Appendix G
Units of Measure

A. Measurement
Magnitudes of measurements are typically given in terms of a specific unit. In surveying, the most commonly used units define quantities of length (or distance), area, volume, and horizontal or vertical angles. The two systems used for specifying units of measure are the English and metric systems. Units in the English system are historical units of measurement used in medieval England which evolved from the Anglo-Saxon and Roman systems. The metric system is a decimalized system of measurement developed in France in late 18th century. Since the metric system is almost universally used, it is often referred to as the International System of Units and abbreviated SI.

1. Length

a. English Units
The basic units for length or distance measurements in the English system are the inch, foot, yard, and mile. Other units of length also include the rod, furlong, and chain.

\[ 1 \text{ foot} = 12 \text{ inches} \]
\[ 1 \text{ yard} = 3 \text{ feet} \]
\[ 1 \text{ rod} = 5.5 \text{ yards} = 16.5 \text{ feet} \]
\[ 1 \text{ chain} = 4 \text{ rods} = 66 \text{ feet} = 100 \text{ links} \]
\[ 1 \text{ furlong} = 10 \text{ chains} = 40 \text{ rods} = 660 \text{ feet} \]
\[ 1 \text{ mile} = 8 \text{ furlongs} = 80 \text{ chains} = 320 \text{ rods} = 1,760 \text{ yards} = 5,280 \text{ feet} \]

b. Metric Units
The basic unit of length in the SI system is the meter. The meter was originally intended to be one ten-millionth of the distance from the Equator to the North Pole (at sea level). The meter has since been redefined as the distance travelled by light in a vacuum in \( \frac{1}{299,792,458} \) seconds (i.e. the speed of light in a vacuum is 299,792,458 m/sec). Subdivisions of the meter are the millimeter, centimeter, and the decimeter, while multiples of meters include the decameter, hectometer, and kilometer.

\[ 1 \text{ meter} = 1,000 \text{ millimeters} \]
\[ 1 \text{ meter} = 100 \text{ centimeters} \]
\[ 1 \text{ meter} = 10 \text{ decimeters} \]
\[ 1 \text{ decameter} = 10 \text{ meters} \]
\[ 1 \text{ hectometer} = 100 \text{ meters} \]
\[ 1 \text{ kilometer} = 1,000 \text{ meters} \]
c. English to Metric Conversions
There are two different conversions to relate the foot and the meter. In 1893, the United States officially defined a meter as 39.37 inches. Under this standard, the foot was equal to 12/39.37 m (approximately 0.3048 m). In 1959, a new standard was adopted that defined an inch equal to 2.54 cm. Under this standard, the foot was equal to exactly 0.3048 m. The older standard is now referred to as the U.S. survey foot, while the new standard is referred to as the international foot. All WYDOT surveys use the U.S. survey foot definition.

\[ 1 \text{ meter} = 39.37 \text{ inches} \]
\[ 1 \text{ meter} \times \frac{39.37}{12} \approx 3.2808 \text{ feet} \]
\[ 1 \text{ foot} \times \frac{12}{39.37} \approx 0.3048 \text{ meters} \]
\[ 1 \text{ mile} \approx 1609.4 \text{ meters} \approx 1.6094 \text{ kilometers} \]

2. Area
a. English Units
In the English system, areas are typically given in square feet or square yards. For larger area measurements, the acre or square mile may be used. Historically, the acre was originally established as an area one furlong in length and four rods in width. Laying out ten of these acres side by side is a square furlong (10 acres). Since a mile is eight furlongs in length, there are exactly 640 acres in a square mile. A survey township is a square unit of land six miles on a side that conforms to meridians and parallels. Each township is further divided into 36 one-square mile sections. Because some of the townships have boundaries designed to correct for the convergence of meridian lines, not all townships and their sections are exactly square.

\[ 1 \text{ square foot} = 12 \text{ inches} \times 12 \text{ inches} = 144 \text{ square inches} \]
\[ 1 \text{ square yard} = 3 \text{ feet} \times 3 \text{ feet} = 9 \text{ square feet} \]
\[ 1 \text{ square rod} = 16.5 \text{ feet} \times 16.5 \text{ feet} = 272.25 \text{ square feet} \]
\[ 1 \text{ square chain} = 66 \text{ feet} \times 66 \text{ feet} = 4,356 \text{ square feet} \]
\[ 1 \text{ square furlong} = 660 \text{ feet} \times 660 \text{ feet} = 435,600 \text{ square feet} \]
\[ 1 \text{ acre} = 4,840 \text{ square yards} = 43,560 \text{ square feet} \]
\[ 1 \text{ acre} = 1/10 \text{ square furlong} = 10 \text{ square chains} = 160 \text{ square rods} \]
\[ 1 \text{ square mile} = 1 \text{ section} = 640 \text{ acres} \]
\[ 1 \text{ township} = 36 \text{ sections} = 36 \text{ square miles} \]
b. Metric Units
Areas in the metric system are given in square meters while larger measurements are given in hectares.

1 square meter $= 1,000 \text{ mm} \times 1,000 \text{ mm} = 1,000,000 \text{ square mm}$

1 square meter $= 100 \text{ cm} \times 100 \text{ cm} = 10,000 \text{ square cm}$

1 hectare $= 100 \text{ meters} \times 100 \text{ meters} = 10,000 \text{ square meters}$

1 square kilometer $= 1,000 \text{ m} \times 1,000 \text{ m} = 1,000,000 \text{ square m}$

1 square kilometer $= 100 \text{ hectares}$

c. English to Metric Conversions

1 square meter $\cong 1.1960 \text{ square yards}$

1 square meter $\cong 10.7639 \text{ square feet}$

1 hectare $\cong 2.4710 \text{ acres}$

1 square kilometer $\cong 247.1044 \text{ acres}$

1 square mile $\cong 2.5900 \text{ square kilometers} \cong 258.9998 \text{ hectares}$

3. Volume

a. English Units
Volumes in the English system are typically given in cubic feet or cubic yards. For larger volumes, such as the quantity of water in a reservoir, the acre-foot unit is used. It is equivalent to the area of an acre having a depth of 1 foot.

1 cubic foot $= 12 \text{ inches} \times 12 \text{ inches} \times 12 \text{ inches} = 1,728 \