45 dB (decibels). Last but more importantly was somehow reducing odors, especially with sewer plants and bio-fertilizer plants being located within this dome.

The foundation of this dome will most likely be made of reinforced concrete, the same type concrete seen everywhere, better known as Portland cement (Constituents: CaO, SiO_2, Al_2O_3, Fe_2O_3, and Gypsum). The great part about Portland cement is that it not only turns into Limestone ($CaCO_3$) over time (Dempster, 1999) when exposed to a Carbon dioxide rich atmosphere, which then reduces interior oxygen lost over time but that Mars itself has the ingredients to make it as well (See Appendix A11). This oxygen and carbon dioxide absorption from the concrete caused issues for Biosphere 2 in the early 1990s but since this city will be located on Mars with a majority Carbon dioxide atmosphere it should be no problem. In short, the 10 foot walls, as well as the dome already is, will have to be layered to reduce oxygen losses and sustain proper air pressure.

Lastly, the main system that will maintain and support this whole operation, the HVAC system. Without this scaled up system Carbon dioxide or Oxygen would most likely build up in parts of the city creating either poisonous or flammable situations. Keeping the air clean and circulating creates a healthy environment just like a typical HVAC system in a house does. Only difference is that it will connected to Sabatier reactors to pump fresh air in and soak up used air (CO_2). At the top of the interior dome there will be a vent to recycle the dry heat that rises. As this residential system requires an air filter so will this city system. This same system will also control the interior temperature and run at a higher rate to create normalized pressure such as an air supported structure has.

2.2.4 AUTOCAD & SKETCHUP

AutoCAD 2015 & 2016 were the softwares used to create and find the accurate square footage and spacing for the structure. As for the difference between the two different year editions, I could not find any during my drawing and processing. This software was also used to create a to scale 2D model of the Phase I design. As the design was drawn it was split up into different layers to determine the square footage for each sector and land use to use later on in the development. To determine the center of the drawing a hexagon was place where the eventual Sector 8 corridors would be. This allowed for accurate angles to be 0, 60, 120, 180, 240, and 330 degrees forming a hexagon. From there the model was laid out and offsets were placed to make this future stencil accurate. Once the model was completed and the square footage figures were placed into Microsoft Excel; the model was then converted into a PDF (See Appendix A14) and a readable 2D stencil imported to SketchUp to construct the 3D model.

SketchUp software was utilized to carry out the creation of the 3D model from the 2D stencil. In the making of the 3D model, the model finally began to take on a life of its own. It too was broken down into several layers, which could be turned on and off to show different uses at the flip of a radio button. Getting back to the model, it was separated to break different utility systems up such as water, sewer, power, and so on. These Sector 8 utility corridors use to have a bowed shape (Oval cross section) but after talking with Texas A&M University Civil Engineering concrete structures expert John Mander said that creating concrete in a curved shape such as these would be difficult, thus it was changed to the straight down corridors seen in Appendix A16. Many of the 3D aspects were shown off to many Texas A&M Engineering professors to ask for their advice/opinions and confirm designs of certain parts of the structure. The 3D model also showed where several areas of conflict could arise, for example, between the interchanges where utility lines, freeways, and railroad segments meet up that could not be seen on 2D maps. It was during this drawing that the dome was decided to be 400 feet tall from the interior and be about four feet thick for a total peak at 404 feet at the apex of the dome.

2.3 PHASE I: ZONING & LAND USE PATTERNS

2.3.1 DETAILS OF INTERNAL SECTORS

This section will deal with the designs of the land uses located inside the dome. Internal sectors are located inside the dome in a climate or atmospherically controlled environment. This is where the inhabitants will eat, sleep, live, and play. This is also where most of them will do their work on maintaining the city and growing food. Within this 2,000 foot diameter the total square footage was easy to determine, which gave actual square footages and percentages of each land use within the structure. The use of AutoCAD software was utilized to carry this part of finding the square footage totals. The percentages come from the Total Area of a Sector compared against the Total Area of Phase I, for instance, Sector 1 has 64,895.6182 square feet within the 3,017,185.5845 total square feet of Phase I, which equals 2.15% of Phase I's total land area. To ultimately clarify, the square footage figures are from the new city's design, which are dictated by Ebenezer Howard's design of 1902. Another important note from the table below is that this represents only horizontal square footage or surface area and not total square footage for potential future multi-story developments, especially since Sectors 1 – 3 are reserved for high density multiple floor/story buildings.

TABLE 2.3: Internal Sectors/Land Use Figures according to the AutoCAD Model

SECTOR/LAND USE (Phase I)	TOTAL AREA (Sq Ft)	PERCENTAGE
Sector 1/High Density Mix Use	64,895.6182	2.15%
Sector 2/High Density Residential	104,679.8758	3.47%
Sector 3/Med Density Residential	142,618.2868	4.73%
Sector 4/Low Density Residential	197,267.6945	6.54%
Sector 5/Community Facilities Hub	97,992.9750	3.25%
Sector 6/ Water & Wastewater	566,979.0862	18.79%
Sector 7/Forestry & Agroforestry	162,521.4680	5.38%
Sector 8/Transportation & Utilities	1,074,573.4378	35.62%
Sector 9/Agriculture	343,194.6208	11.37%
Sector 10/Industrial & Solid Waste	232,303.2319	7.70%
Sector 11/Parks & Recreation	30,159.2895	1.00%
TOTALS	**3,017,185.5845**	**100.00%**

Sector 1 is located outside the first ring street. This land use is high density mixed use between residential and commercial/office. This sector will more than likely be home to mix use towers of 20 to 25 floors. Retail will be located between 1st and 3rd floors while the rest would be office or residential use. Hotels could also be located in this sector. Basement levels can vary but must act as a backup protection in case of an extreme radiation event where the dome will not provide sufficient protection. Most utilities entering these prime lots will be in located in basement levels. Most of the population (Simulations of 1,000; 5,000, and 10,000 are carried out below) will be located in this sector, percentages of people will get smaller towards Sector 4.

Sector 2 is located facing outward toward the second ring in the city. This sector will be mainly compromised of high density residential units with little to no retail. Small locally owned businesses can operate within sector. Floor counts in this sector will be 10 to 20. The designs recommendations are the same at Sector 1 just less floors.

Sector 3 will offer mid-rise lofts or multi-family apartments and is located facing inward toward the second ring street and Sector 2. Along this same street will be the Sector 11 green spaces. The maximum floor count for this sector will be 10 with the minimum being 3. This sector will also allow for locally owned businesses to operate but in sparser numbers, confined mainly to the roundabouts and Sector 11 green spaces areas.

Sector 4 is the single-family housing land use. These are individual houses that will closely resemble suburban housing with set-backs, which it technically is because it is located on the last and third ring street located right next to the Sector 8 corridors. Duplexes could be used in these lots as well. The floor count in this sector is 1 to 3 and will also include basements for emergency/storage purposes.

Sector 5 is a split level land use. Ground level and above is a central building that is equivalent to a command center or a city hall, while below ground will be a regional transportation system station hub. This system could be anything from a simple subway system to the Hyperloop Passenger Plus system (Musk, 2013). This section will also be home to civil services such as fire, police protection, educational, and healthcare facilities.

Sector 6 is responsible for producing drinking water and treating sewage that could eventually become fertilizers. To begin with, the two large reservoirs that are 231,881.78 square feet each in size and can hold up to 10,434,679.91 cubic feet of water each. The depth of the two reservoirs are 45 feet deep because this is the same level the water transmission and distribution mains are located, which will help avoid other levels and interfere between other utility lines. There will be one water plant at each reservoir as well as one wastewater treatment plant at each, which will introduce redundancy to the system. Each water plant will be located on 33,167.44 square feet of land adjacent to their reservoirs. One unique feature about these plants will be the use of Ultraviolet Light lamps for water treatment instead of using or importing chemicals (Uslu, Demirci, & Regan, 2015). If it comes down to it then chlorine could be used after it is processed from Mars (Appendix A10). This method of treatment requires a lot of energy but a large reduction of chemicals having to be imported or manufactured is the main benefit. Water will also be used as coolant for the nearby nuclear plant (external) slot or Sector 15, this closed loop system of course will have its own water not for human consumption. Each of the wastewater treatment plants will be located on 8,816.95 square feet of land. These plants will treat liquids and release them into the reservoirs while sending the treated solids/sludge to the bio-fertilizer plants next door for further processing and removal of pathogens before being sent to Sector 9. One of two future issues located within the water treatment systems is the removal of strong pharmaceuticals or excess estrogen from recently treated water, which can cause long term side effects in humans and animals (Deo & Halden, 2013). The second is related to an issue that took place on the International Space Station in 2009 involving the Water Management and Recovery systems. The issue itself involves Calcium Sulfate from Astronauts urine, which comes from higher than average bone loss in the Astronauts due to their microgravity environment. Regardless, these Calcium deposits were large enough to clog the filters and stop the system from operating nominally (Carter, Pruitt, Brown, Schaezler, & Bankers, 2015), which on Mars could happen to both if not all treatment plants if not prevented or reduced.

Sector 7 is preserved for forestry, which once upon a time was going to be the primary means of oxygen production and carbon dioxide removal, but measuring the production and reduction of the two gases would be more difficult than using Sabatier reactors. The entire two sections are now made up of Sector 7 and 10, which use to be all zoned Sector 7 at one point, this was changed since the Sabatier processes could most likely make up for the amount of oxygen lost from the potential forest section that was converted to Industrial uses. The trees would more than likely be spaced out 20 feet by 20 feet leaving room for foliage growth and root growth. Given the total amount of land use at 162,521.4680 square feet, it can be estimated that there will be room for a grand total of 406 trees located in Phase I.

Sector 8 corridors are transportation and utility corridors. These vital lines carry everything from clear air, water, sewer, electrical transmission lines, rail freight, to freeway lanes. The reader can see this cross section view in Appendix A16, these pressurized water or sewage pipes and electrical transmission wires (765 kV, 345 kV, etc.) are only representative in size. Each utility will have its own segment of the corridor reserved for it with slots for expansion if the demand requires it. These internal corridors go 50 feet into the ground and will be pressurized connections between cities/phases. It is the consolidation and organization of these utility corridors that will allow growth beyond just one city. An example of organization is how the water and sewer line systems are separated and below electrical lines, this is to reduce blackouts and contamination if there was ever to be a leak from the pipes. There will also be air ventilation shafts carrying fresh air (oxygen) and used air (carbon dioxide) to and from the Sabatier-HVAC segment to keep fresh air circulating. With that being said, there will also be emergency airlocks between the cities and these corridors in case there is an accident such as a breach on either side causing a pressure loss.

Sector 9 is the agricultural hub and food production centers. This sector will be focusing on plant growth for now (Maggi & Pallud, 2010) and no animal herding of any type will be permitted early on because it is simply easier to import seeds than large or medium sized animals from Earth. These farm sites are in the proximity of the bio-fertilizer plants and water sources, both near Sector 6. As discussed above there are many factors that will play into the productivity of this sector, but this segment is about the design and uses of the sector. Some crop types to be grown here and have been experimented with by NASA/Other space agencies are wheat, tomatoes, and carrots to name a few (Wamelink, Frissel, Krijnen, Verwoert, & Goedhart, 2014). Grains will be given 34%, Vegetables 33%, and Fruits 33% of Sector 9 square footage. The percentages for the food groups might look familiar, this is because the land percentages allotted to the food crop will be based off the Food Nutrition Pyramid from the US Department of Agriculture (USDA), minus the sweets, meats, and dairy groups for this instance, which can be imported from Earth by refrigeration and bulk bags. In the future, those land uses will be added back to Sector 9 for them to reflect the true percentages of the pyramid. According to a production guide for wheat (The University of Georgia Extension Service, 2015) wheat seeds should be row spaced out 7.5 inches (X Axis) and in row spacing should be spaced 2.5 inches apart (Y Axis), these will be given 34% of the 343,194 square feet to grow. Next, 33% will be split 50/50 for the vegetables carrots and tomatoes (Should be placed under fruits but food group wise it is under vegetables), which comes out to 56,627.1124 square feet each. Lastly, fruits such as strawberries will be given the last 33%, coming out to 113,254 square feet to grow on. For example, assuming 100% germination (all seeds planted sprout) of the 897,586 seeds, yields should equal to 1.26 US short tons (1,139.95 kg) since each individual grain weighs around 0.045 ounces (0.020 kg). The formula below can be used to determine the number of trees or plants per square foot:

*Total Square Feet / (In Row Spacing Feet[Y axis] * Row Spacing[X axis])*

Sector 10 will be broken into two activities, these are industrial uses and solid waste management slots. Beginning with Industrial, the one day financial backbone of the city. This sector is singlehandedly tasked with making the city self-sufficient resource wise and creating supply chains for future industries and businesses to startup. This sector is about creating future opportunity and increasing inventories. It is having to build the economy from the ground up. One bonus to this sector is that it is located next to the internal wall, allowing for facilities to pump out unusable byproduct pollutants to the exterior (greenhouse gases might actually terraform Mars). Most of the operations in this sector in Phase I will be small scale with low outputs. Furthermore, Solid waste management will have two recycling plants (8,311.0531 square feet plots for each) and two incinerator plants (8,051.2967 square feet plots for each) if waste materials cannot be recycled. Incinerators can generate electricity and can pump their unusable pollutants to the exterior, thus the reasoning for their location next to the internal wall. There will be no such thing as a landfill land use here on Mars. Reusability will be a huge key to success for this city. Reducing the number of resources that need to be imported from Earth on a regular basis to keep certain functions of the city running will play a major role in this, such as using certain in-situ resource methods that will be discussed later.

Sector 11 is preserved for green space and parks. These recreational areas will allow inhabitants to stretch their legs and enjoy greenery on an otherwise red planet. Though these areas might be smaller (around 5,000 square feet per roundabout park) in the Phase I designs, the larger the Phase the larger the green space will be, which will also offer diverse recreational uses such as running tracks, closed loop water features, or basketball courts to name a few. These sites could also one day be converted to cemeteries if the need arises, which it most likely will if this is to be a long term city.

2.3.2 LOCALIZED SPECIALIZATIONS

Depending on the location and proximity to natural resources from the suitability analysis this will decide the type industries or activities that will take place within or outside the dome. Sector 10 gives about 100,000 square feet per parcel or 200,000 square feet in total for the two parcels within the Phase I dome for small scale industrial or material refining operations. Freight rail yards will be a split segment between the internal and external sides of the dome, these will also be shared under Sector 8 corridor, Sector 10 parcels, and external Sector 16 but these rail yards are still being determined at the Phase I level logistically. Other specializations could include office/retail, healthcare, or tourism related industries. Especially the tourism industry for cities in the vicinity of Olympus Mons (Tallest Mountain/Dormant Shield Volcano in the Solar System) or Valles Marineris (Canyon larger than the Grand Canyon in Arizona). The sky is the limit on any industry for entrepreneurial opportunities to rise because there is just so much left to explore with regard to any aspect on Mars.

2.3.3 DETAILS OF EXTERNAL SECTORS

Lastly, this section will go over the land uses located outside of the dome. These land uses will be exposed to the harsh environment, however some land uses cannot take place or fit under the dome in the internal slots, thus the need to move them outside. As seen in Table 2.2 all the activities listed could not be carried out or completed within the dome. These external locations are determined by the angles of the Sector 8 corridors leaving the Phase I city, they are split and in some instances kept apart of safety reasons. These external options have no restricted size or depth until they reach the next Phase structure. One example is the location of the launching and landing pads slots (Sectors 12 & 16), these are out of vicinity of the Sector 15 power plant slot. They are also distanced from communication fields of Sectors 13 and 14. These slots are not set in stone but the safety precautions shown above will remain because depending on their location and the side of the natural resources to be extracted could determine where Sector 17 will be located and what the city will specialize in. Now on to the details about each exterior sectors.

Sector 12 is a land use reserved for launching satellites or any payloads into orbit or further. This sector should not be located near the power plant or Sector 15 and blast exhaust ports should be faced away from the Phase and set up much in the same way as the Space Launch Complexes 40 or 41, to name a few, at Kennedy Space Center in Florida. These should not be located at every Phase, just concentrated near larger freight/manufacturing hubs and landing pads. But when they are located nearby, they need to be adjacent to the Sabatier “Refineries” reactors to gain access to the liquid methane fuel they could use.

Sector 13 is an external land use allocated for Satellite Relay dishes. These are used to communicate with satellites and beyond. The types of satellite dishes that can be located here include large parabolic dish antennas, directional/high gain antennas (HGA), or some omnidirectional antennas that are not in Sector 14 to name few. The site can be set up much like the Karl G. Jansky Very Large Array located in Socorro County, New Mexico. Simply put, this sector can be used for communication and deep exploration purposes.

Sector 14 as mentioned before will be an antenna field using Omni-directional antenna towers that could be tasked with broadcasting AM/FM-radio, television, or cellular phone service signals throughout an area. Frequencies will most likely follow the already set standards for broadcasting and certain bandwidths will be reserved for certain uses. Most of these towers will be pushed farther back from the city structure as to reduce catastrophic damage if an antenna were to fall over due to high wind or some other anomaly. The site will be located around a base station connected up to the telecommunication lines of Sector 8 around 1,000 feet (0.3048 km) or so away from the city.

Sector 15 will provide the area for the majority of the primary power sources for the city or eventual region that will be from nuclear energy. A Canada Deuterium Uranium Supercritical Water Reactor (CANDU-SCWR) was chosen for the reactor type, this Generation IV reactor such as this will generate an estimated 1220 Megawatts of electricity (MWe) (Torgerson, Shalaby, & Pang, 2006) per reactor unit. This generation of reactors should be available in the 2030s. The reactor coolant will use light (regular) water and the moderator will use heavy water, which can be manufactured in nearby Sector 10. Heavy water or Deuterium can be manufactured from the water produced from the Sabatier Reactors in land use Sectors 8/10 or from the hydrogen from the Sabatier + Electrolysis Reactors (Miller, 2001) or it can be imported from Earth in tanks. These types of nuclear reactors were selected to take advantage of Thorium reserves on Mars as the main fuel source (Boczar, et al., 1998), as shown in Appendix A7. Another reason these types were selected were to take advantage of online refueling, meaning there will be no downtime to shut the reactor off and waiting for it to cool when changing out fuel rods. Plus, if Thorium cannot be used, the CANDU reactors can take numerous other forms of fuel. Thorium also has a much shorter half-life than Uranium or Plutonium does, thus increasing safety over time. Naturally Thorium by itself is not fissile but fertile (Jeong, Park, & Ko, 2008), which means it requires one extra neutron from either Earth imported Uranium or Plutonium to start the fuel cycle process within the reactor to provide power. This sector will also be placed away from the city since the nuclear option is used out of the other options of solar or wind power but it does not mean those two options will not be used as secondary or backup methods of energy generation (diversity is again good). Fusion Reactors could be utilized as well, but this project mainly focused on today's existing and already proven/operational technology meaning this project will have a stronger possibility of existing as technology progresses forward. With that being said, of the Fusion Reactors in today's Research and Development phase, I believe Lockheed Martin's High Beta Compact Fusion Reactor has the best chance of coming to fruition (Norris, 2014). Another reason the energy generation facility will be placed away from the city is to reduce possible radiation exposure while not increasing wire lengths and therefore costs. There will also be backup battery systems possibly such as Tesla PowerPacks, which are comparable to emergency diesel generators back on Earth for community facilities. There is no set boundary size for this land use other than the Sector 8 corridors and other city phases, but if wind power is used there must be a large setback for the windmills.

Sector 16 is a spacecraft landing area, whether the craft uses a runway or pad it will be located in this land use slot. It too needs to be located in the vicinity of the Sabatier "Refineries" reactors to gain access to the methane fuel source, along with the liquid oxygen resource if the need arises. This area will be treated as an inbound only airport with regard to freight and passengers coming through. This sector should be located right next to the Sector 12 to lower distance between inbound (this sector) and outbound (Sector 12) sites. As for the site's landing pads, they will very look similar to SpaceX's Landing Zone 1 at Kennedy Space Center in Florida. This land use must also not be located near the Sector 15 power generation slot.

Sector 17 is reserved for the heaviest and most intense of activities on Mars, mining and extraction of natural resources. Some resources include frozen water deposits, iron ores, silicon dust, and thorium ores. None of these resources according to satellite surface data are in super dense concentrations, thus leaving only a handful of options to extract them such as surface mining (strip or open-pit mining) and eventually underground mining (shaft mining) if land surveys show it is worthwhile. These types of mining operations will require heavy machinery and equipment to be used, which will need to be imported from Earth or somehow manufactured on Mars. Also to note, environmental quality problems should not be an issue for mining since there is no wildlife to be affected and water is in a groundwater is in a more than likely frozen state. Mining frozen water will present its own challenges especially if it requires a desalination process before entering Sector 6 and the human water supply system (Stillman, Michaels, Grimm, & Hanley, 2016). This sector will cut down importing costs as the rate of using in-situ resources goes up (Meyer & McKay, 1996).

2.4 LAND SUITABILITY ANALYSIS & SITE LOCATION

Now I will be moving into the main purpose of this paper since the history and background knowledge of garden cities and the design have been established. Like any future land development project, a Land Suitability Analysis (LSA) must be conducted to provide data based on subjective criteria set by the developer or local regulations such as proximity to utilities or watersheds. The history of the LSA goes back to Ian McHarg, who used an old fashion method of overlaying transparent maps on top of each other to highlight flood zones, endangered vegetation, slope/drainage, and other natural features. These features had darker colors compared to areas that had little to no subtractive issues which had zero colors or was transparent in color (example could be a Black & White version of Appendix A18). This overlay was eventually used to illustrate the suitability of land for near future urban development (McHarg, 1967). To further define the LSA, it is a process that "aims at identifying the most appropriate spatial pattern for future land uses according to specific requirements, preferences, or predictors of some activity" (Malczewski, 2004). Most criteria for Earth LSAs include being located on the smoothest slope of terrain, not being located inside a 100-year floodplain, and located close to utilities and road connections. Bottom line, it is used to get the most bang for your buck, or find the next best location to save money by not having to raise construction costs or flood insurance fees. In this case, our location is Mars, the fourth planet from our Sun.

Before I jump deeper into the LSA, I will give the surface and atmospheric conditions of Mars to lay the ground work for the LSA. According to NASA, this planet is located approximately 142 million miles from our Sun. The planet's diameter measures 4,220 miles, which is almost half of Earth's diameter (7,926 miles). The gravity of Mars is 0.375 or 1/3 of Earth's gravity, which comes down to an example of 100 lbs. on Earth equals 38 lbs. on Mars. The temperatures can range anywhere from -284º F (-140º C) to 86º F (30º C) but it depends on which of the four seasons it is. Speaking of which, the cause of the seasons, Mars can approximately can tilt at a 25º angle compared to Earth's 23.5º tilt, which means Mars has longer seasons and not because of its larger yearly elliptical orbit around our Sun (NASA, 2016). The atmosphere of Mars is made up of around 95% Carbon dioxide, <2% Argon, <2% Nitrogen, and <1% other gases. This same atmosphere has an average pressure of 0.60 kPa (0.09 psi) or 100 times less dense than Earth's, thus showing the Martian atmospheric pressure to be equivalent of 22 miles above Earth's surface. The planet also has no magnetosphere surrounding it much like Earth has, instead, it has small "umbrellas" of weak magnetic fields located close to the surface spread across the planet in different places (Appendix A3). Lastly and most importantly for the LSA, the soils of Mars (See Appendices A5 – A11) consist of the necessary minerals for construction (cement ingredients and iron), food production (water and some soil nutrients), and energy production (Thorium).

The LSA criteria for locating the city on Mars will be based on safety and proximity to important natural resources. Safety and security of the inhabitants is the top priority, much like all manned NASA missions include. This priority is the equivalent of many cities having disaster mitigation plans to keep their citizens and other assets safe. Being located in this hostile environment of super freezing temperatures, increased chances of radiation exposure, and decreased atmospheric pressure is tough but manageable. Creating an artificial climate to control temperature is not an issue, the issue is the design, scale, and construction of the combo Sabatier-(de)humidifier-HVAC system used to do so. It also helps to have a location close to the warmer Equator of Mars to lessen the stress put on the system or individuals. This same system should also be strong enough to create an artificial pressure within the dome much like an air-supported structure does on Earth. The toughest challenge though is reducing radiation exposure, which can be done three ways. (1)The city can take advantage of stronger than the Mars average magnetic fields in the southern hemisphere or (2) it can build a thicker dome with a larger water requirement to stop harmful particles from entering the city. (3) The third way, which will end up being in the building codes anyway, is to build basements that can protect inhabitants in times of solar flares or excessive cosmic rays in any emergency.

Lastly, the resources to help build, maintain, and sustain the city will be discussed. Of the concentration data maps collected only five periodic elements and one very important compound were collected via remote sensing (every periodic element reflects differently in the spectrum of visible light such as red, blue, and green) from the 2001 Mars Odyssey satellite. These five elements were Iron (Fe), Thorium (Th), Silicon (Si), Potassium (K), and Chlorine (Cl). The one compound is the most important of them all, H_2O or water. The LSA weights from the Raster Calculator tool for Water (50%), Iron (30%), and Thorium (10%) were the highest while Silicon (5%), and Potassium (5%) were lowest. Reasoning for those weights is that water is for human consumption and processing breathable oxygen. Iron was to construct the city and Thorium to power the city from reactors once it was processed. Silicon was important in the latter elements because it could lead to industrial opportunities (such as making computer chips for example), meanwhile potassium could be used as a fertilizer. Chlorine ended up not being used in the suitability analysis because it distorted the other elements by size, since it was 5x5 while the other maps were 2x2 (See Appendix A10 for reasoning). Bottom line, the LSA weights were subjective because there was not any readily available literature to draw from since nothing like this, at this scale, has ever been done before.

2.4.1 LSA DATA SOURCES & SATELLITES

The majority of the Mars surface and atmospheric datasets used to contribute to the LSA of the project are from NASA's Planetary Data System (PDS) and USGS's Planetary Interactive GIS Web Analyzable Database (PIGWAD) server. Another minor source included the PDS: The Planetary Atmospheres Data Node. All of these Mars datasets were collected or created by NASA's 2001 Mars Odyssey satellite, which has been in operation since 2001 and is still operational as of March 2016. One of the tools from it used was the Gamma Ray Spectrometer (GRS), which is a remote sensing tool used to identify the concentrations of periodic elements such as iron or thorium and the locations of frozen surface water. Other satellites included NASA's Mars Reconnaissance Orbiter (MRO) and Mars Global Surveyor (MGS) along with European Space Agency (ESA)'s Mars Express. MRO data was used to collect surface ground temperatures in Kelvin, this came by the Mars Climate Sounder (MCS) tool. MGS data was used from the Thermal Emission Spectrometer (TES) tool to show such mineral maps that showed mineral concentrations such as the geologic mineral Hematite but these maps were not used in the analysis since periodic element maps were available. This same satellite was also used to capture the magnetic field of the planet by the Magnetometer and Electron Reflectometer (MAG/ER) tool. All ground and soil samples data was obtained from the rovers Spirit [MER A], Opportunity [MER B], and Curiosity [MSL] as seen in Appendix A11.

The Digital Elevation Model (DEM) was created from the Mars Orbiter Laser Altimeter (MOLA) tool aboard the MGS satellite, which was mapped in September 1997 to June 2001 to find terrain elevations that eventually lead to the slope map in ArcGIS. The DEM was retrieved from the USGS PIGWAD server, this was in the format of a .cub file that ArcGIS found readable. The magnetic field and periodic element concentration maps were all in table form. Some the temperature or climate data was in table format as well. The USGS also created a vector geology map that was converted to raster for the suitability analysis but not used because it was not necessary yet. All the data used and analyzed in this study were collected by the group of satellites between 2001 and 2006 while the unused climate maps were from 2013 to 2015. Most of the data retrieved from satellites were raw data in .txt or .tab file formats, which turned into a troublesome process of making them readable in ArcGIS.

2.4.2 LSA SOFTWARES & METHODS

These same .tab files from the PDS server had to be converted to .csv files before being imported to Microsoft Excel. They were in text format when imported, which means the data could not be numerically read and processed by ArcGIS (10.3.1). These data files consisted of the 2x2 (Latitude and Longitude location readings from 2001 Mars Odyssey) periodic elements and temperature maps. Once these files made it into .csv format they were imported into ArcGIS using the Data Interoperability extension tool. These files had to be converted to become readable data to display their XY coordinates properly in ArcGIS. These coordinates were projected on the Mars map, which used the GCS_Mars_2000 projection and the datum was D_Mars_2000, both standards within ArcGIS geographic coordinate systems. Once the coordinates were displayed the Point to Raster tool was utilized to create a map showing the intensities and concentrations of the periodic elements in the surface soil mentioned above. After that process was complete and some cosmetic work (switching maps from Nearest Neighbor to Bilinear Interpolation) to the maps they were ready to be used in the suitability analysis.

This was the same painstaking method for the climate maps as well, but these maps were not entirely useful in the analysis because the way the data was collected from the satellites. These temperature maps (Mars Year 32 Autumn, Winter, Summer, and Spring) only showed what the temperature was right beneath the satellite's orbit where it scanned and captured the surface temperature if there was not a dust storm present to interfere with scanning. Bottom line, it was a temporal and spatial issue attempting to capture the daily temperature data but what this data did was it created a range of what the highs and lows were in an area during a particular season during the day or night. There was no way to cleanly estimate and fill the 1,900 mile plus gaps between temperature reading paths/strips (An example is in Appendix A2).

The slope map was created from the DEM, it showed the degree on, which the city could be built. The categories in the slope were smooth to steep, obviously smooth will have the higher weight compared to steep terrain. There was also a hill shade map created from the DEM to show terrain smoothness but it was not included in the suitability analysis because slope already accomplished what was needed. This DEM map of Mars based on the 5M Quadrangles can be seen in Appendix A1, the projection for this map, and all the other maps from here on out, has distorted the north and south pole regions while the equatorial regions are accurate, better known as a Mercator projection. The GIS coordinate system also uses 0 E. to 360 W. degrees latitude system instead of -180 E. to 180 W. degrees map system that is usually seen.

The Reclass tool was used on several of the variables within the LSA. Reclass could simplify such maps as the magnetic field to show "stronger" field strengths measured in Nanoteslas (nT) while erasing weaker strengths (Unclassified Map seen in Appendix A3, an Example Reclassed Map showing 24 nT or higher in A4). These magnetic fields on Mars (Maximum 211 nT) are much weaker than Earth's (Minimum 25,000 nT) and because of this the magnetic field variable will be left out of the suitability analysis for Mars but left in the GIS tool for future use on other planets. The Reclass tool was also used to determine the elevation where the atmospheric pressure was sufficient to operate the Sabatier reactor pumps to draw in the necessary CO_2 without having to use a lot of energy to do so. The average surface pressure on Mars is 0.60 kPa, which according to the z values for the DEM in ArcGIS the average elevation is -720 meters below the datum (Olympus Mons and Hellas Planitia are outliers, thus they cannot be used to find the average elevation of Mars, the DEM Histogram can be seen in Appendix A20). The Reclass tool was used on the DEM to separate -720 meters and below the datum from the rest of the elevations (Appendix A21). Last included a latitude restriction above the 65 degree north and below 65 degree south latitudes to ensure no cities will be close to the nearly always frozen north and south polar regions of the planet. The final part of the LSA was the Combine tool, this tool took the reclassified slope, pressure, and element maps and stacked them one top of each other to create an overlay showing the color white for suitable land and black for unsuitable land. There are no weights for the final LSA map because all the important weights were carried out in the earlier part of the LSA, leaving nothing left to do but stack the images and make them transparent.

SEE APPENDIX A17 FOR THE ArcGIS LAND SUITABILITY TOOL

2.4.3 POTENTIAL SITES

Based on the LSA's suitable areas, I subjectively selected several areas based on proximity to natural resources such as water or lower elevation for atmospheric pressure to be right for the Sabatier reactor pumps. I ended up leveling it down to a site that is located in Northeastern Aeolis Quadrangle (Google Earth, Mars: 6°37'45.63"S and 168°12'3.84"E), also seen in Appendix A18), the site is about 391 miles (630 Kilometers) Northwest of the location where the Spirit Rover (MER-A) landed and located approximately 1,132 miles (1,822 Kilometers) East of the currently operating Curiosity rover (MSL). Geographically the site is located 122 miles (197 Kilometers) Northeast of Reuyl crater. This site was chosen because of its proximity (Located within a 300 mile/482 km radius of all high concentrations of the five elements, Appendix A19) to higher than the planet's average concentrations of water, iron, and small deposits of thorium along with being located 238 miles (383 Kilometers) south of the Equator. Other sites could have been chosen closer to the Equator but this would put them farther away from the natural resources needed.

3. SCENARIOS

3.1 BASIS FOR SIMULATIONS

In each of the three scenarios used below, Microsoft Excel was utilized to make the three simulations stream lined and less time consuming. They were set on a per person uses certain materials per day constant. In the city individuals will have their resources rationed, this is to ensure that resources are depleted efficiently before either scheduled imported resupplies occur or the self-sufficient status is achieved. However for some resources, building codes will include backup systems that will include air locking buildings that supply oxygen and water from mini Sabatier reactors and electrolysis systems if the dome is compromised. This is why I believe the limiting resource for this city will be food and not water or air, which relies on a multitude of items to go right including quality soil, seeds germinating, or even proper sunlight to name a few. Water is not the issue because it will be generated from the Sabatier reactors that are basically surrounded by an endless supply of Carbon dioxide to draw from and recycled hydrogen from water to keep this system in constant production in an almost closed loop system. Electricity will be generated in a diversity of ways thus reducing its possibility of being a limiting factor for the city. In these simulations I measured water use, electricity use, oxygen use, food use, and waste created whether gas, liquid, or solid based on (James, Chamitoff, & Barker, 1998) and (Boston, 1996) tables. The maximum consumption and production numbers were chosen because this way if they do not use the maximum there will be leftovers instead of choosing the minimums and having over use leaving nothing but looming disaster. These consumables and waste products generated per person are posted below.

TABLE 3.1 PER PERSON USES (Per Earth Day)

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

TABLE 3.2 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

I compared these uses and byproducts to the capacities based on the sector/land use square footage allotted to them from the AutoCAD and SketchUp drawings to find out how many Earth Days and Mars Sols (1.027491251 times longer than an Earth Day) the supplies would last if not resupplied or replenished. Urban carrying capacity on Mars based on the Phase I design will need to be evaluated further based on an urban carrying capacity scoring model from China (Wei, Huang, Li, & Xie, 2016). Depending on those figures and facility production values can we determine if 1,000 or 5,000 or even 10,000 population sizes are feasible for the long term, which will mean getting a passing or failing grade in that scenario. The methods and results will be displayed below in sections 3.2 through 3.4.

3.2 1,000 INHABITANTS

This is the straight forward and, in my opinion, less detailed simulation. Simply put, all the person per day consumptions and productions were multiplied by 1,000. These were compared against the Capacities offered by Phase I. Using the formula: *Capacity / Daily Usage = Days Left*, gave us the answer, which was also converted to Mars Days (Sols) as well. The capacity for oxygen is estimated because the four Sabatier reactor facilities used are based off the small reactor used in Zubrin's paper (Zubrin, Muscatello, & Berggren, 2013). As for the wastes created, methods are listed to removal or negate them, solid waste is converted into electricity if it is not recycled, which is added back into the capacity total. The amount of kWh per cubic meter of sewage processed came from a study that measured energy consumption of wastewater treatment plants (Silva & Rosa, 2015), the figure chosen off of page 513 came from the maximum 85 Wisconsin Waste Water Treatment Plants (WWTPs) (1.4 kWh/m^3). Food totals were also reduced from what would be higher weights because there was only enough literature to cover wheat, tomatoes, and carrots, which left more than enough water over. This means that if there were larger variety of crops being grown the amount of food would go up (more days/sols left) and water use would follow (water days/sols left would decrease). The Population Density is 54,721 people per square mile, this number is high because the 538 foot radius surface living area in a Phase I is 0.0183 square miles or 509,461 square feet.

TABLE 3.3 1,000 PEOPLE (PASSED)

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

3.3 5,000 INHABITANTS (PASSED)

Much like mentioned above, all the person consumptions and productions were multiplied by 5,000 this time. This lead to an increase in consumption and a decrease in days left of resources if productions were to halt or supplies run out. The Population Density is 273,607 people per square mile, this number is high because the 538 foot radius surface living area in a Phase I is 0.0183 square miles or 509,461 square feet.

TABLE 3.4 5,000 PEOPLE

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

3.4 10,000 INHABITANTS & OPTIMAL POPULATION

Lastly, all the person consumptions and productions were multiplied by 10,000. The Population Density is 547,213 people per square mile, this number is high because the 538 foot radius surface living area in a Phase I is 0.0183 square miles or 509,461 square feet. As of no surprise the less people there are the longer the supplies and resources will last.

TABLE 3.5 10,000 PEOPLE (FAILED)

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

Given the outcome for this simulation, this means for the optimal population for the city is between 5,000 and 10,000 inhabitants. The limited number of days left of food supplies is subjective but in this case less days are worse and more days are better. Therefore, there should be at least a 3 day (5 Sols) supply of food located in the city and not on backup “life boats” in case of an emergency. As stated before, water, oxygen, and electricity should not be issues. Using this 3 day (5 Sols) minimum for the food supply, the optimal number of inhabits for Phase I is around 5,550. This creates a population density of 303,703 people per square mile. All the other resources had longer time periods than food before exhaustion.

TABLE 3.6 OPTIMAL POPULATION (5,550 Inhabitants)

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.	4,995 kg 11,012.09 lbs.	8,800 kg 19,400.68 lbs.	9.78 Days	10.05 Sols
Water	10 kg 2.6 Gal	55,550 kg 14,674.76 Gal	590,952,369 kg 156,113,107 Gal	10,648.00 Days	10,940.72 Sols
Food	2.5 kg 5.5 lbs.	13,875 kg 30,589.14 lbs.	41,631 kg 91,780.644 lbs.	3.00 Days	3.08 Sols
Electricity	50 kW 1,200 kWh	277,500 kW 6,937,500 kWh	1,220,000 kW 29,281,224 kWh	4.37 Days	4.49 Sols
Material	**Waste Per Person Per Day**	**Total Waste Produced Per Day**	**Conversion Processes**	**Energy Used in Process**	**New Material**
Carbon Dioxide	1.2 kg 2.42 lbs.	6,105 kg 13,459.22 lbs.	Sector 8/10 Sabatier Reactors	1,054,944 kWh	Oxygen O_2
Wastewater (Sewage)	2.5 kg 0.66 Gal	13,875 kg 3,665.39 Gal	Sector 6 Sewer Plants	24 kWh	Water H_2O
Solid Waste (Trash)	0.2 kg 0.44 lbs.	1,110 kg 2,447.13 lbs.	Sector 10 Incineration (OR Recycling)	1,224 kWh	Power kWh

4. SUMMARY AND CONCLUSIONS

4.1 SUMMARY

To summarize this urban land use pattern or modularized city on Mars, it will do what it was designed to do, which is to provide a reminder of what home is like back on Earth. It will also protect its inhabitants from the hostile exterior environment and grow with them over time, but it will also decay with them as well if they do not maintain it. In short the city will provide the necessities of life: food, water, air, and shelter. This in turn will create social, economic, and scientific opportunities to anyone who chooses to come. This Phase I will provide the foundation for a much larger colony system (seen in Figure 3), which over time will create a self-sufficient/closed loop system that this new urban system will require if it wants to sustain itself longer than one Earth month.

4.2 CONCLUSION

With that being said, the first few days or weeks of construction and resource gathering will be crucial to the survival of this endeavor. Funding early on will still be an issue for this city much like Howard's was but this paper was more focused on the design and functions of the city and not the fiscal operations. Perhaps that can be done in another paper.

To further continue this research, better quality and quantity of site data is required before anything else can be done. One suggestion is placing a geostationary satellite over the selected site (Aeolis quadrangle) for more detailed periodic element concentrations along with more than five elements, magnetic field intensities, and hourly temperature maps. More ground data would not hurt either, finding out what is in the soil or beneath the soil could be used to determine the required depth and strength of a dome's foundation. It could also be extremely helpful in determining if establishing a large city or one day region there is a short term or long term endeavor.

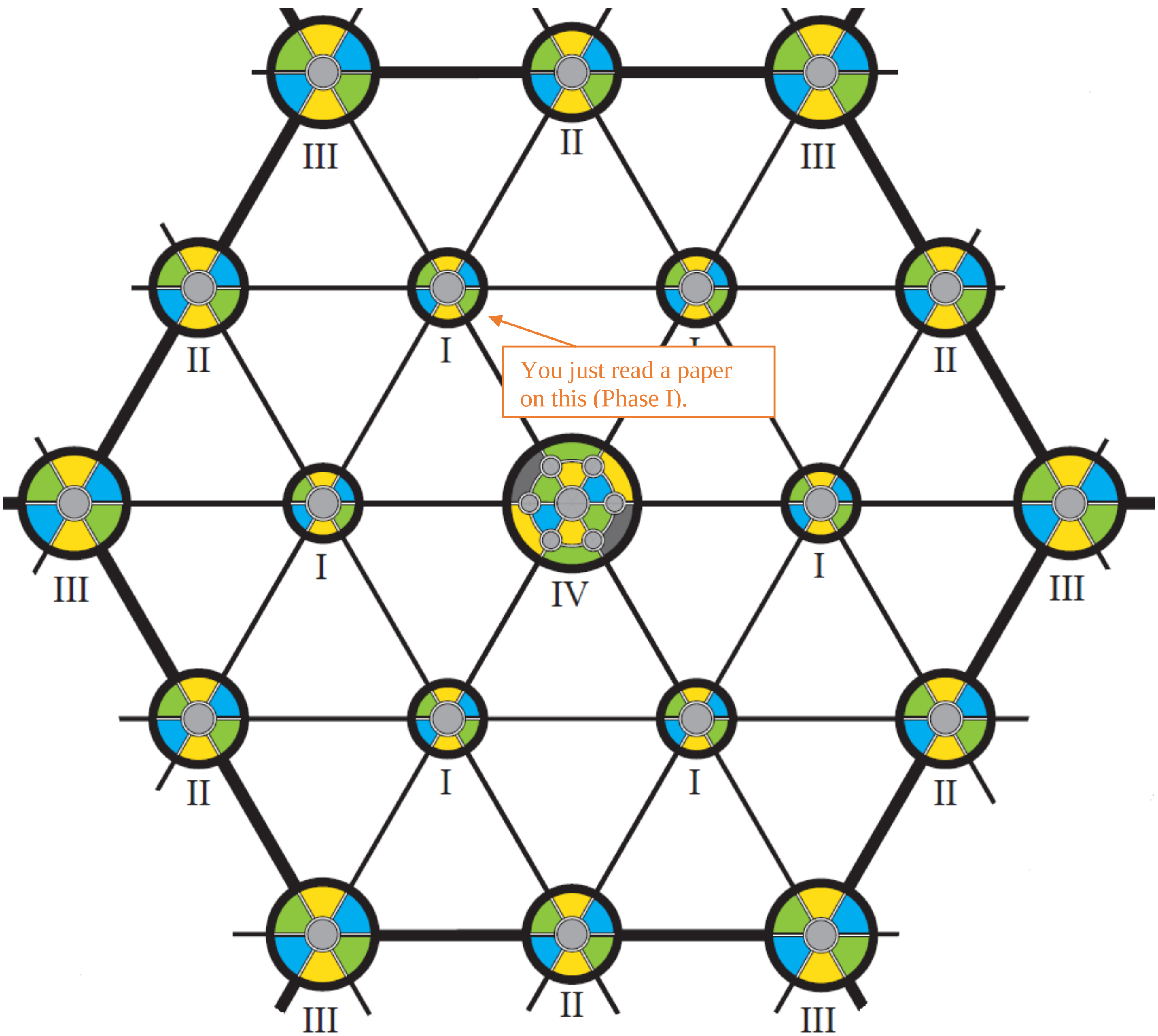
Speaking of the region, the future larger and more complex Phases II, III, and IV will closer resemble Howard's Garden city than this one (Phase I). The potential future regional design can be seen in Figure 3, it will not be designed as rigid as this but the reader can get a sense of the future; this map is not to scale either, just a visualization.

The city was scaled down to bare basics to prove it can be placed under a reasonable sized dome creating an artificially controlled internal environment. To put things into perspective, these cities minus the local Martian topography can be spaced out in the central place theory pattern that can have the cities classified by socio-economic size/industrial strength meaning one day these Phase I cities will be the small towns such as Jamestown or Roanoke were when they were established in the 17th century compared to present day. Perhaps a Phase IV could one day resemble a New Amsterdam, which is now present day New York City.

The implications from the project reach far and wide. On Earth for example, given the rate humanity is introducing more Carbon dioxide and Methane into the atmosphere the less likely it will be considered habitable in the future. Rising sea levels as well could change humanity's environmental situation. Both these activities could force humanity to live in artificially, climate controlled, closed looped system, biospheres/domed cities on Earth to survive. As for the implications for NASA, the LSA Tool that was created in ArcGIS could benefit them for other missions to other planets/moons. The tool is not perfect, but it gives an idea of the necessary variables to pick and choose a site based on habitable criteria for humans. It is also this same tool that made me realize that future unmanned missions to orbit other destinations need to have a standardized design to retrieve the very information used in this project that can be placed in the tool and run. Not every planet has a DEM or climate data maps that are ArcGIS ready, in fact there are only two planets in our solar system that have altitude/elevation maps, the other being Mercury.

This project is just the start and the work will continue on all the Phases well after this is published and nor will it be the only edition for this Phase depending on future further findings. Now to offer a final thought on all of this, I sometimes cannot help but see the similarities between Ebenezer Howard's hexagonal cities design and some if not most snowflakes under a microscope. I doubt any of this is just a coincidence.

FIGURE 3 EXPLANATORY PHASE V REGIONAL MAP (Excluding Topography)



REFERENCES

Aniol, J. R., Dowd, J., & Platten, D. (2009). New Dallas Cowboys Stadium: Longest Single-Span Roof Structure in the World. In L. Griffis, T. Helwig, M. Waggoner, & M. Hoit (Ed.), *Structures Congress 2009: Don't Mess with Structural Engineers: Expanding Our Role. 341*, pp. 1-10. Austin: American Society of Civil Engineers. doi:10.1061/41031(341)265

Avise, J. C. (1994, June). The Real Message from Biosphere 2. *Conservation Biology, 8*(2), 327-329. Retrieved May 18, 2015

Boczar, P. G., Chan, P. S., Dyck, G. R., Ellis, R. J., Jones, R. T., Sullivan, J. D., & Taylor, P. (1998). Thorium Fuel-Cycle Studies for CANDU Reactors. *Thorium fuel utilization: Options and trends* (pp. 25-41). Vienna: International Atomic Energy Agency. Retrieved January 2016

Boston, P. J. (1996). Moving in on Mars: The Hitchikers' Guide to Martian Life Support. In C. R. Stoker, & C. Emmart, *Strategies For Mars: A Guide to Human Exploration* (Vol. 86, pp. 327-361). San Diego, California, USA: Univelt, Inc. Retrieved January 2016

Carter, L., Pruitt, J., Brown, C. A., Schaezler, R., & Bankers, L. (2015). Status of ISS Water Management and Recovery. *International Conference on Environmental Systems (ICES). 45*, pp. 8-9. Bellevue: American Institute of Aeronautics and Astronautics. Retrieved March 31, 2016

Connors, M. M., Harrison, A. A., & Akins, F. R. (1985). *Living Aloft: Human Requirements for Extended Spaceflight.* Washington, District of Columbia, USA: National Aeronautic Space Administration (NASA). Retrieved February 5, 2016

Dempster, W. F. (1999). Biosphere 2 engineering design. *Ecological Engineering, 13*, 31-42. Retrieved February 2, 2016, from http://files.urbanlandscapelab.org/core1/readings/recommended/BIOSPHERERESEARCHPASTPRESENT_1999.pdf

Deo, R. P., & Halden, R. U. (2013, September 11). Pharmaceuticals in the Built and Natural Water Environment of the United States. *Water, 5*(3), 1346-1365. doi:10.3390/w5031346

Duany, A., & Talen, E. (2002). Transect Planning. *American Planning Association Journal*, *68*(3), 245-266. Retrieved December 2015

Grigsby, D. K., & Ehrlich, N. J. (1991). Space Exposed Experiment Developed for Students (SEEDS). *LDEF, 69 Months in Space: First-post retrieval symposium*, 1634-1635. Retrieved from http://articles.adsabs.harvard.edu/full/1991NASCP3134.1635G

Guetersloh, S., Zeitlin, C., Heilbronn, L., Miller, J., Komiyama, T., Fukumura, A., . . . Bhattacharya, M. (2006, October). Polyethylene as a radiation shielding standard in simulated cosmic-ray environments. *Nuclear Instruments and Methods in Physics Research B, 252*(2), 319-332. doi:10.1016/j.nimb.2006.08.019

Harding, R. (1989). *Survival in Space: Medical Problems of Manned Spaceflight.* London and New York: Routledge. Retrieved January 2016

Howard, E. (1898). *To-Morrow: A Peaceful Path to Real Reform.* London: Swan Sonnenschein & Co. Ltd.

Howard, E. (1902). *Garden Cities of To-Morrow*. London: Swan Sonnenschein & Co. Ltd.

James, G., Chamitoff, G., & Barker, D. (1998). *Resource Utilization and Site Selection for a Self-Sufficient Martian Outpost.* Houston: NASA.

Jeong, C. J., Park, C. J., & Ko, W. I. (2008). Dynamic analysis of a thorium fuel cycle in CANDU reactors. *Annals of Nuclear Energy, 35*, 1842-1848. doi:10.1016/j.anucene.2008.04.010

Khodzhayev, D. G., & Khorev, B. S. (1972). The Conception of a Unified System of Settlement and the Planned Regulation of city Growth in the USSR. *Soviet Geography, 13*(2), 90-98.

Lewis, J. (2015). Preserving and Maintaining the concept of Letchworth Garden City. *Planning Perspectives, 30*(1), 153-163. doi:10.1080/02665433.2014.971127

Macfadyen, D. (1935). Sociological Effects of Garden Cities. *Social Forces*, 250-256.

Maggi, F., & Pallud, C. (2010, July). Martian base agriculture: The effect of low gravity on water flow, nutrient cycles, and microbial biomass dynamics. *Advances in Space Research, 46*, 1257-1265. doi:10.1016/j.asr.2010.07.012

Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. *Progress in Planning, 62*, 3-65. doi:10.1-16/S0305-9006(03)00079-5

McHarg, I. (1967). An Ecological Method for Landscape Architecture. *Landscape Architecture*, *57*(2), 105-107.

Meyer, T. R., & McKay, C. P. (1996). Using The Resources of Mars for Human Settlement. In C. R. Stoker, & C. Emmart, *Strategies for Mars: A Guide to Human Exploration* (Vol. 86, pp. 393-442). San Diego, California, USA: Univelt, Inc. Retrieved January 2016

Miller, A. I. (2001, February 1). Heavy Water: A Manufacturers' Guide for the Hydrogen Century. *Canadian Nuclear Society Bulletin*, *22*(1), 1-14. Retrieved January 2016

Musk, E. R. (2013). *Hyperloop Alpha.* Los Angeles: Tesla & SpaceX Corporations. Retrieved May 2015

NASA. (2002). *Understanding Space Radiation.* Houston: NASA Johnson Space Center.

NASA. (2016). *Mars Facts.* NASA. Retrieved March 11, 2016, from http://mars.nasa.gov/allaboutmars/facts/#

Norris, G. (2014, October 20). Skunk Works Reveals Compact Fusion Reactor Details. *Aviation Week & Space Technology*, pp. 1-3. Retrieved March 31, 2016, from http://web.archive.org/web/20141017164725/http://aviationweek.com/technology/skunk-works-reveals-compact-fusion-reactor-details

Office of Communications at NASA-SSC. (2015, September). NASA-SpaceX testing partnership going strong. *Lagniappe*, pp. 3-4.

Rummel, J., & Volk, T. (1987). A modular BLSS simulation model. In R. D. MacElroy, & D. Smernoff (Ed.), *COSPAR Advances in Space Research. 7,* pp. 59-67. Toulouse: Pergamon Press. Retrieved February 2016

Silva, C., & Rosa, M. J. (2015). Energy performance indicators of wastewater treatment: a field study with 17 Portuguese plants. *Water Science & Technology, 72*(4), 510-519. doi:10.2166/wst.2015.189

Stillman, D. E., Michaels, T. I., Grimm, R. E., & Hanley, J. (2016). Observations and modeling of northern mid-latitude recurring slope lineae (RSL) suggest recharge by a present-day martian briny aquifer. *Icarus, 265*, 125-138. doi:10.1016/j.icarus.2015.10.007

The British Medical Journal. (1930, June 28). Ten Years of Welwyn Garden City. *The British Medical Journal, 1*(3625), p. 1184. Retrieved March 14, 2016, from http://www.jstor.org.lib-ezproxy.tamu.edu:2048/stable/25336552

The University of Georgia Extension Service. (2015). *2015-2016 Wheat Production Guide.* The University of Georgia, Cooperative Extension Service. Athens: The University of Georgia Press. Retrieved February 7, 2016, from http://www.caes.uga.edu/commodities/fieldcrops/gagrains/documents/Final2015_2016_WheatProductionGuide.pdf

Torgerson, D. F., Shalaby, B. A., & Pang, S. (2006, April 26). CANDU technology for Generation III+ and IV reactors. *Nuclear Engineering and Design, 236*, 1565-1572. Retrieved January 2016

U.S. Department of Energy. (1993). Effects of Radiation on Water Chemistry (Synthesis). In U. D. Energy, *DOE Fundamentals Handbook* (Vol. 2, pp. 1-11). Washington, District of Columbia, United States of America: U.S. Department of Energy. Retrieved February 2016, from http://energy.gov/sites/prod/files/2013/06/f2/h1015v2.pdf

Uslu, G., Demirci, A., & Regan, J. M. (2015, June). Efficacy of Pulsed UV-Light Treatment on Wastewater Effluent Disinfection and Suspended Solid Reduction. *Journal of Environmental Engineering, 141*(6), 1-10. doi:10.1061/(ASCE)EE.1943-7870-0000912

Wamelink, G. W., Frissel, J. Y., Krijnen, W. H., Verwoert, M. R., & Goedhart, P. W. (2014, August). Can Plants Grow on Mars and the Moon: A Growth Experiment on Mars and Moon Soil Simulants. (A. de la Fuente, Ed.) *PLoS ONE, 9*(8), 1-9. doi:10.1371/journal.pone.0103138

Wei, Y., Huang, C., Li, J., & Xie, L. (2016). An Evaluation model for Urban Carrying Capacity: A case study of China's Mega-cities. *Habitat International, 53*, 87-96. doi:10.1016/j.habitatint.2015.10.025

Zubrin, R., Muscatello, A., & Berggren, M. (2013). Integrated Mars In Situ Propellant Production System. *Journal of Aerospace Engineering*, 43-56. doi:10.1061/(ASCE)AS.1943-5525.0000201

APPENDIX A INDEX

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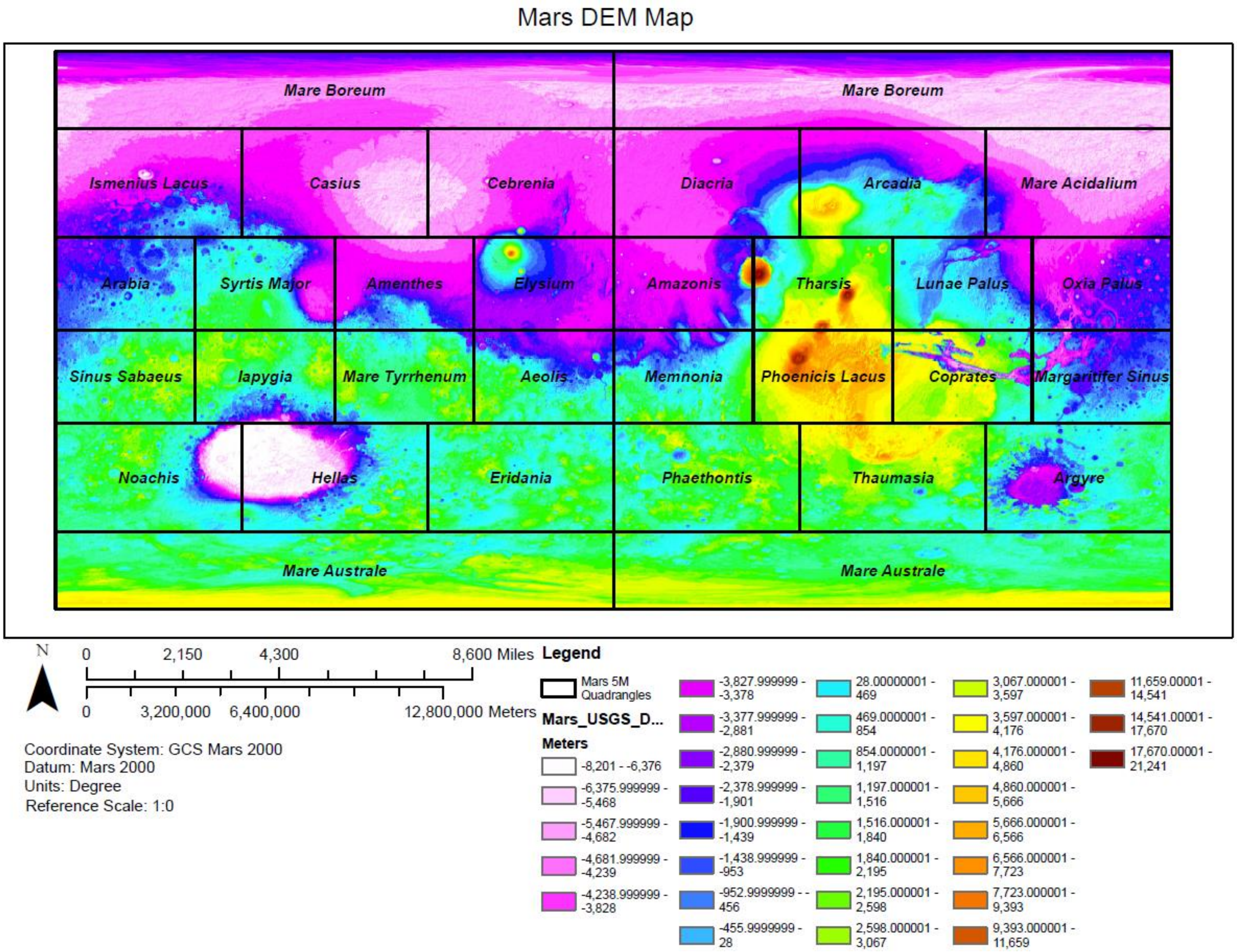
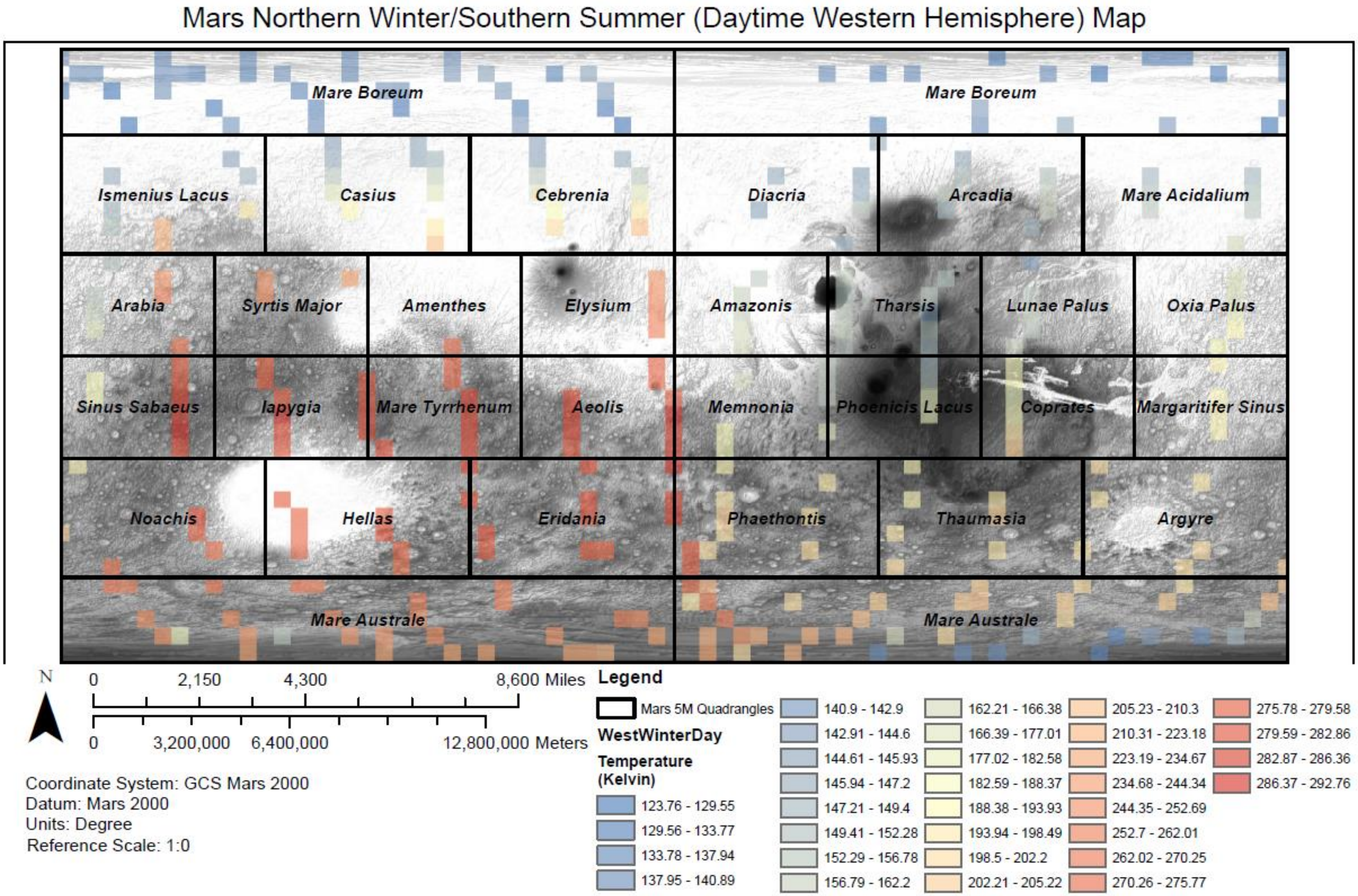
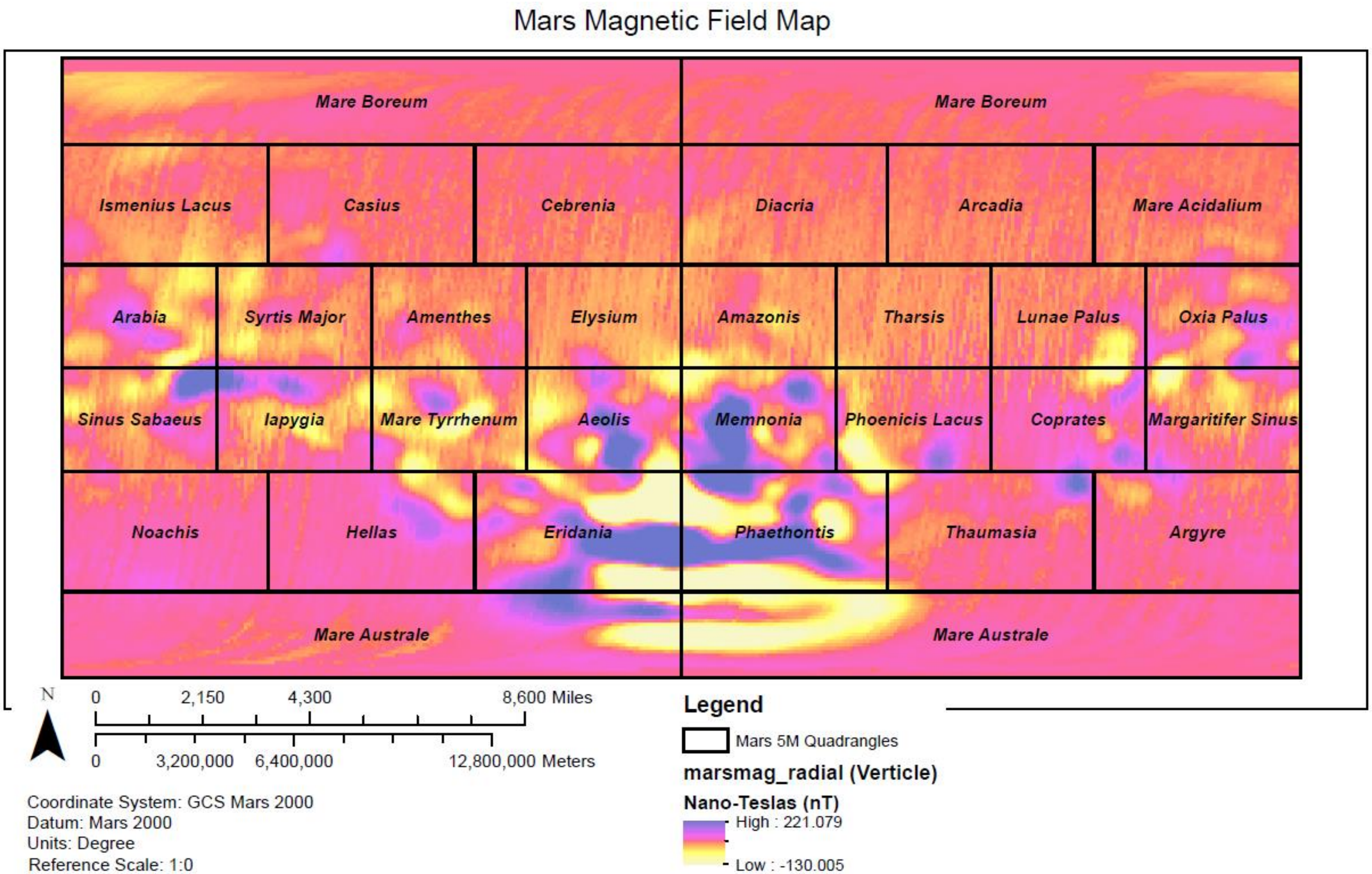
Appendix A1: Mars Digital Elevation Map (0 [West] to 360 [East] degrees)



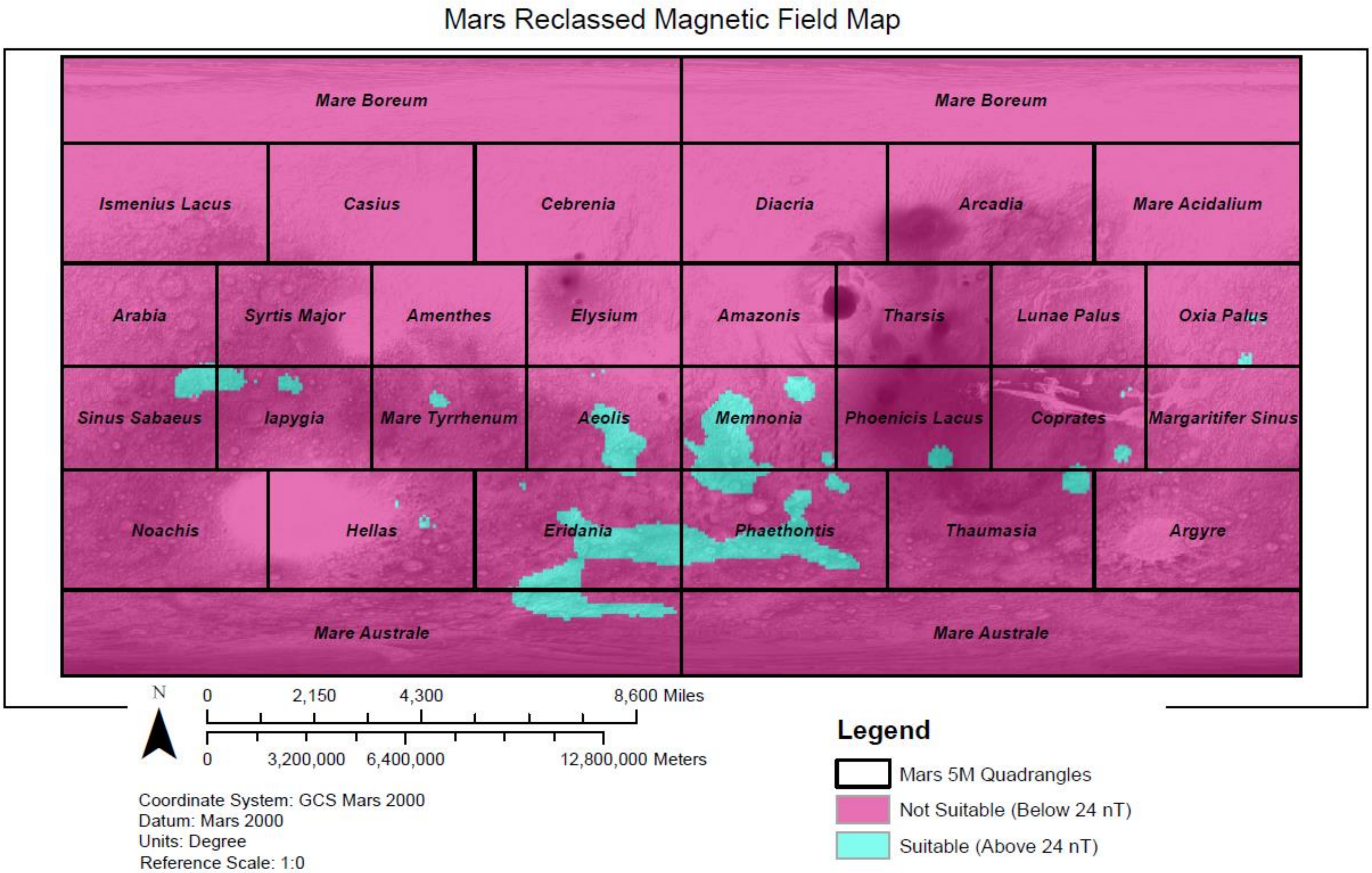
APPENDIX A2: Mars Example Climate Map (From January 11, 2015: Martian Year 32 Northern Winter Solstice)



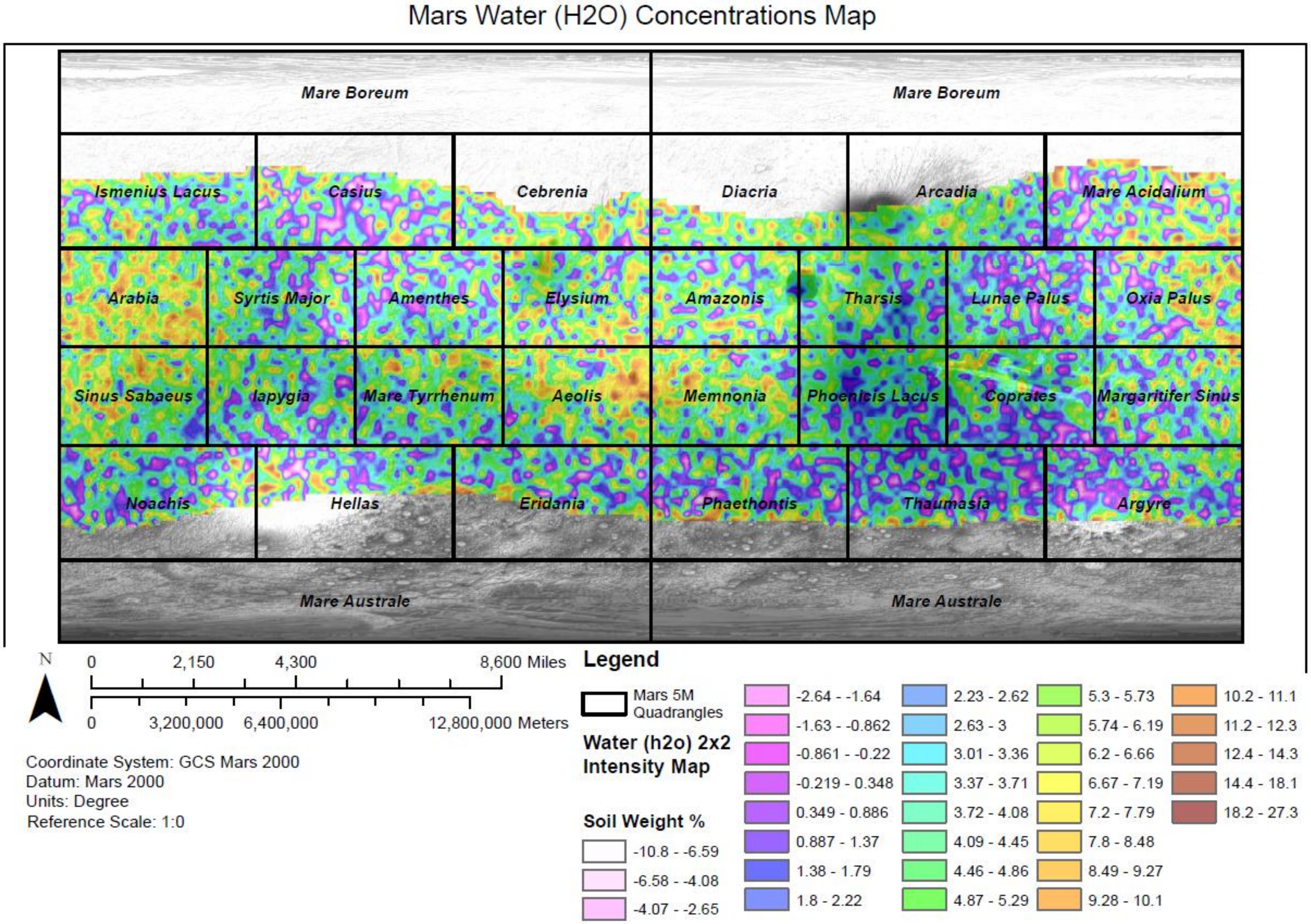
APPENDIX A3: Mars Magnetic Field (Or Umbrellas) Map [Example of Unclassified Map]



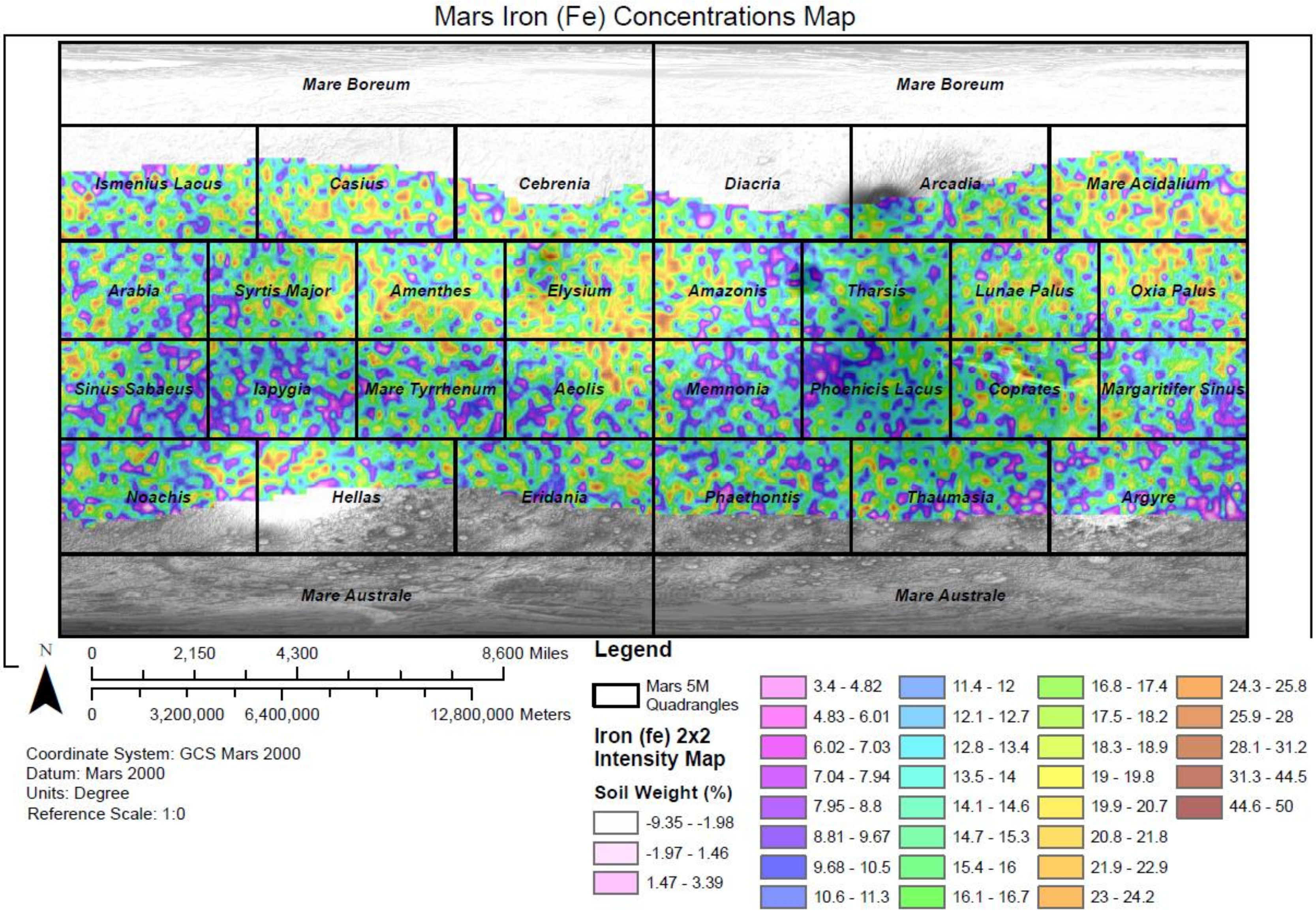
APPENDIX A4: Example of a Reclassed Map



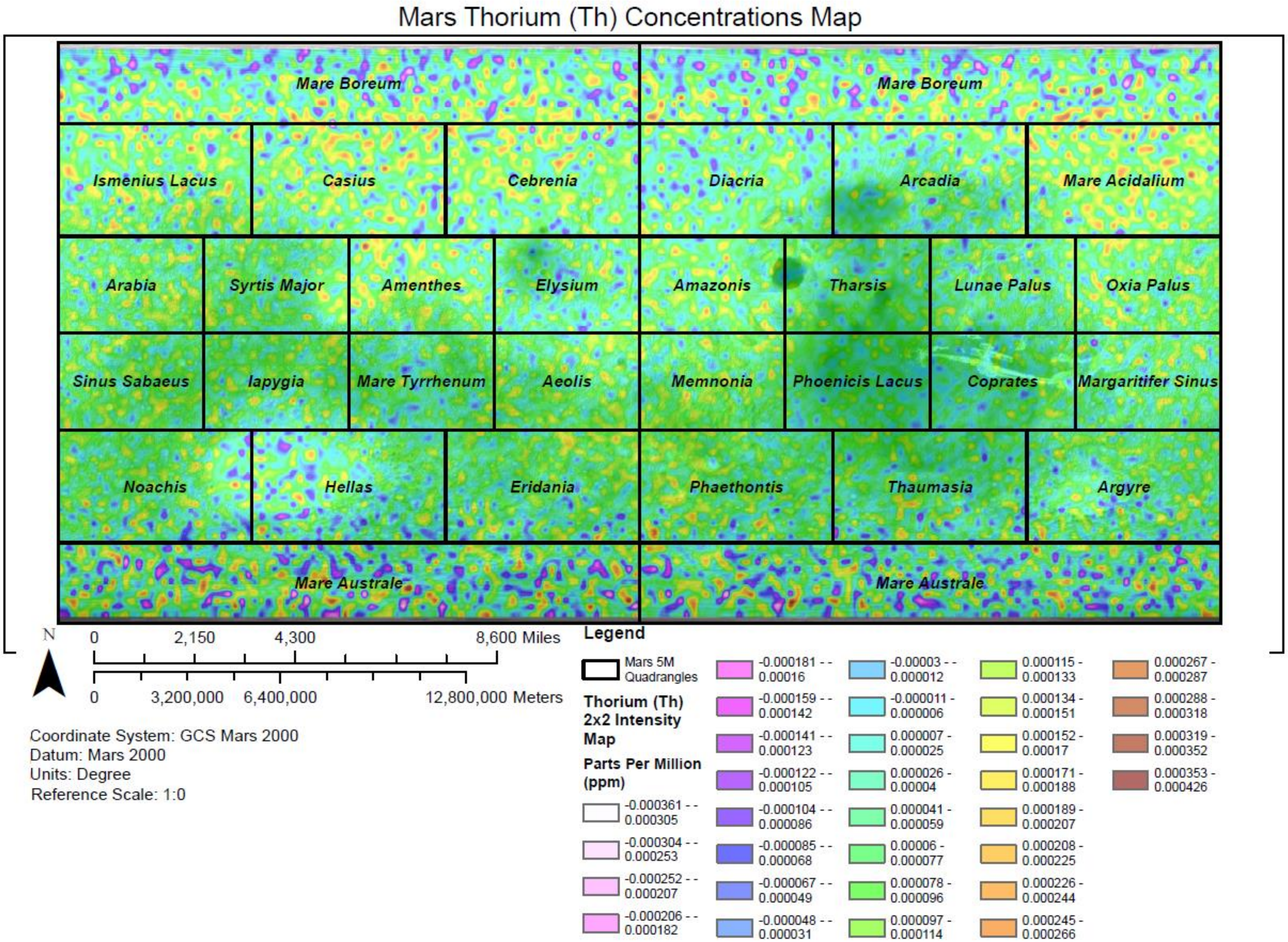
APPENDIX A5: Water Concentrations Map



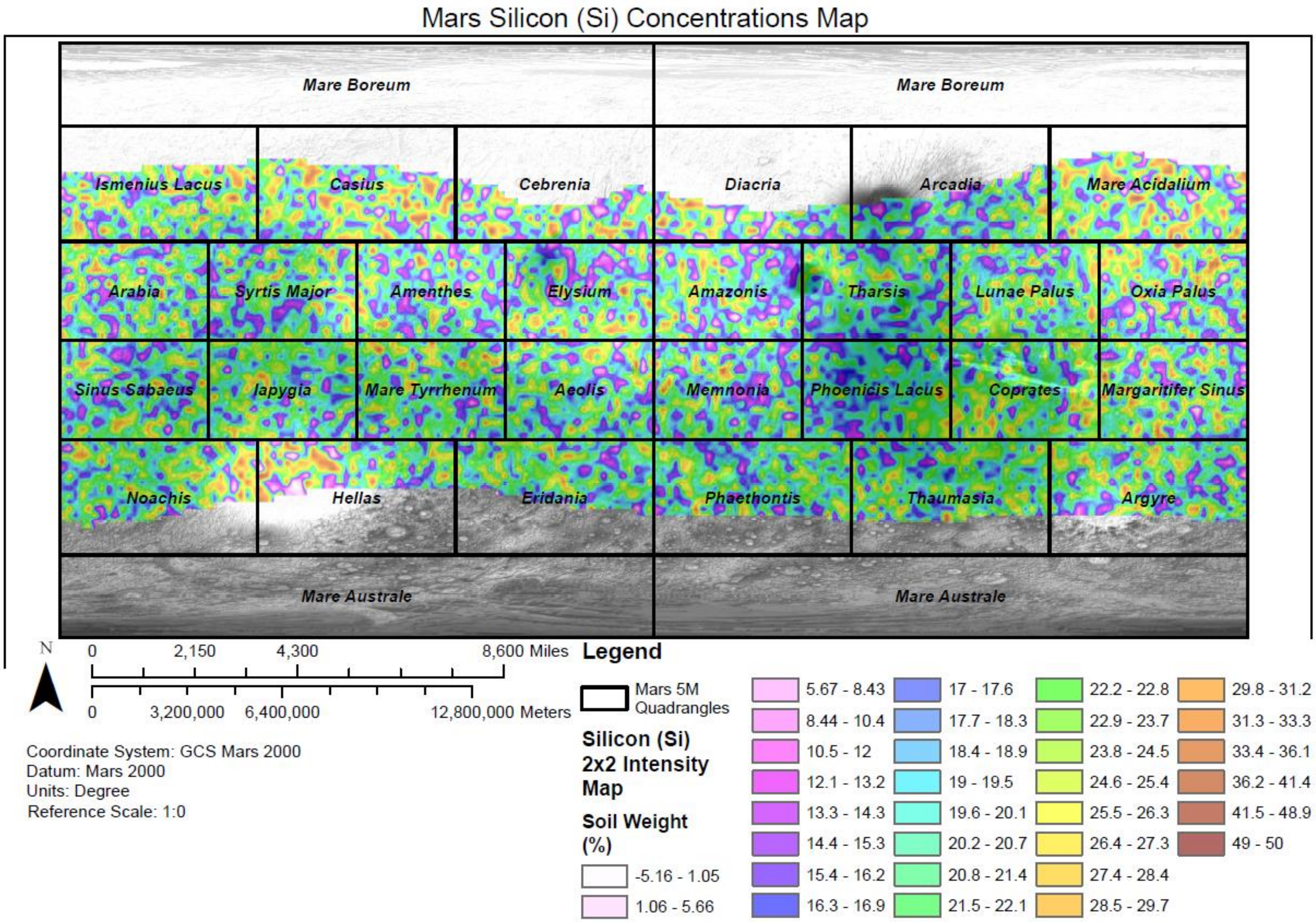
APPENDIX A6: Iron Concentrations Map



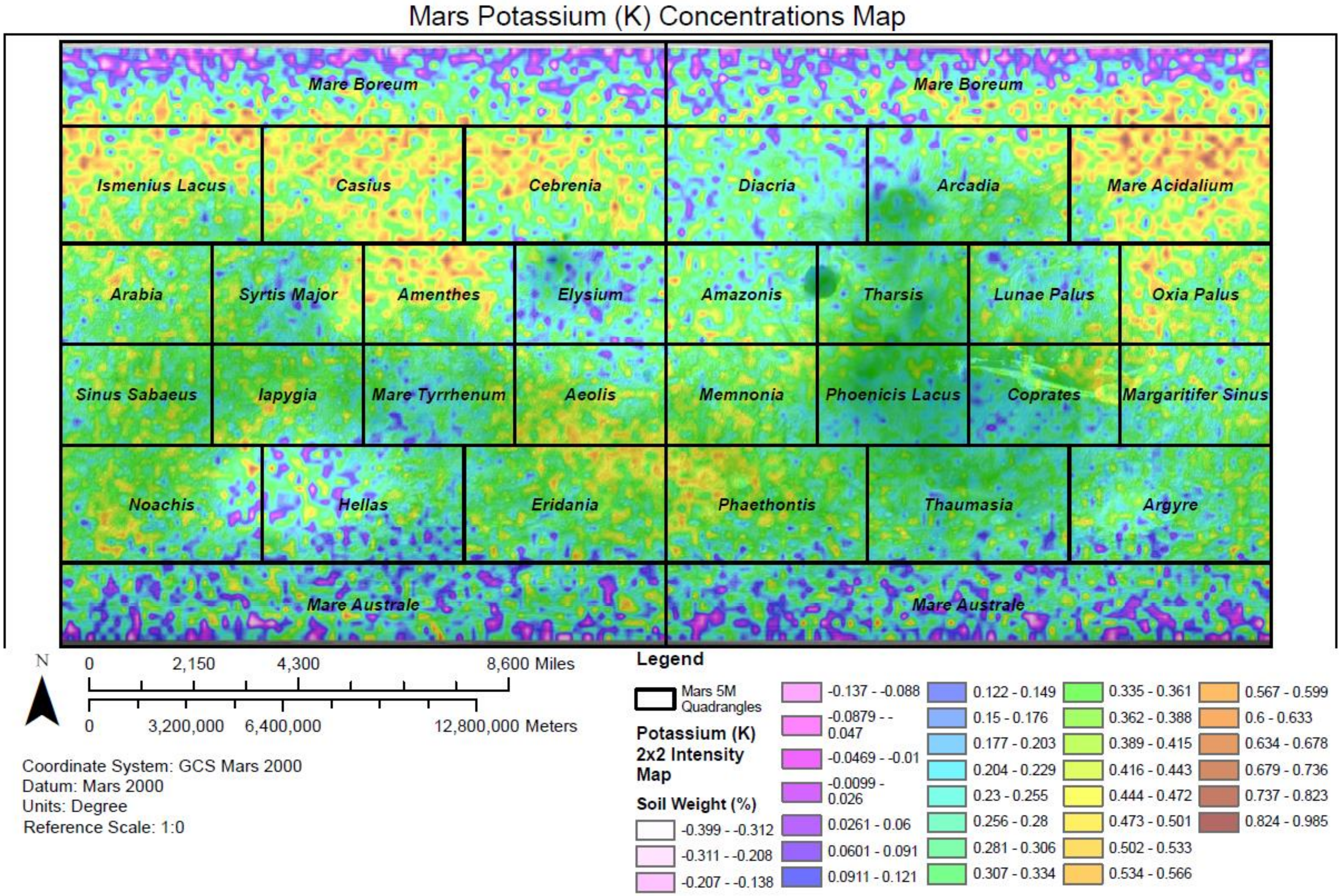
APPENDIX A7: Thorium Concentrations Map



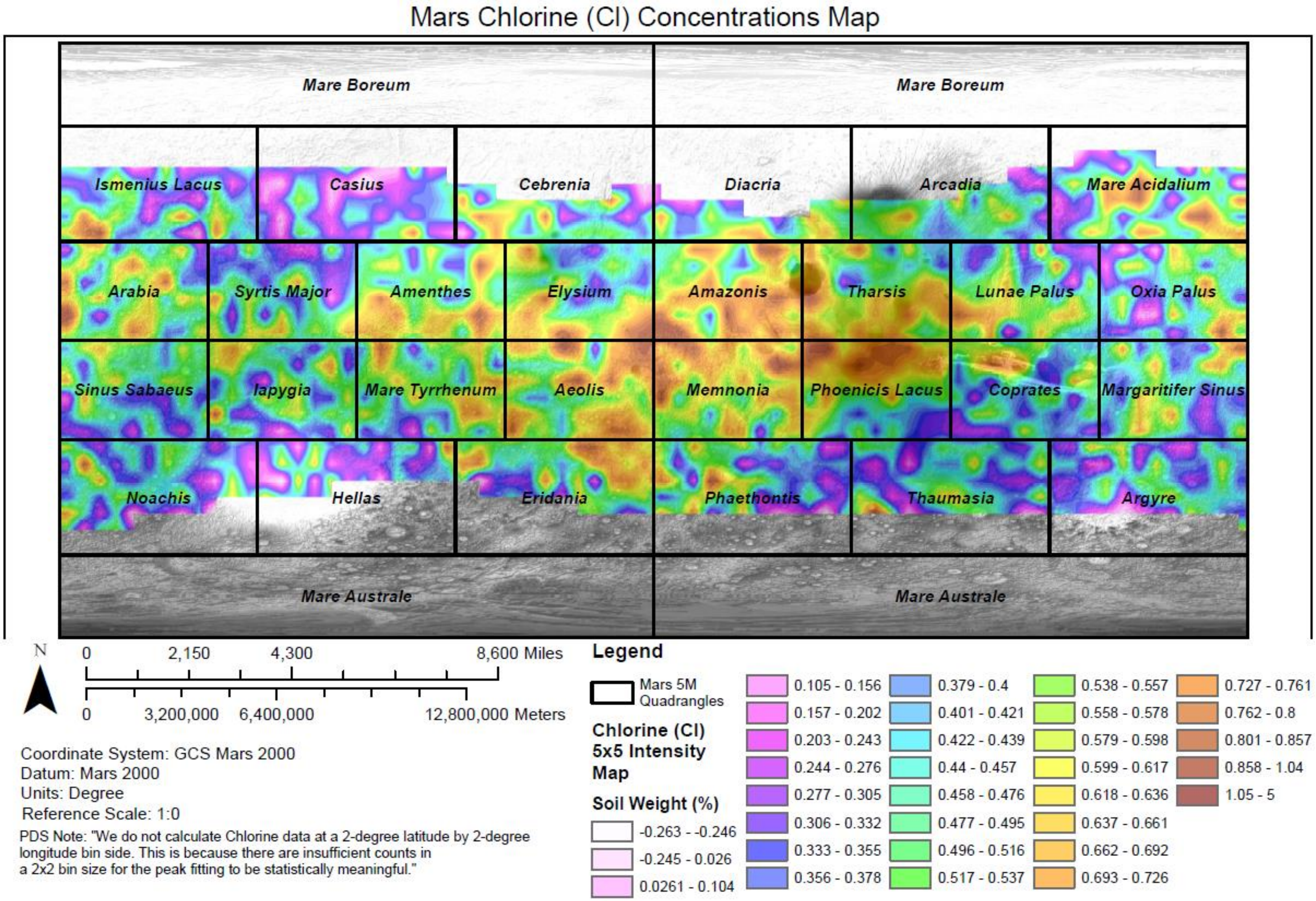
APPENDIX A8: Silicon Concentrations Map



APPENDIX A9: Potassium Concentrations Map



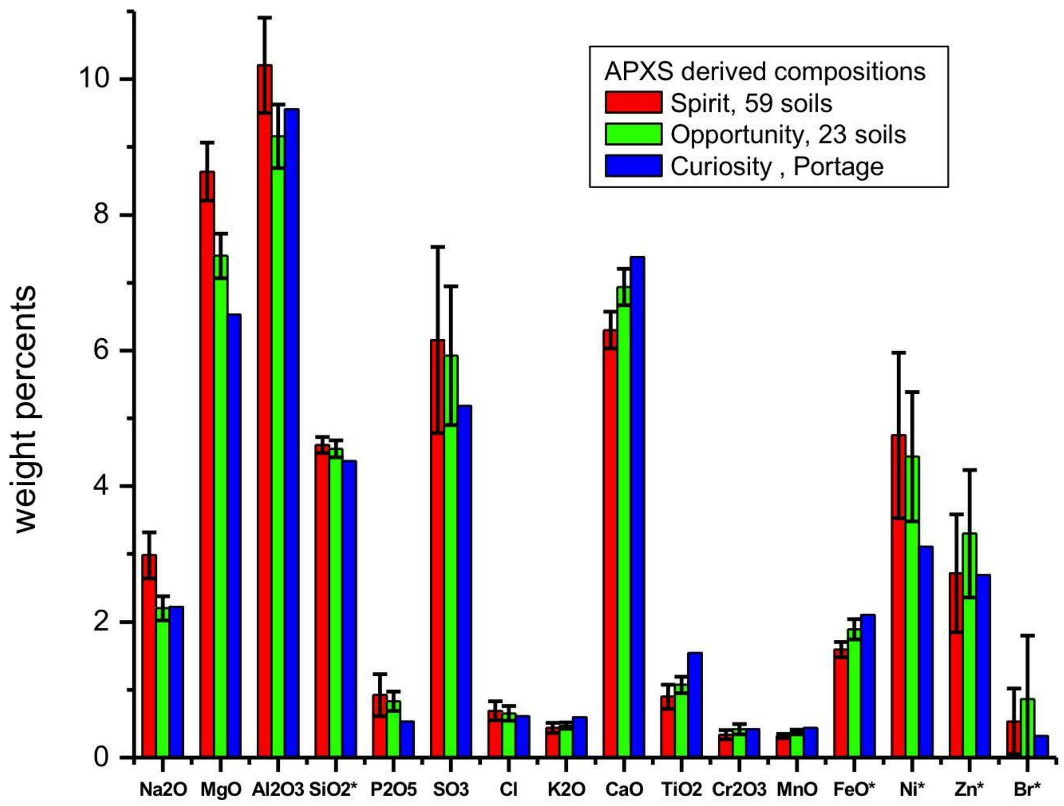
APPENDIX A10: Chlorine Concentrations Map



APPENDIX A11: Curiosity [MSL], Opportunity [MER B], and Spirit [MER A] Rovers Soil Samples

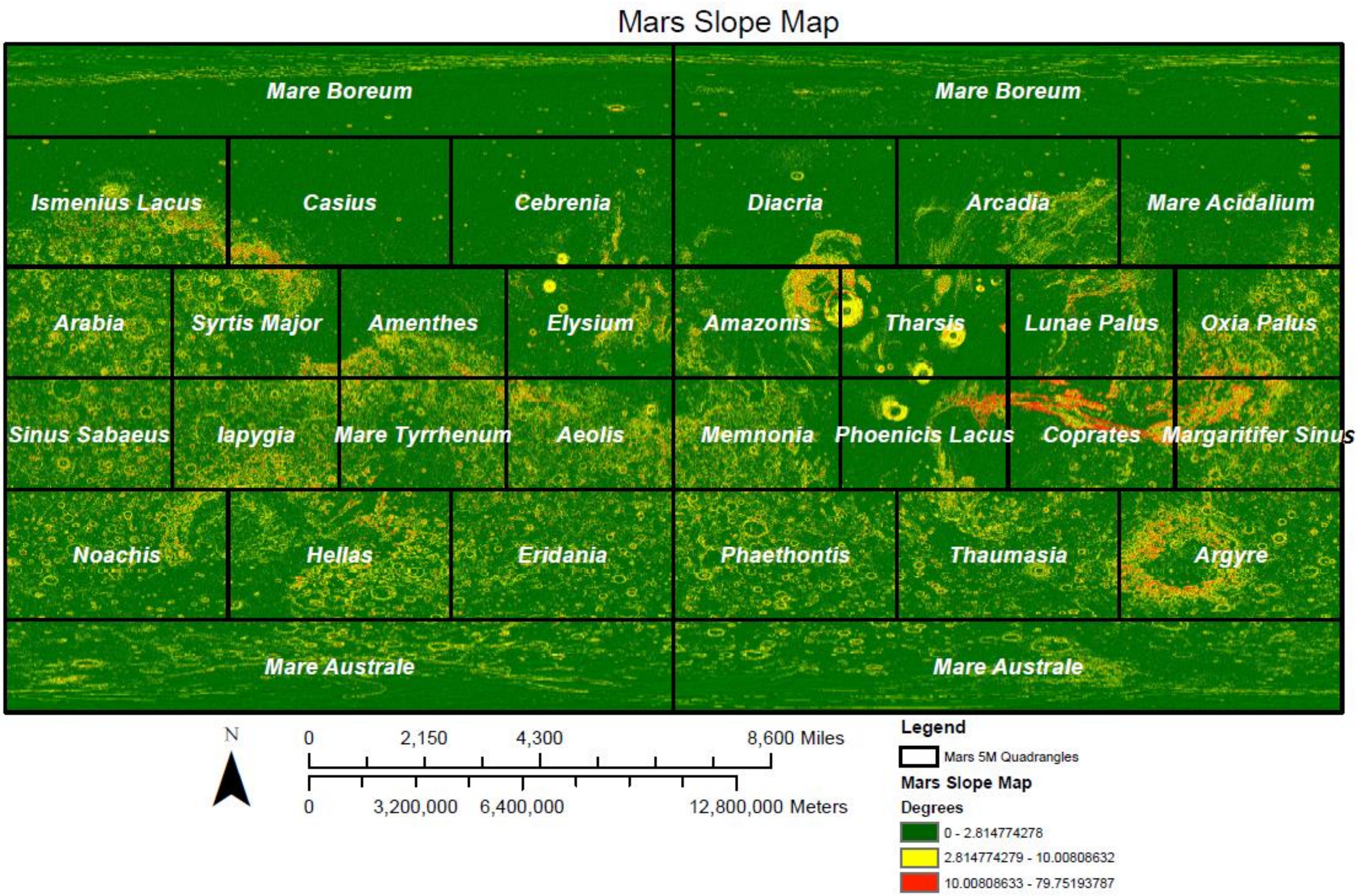
December 03, 2012

"This graph compares the elemental composition of typical soils at three landing regions on Mars: Gusev Crater, where NASA's Mars Exploration Rover Spirit traveled; Meridiani Planum, where Mars Exploration Rover Opportunity still roams; and now Gale Crater, where NASA's newest Curiosity rover is currently investigating. The data from the Mars Exploration Rovers are from several batches of soil, while the Curiosity data are from soil taken inside a wheel scuff mark called "Portage" and examined with its Alpha Particle X-ray Spectrometer (APXS).



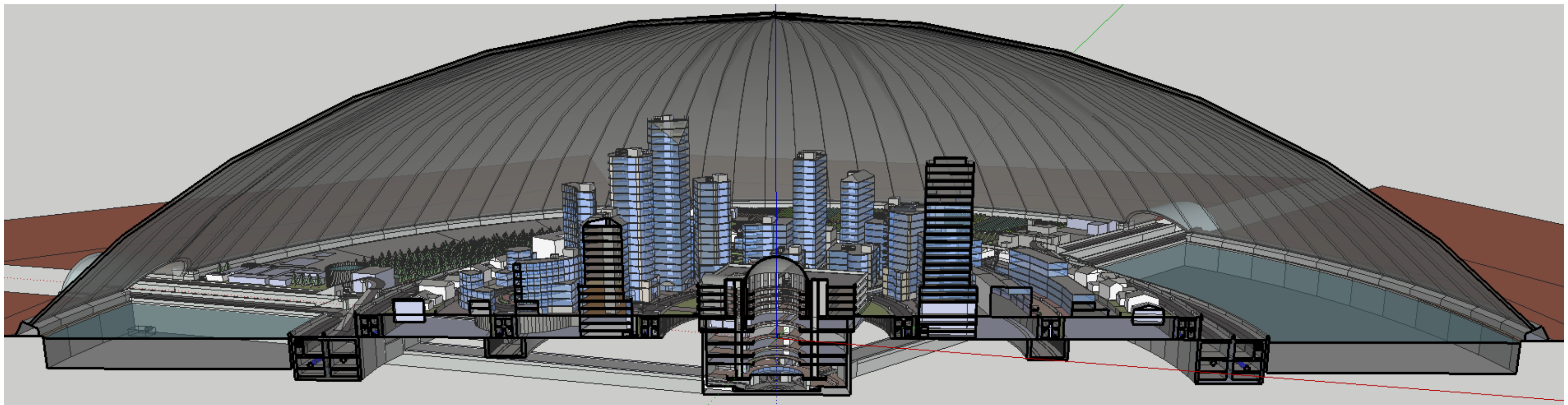
Error bars indicate the variations for the given number of soils measured for the Mars Exploration Rovers along the traverse. Note that concentrations of silicon dioxide and iron oxide were divided by 10, and nickel, zinc and bromine levels were multiplied by 100." **Source:** *NASA/JPL-Caltech/University of Guelph***,** http://photojournal.jpl.nasa.gov/catalog/PIA16572

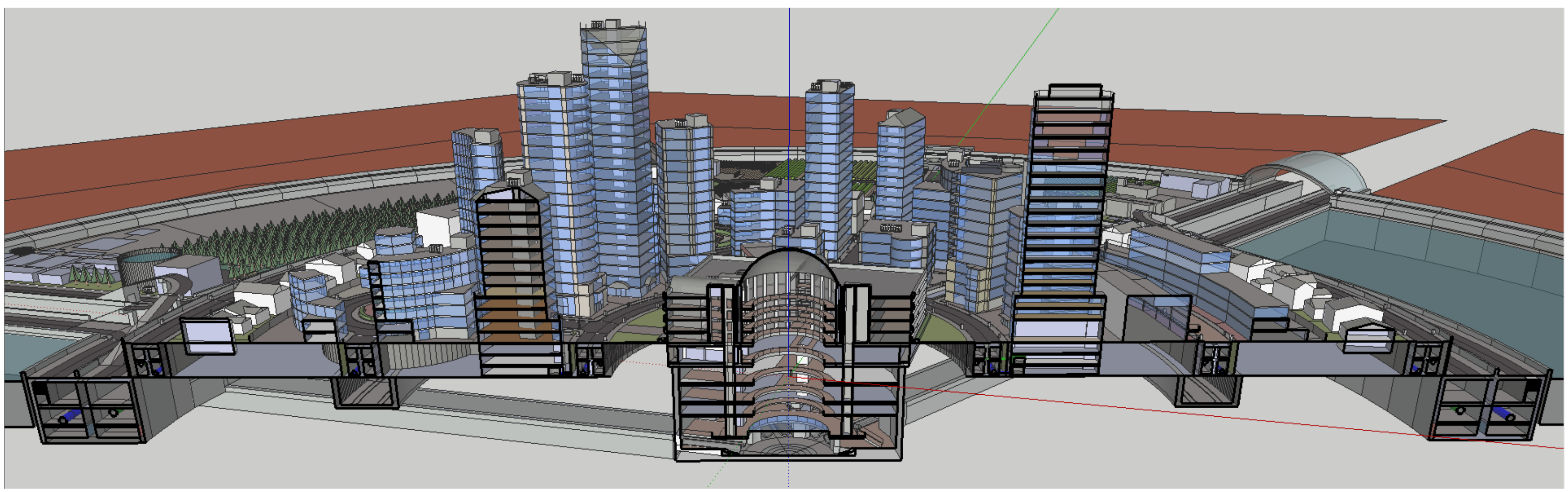
APPENDIX A12: Mars Reclassified Slope Map: (0 = Flat Terrain, 79.75 = Steep Terrain)



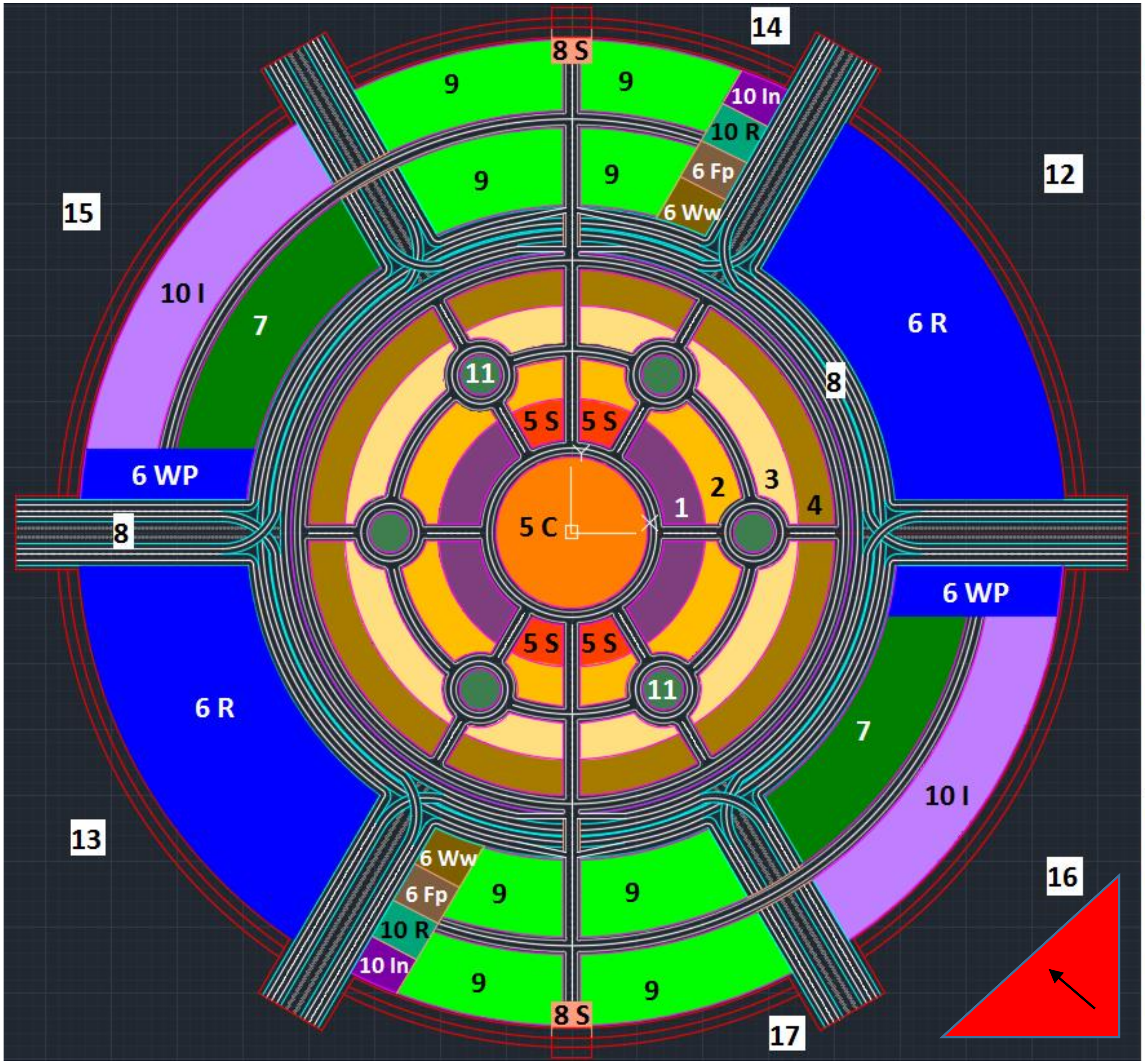
APPENDIX A13: Phase I Cross Section from AutoCAD (As of March 25, 2016)

<u>Top</u>: Dome Layer On. <u>Bottom</u>: Dome Layer Off.



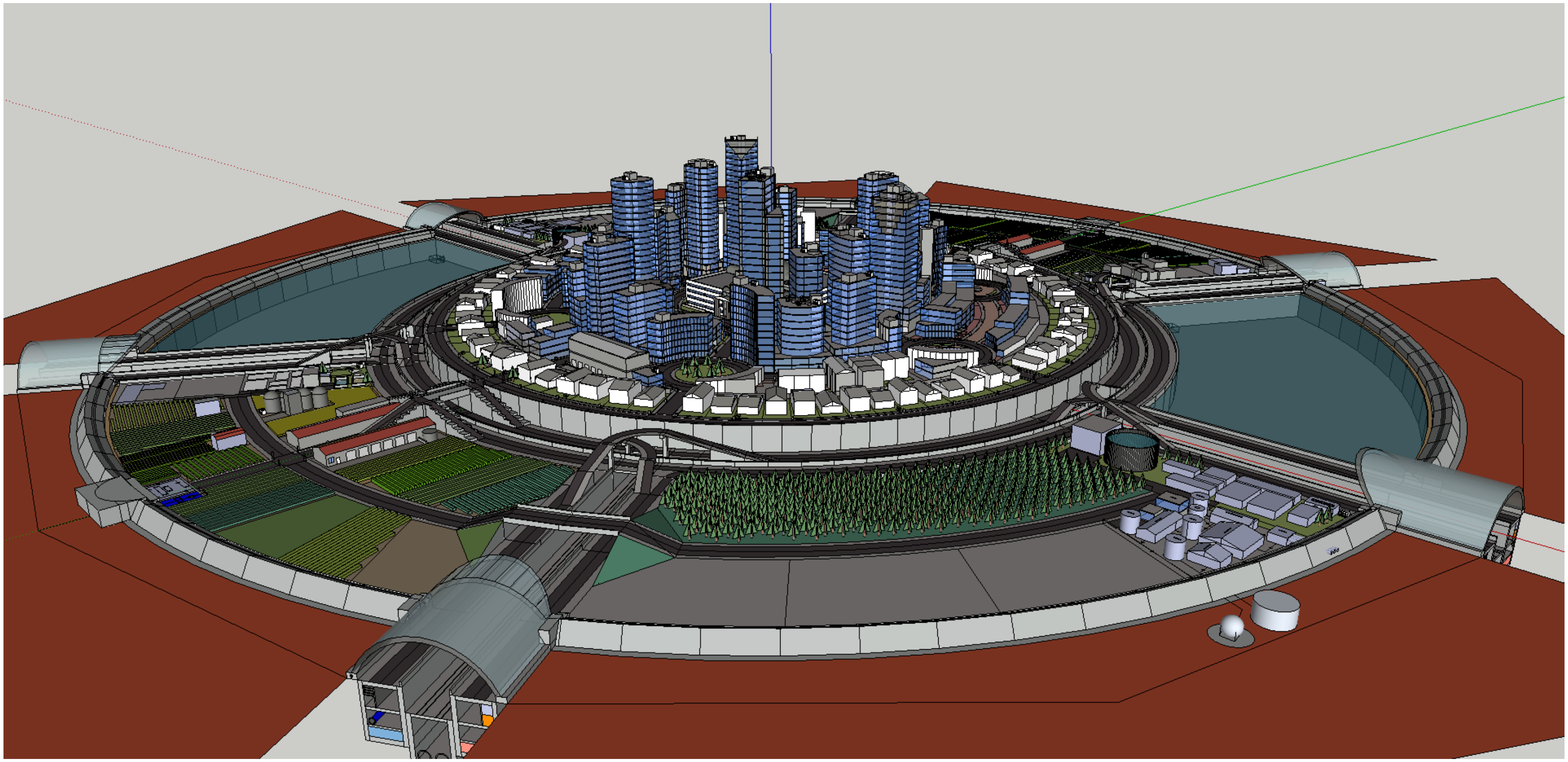


APPENDIX A14: AutoCAD Phase I 2D Model Based off Table 2.3 (Red Triangle = Viewpoint for Appendix A15)



<u>Interior</u>
1 : Sector 1
2 : Sector 2
3 : Sector 3
4 : Sector 4
5 C : Sector 5 Center
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
<u>Exterior</u>
12: Launching Pads
13: Receiving Fields
14: Antenna Fields
15: Power Plant Slot
16: Landing Areas
17: Extraction Fields

APPENDIX A15: Phase I Visualization Screenshot from SketchUp (Dome layer off) [As of 3/25/2016]

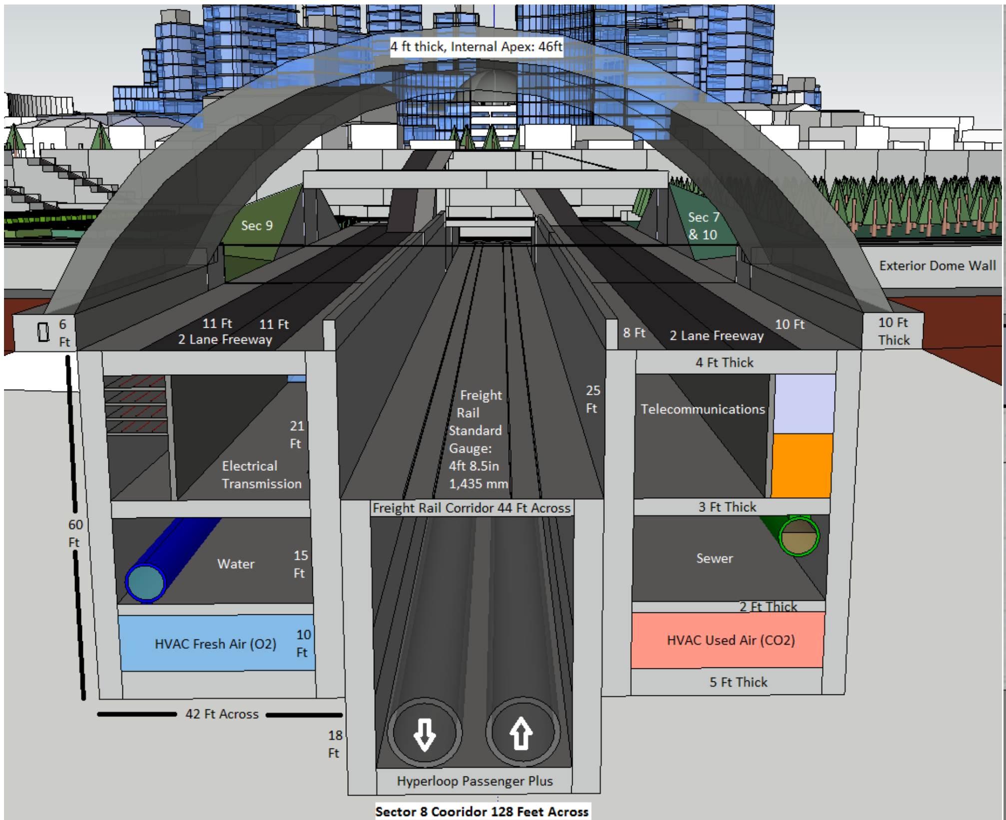


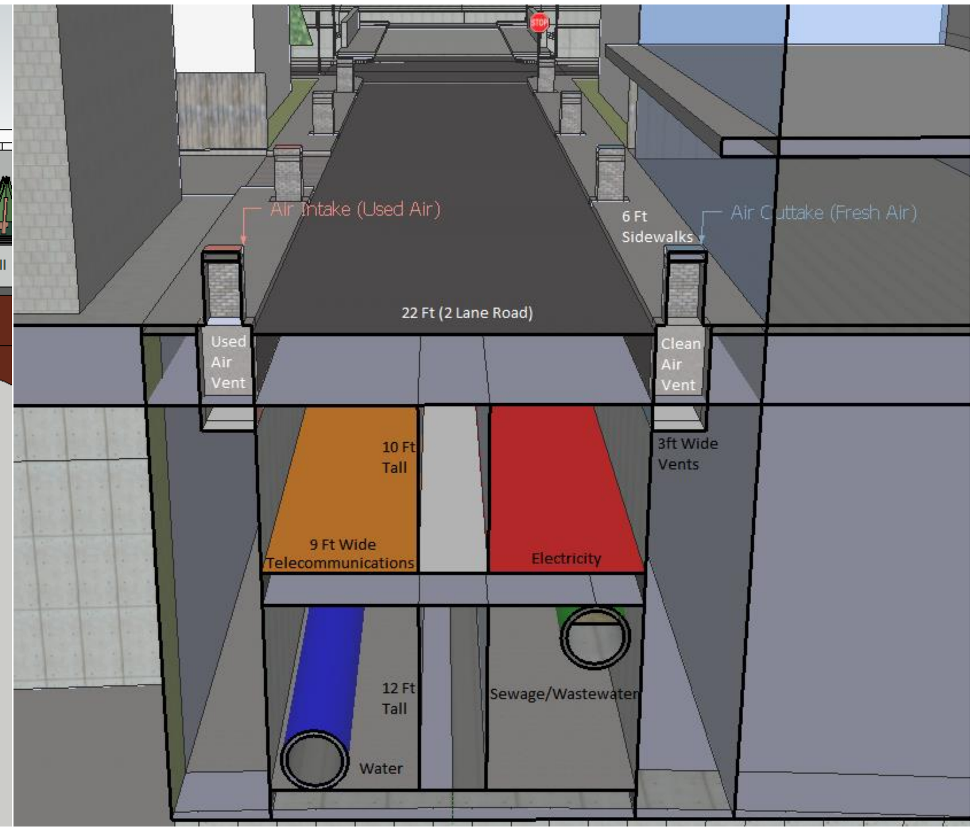
Solid Green Line = North (Y Axis)

Dotted Red Line = West (X Axis)

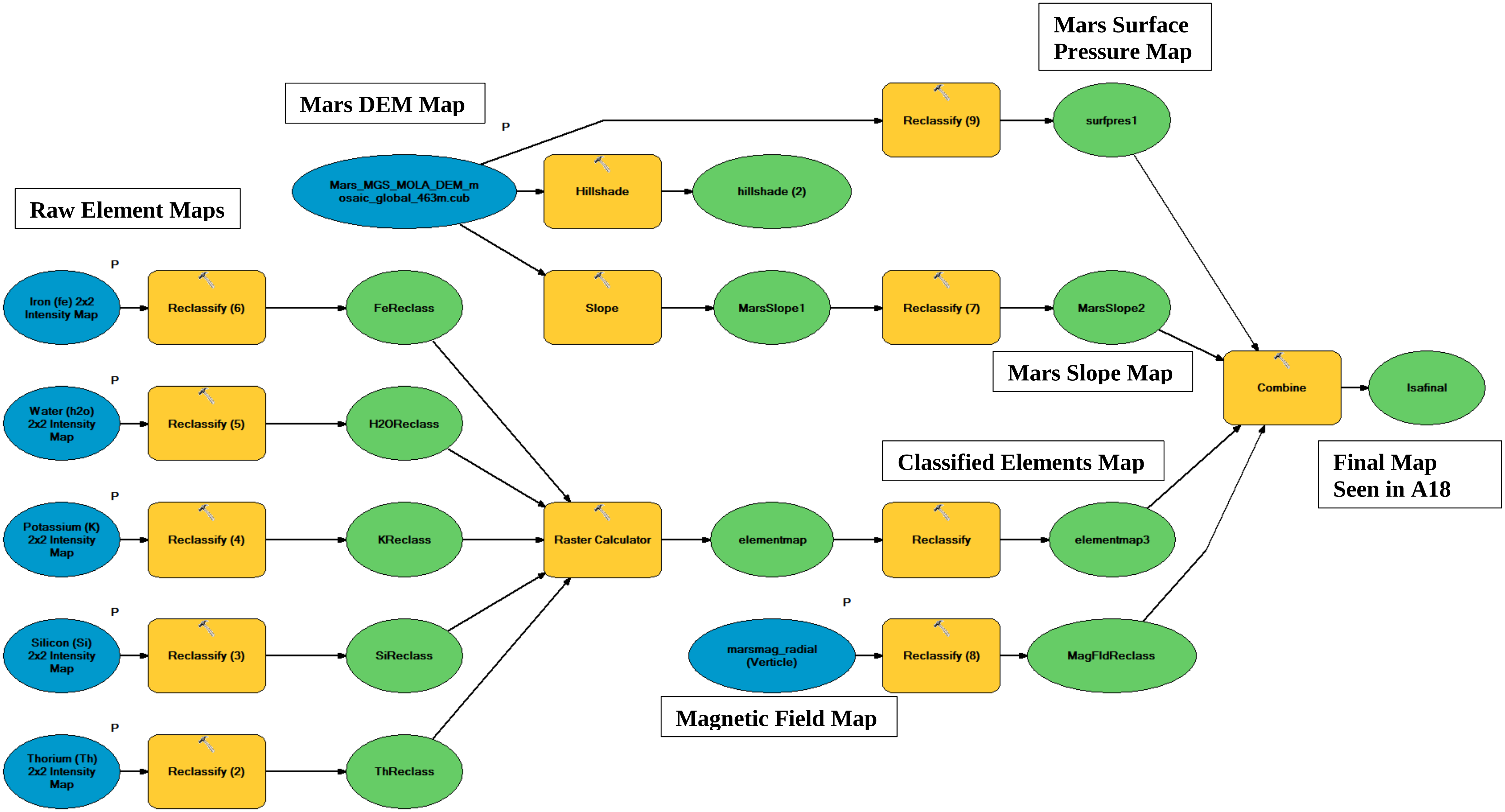
APPENDIX A16: Sector 8 Cross Section (Utility and Transportation Corridors)

Left: Transmission Corridors (City/External Sectors to City). Right: Distribution Corridors (Within Cities).

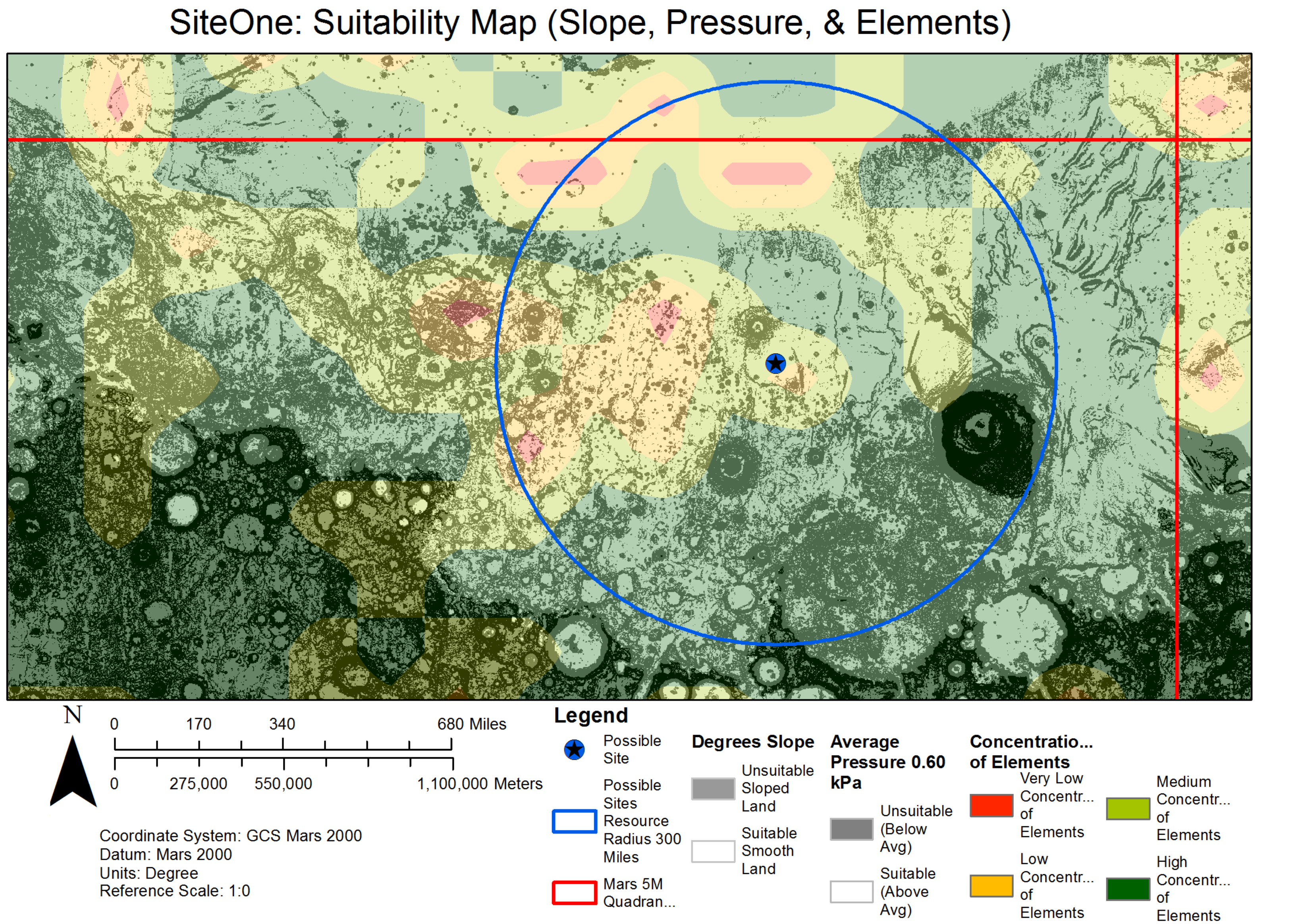




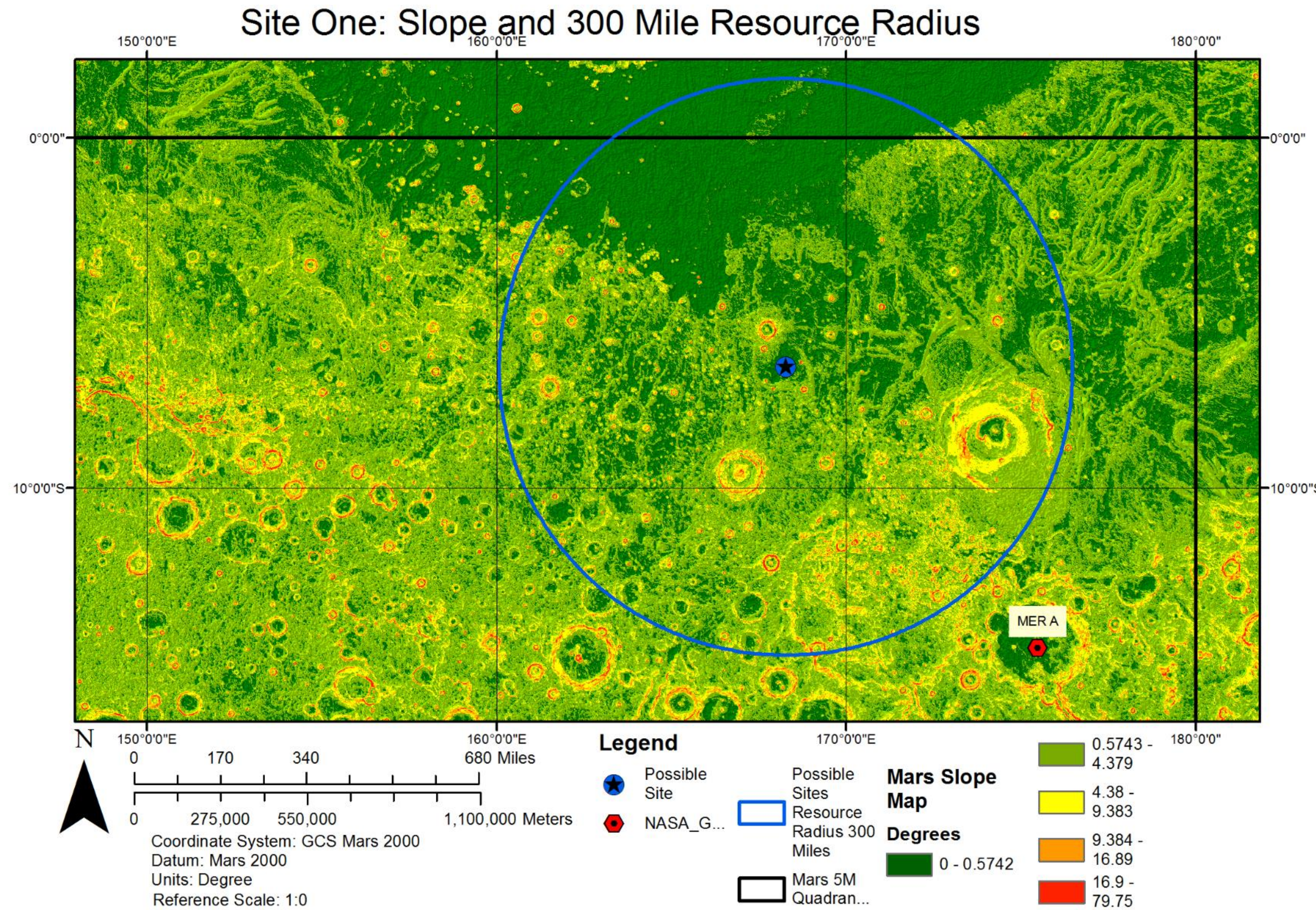
APPENDIX A17: ArcGIS Land Suitability Analysis (LSA) Tool from ModelBuilder



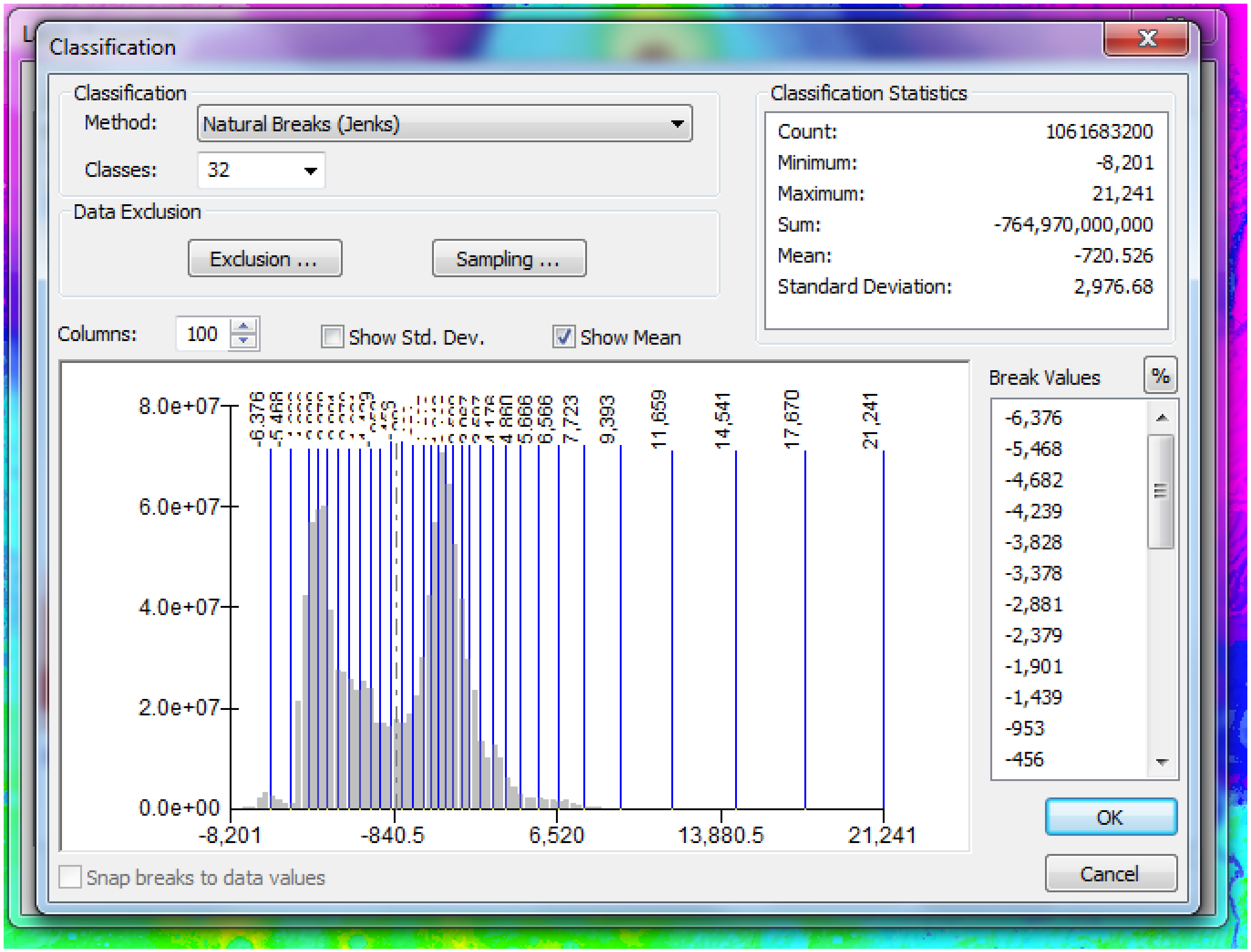
APPENDIX A18: Potential City Location in NE Aeolis based on Suitability Analysis



APPENDIX A19: Potential City Location in NE Aeolis with Resource Radius of 300 Miles/482 Kilometers



APPENDIX A20: Mars DEM Elevation Histogram (Used to find Actual Mean [Average] Elevation of Mars)



APPENDIX A21: Atmospheric Surface Pressure Map of Mars (Based on the Average DEM Elevation)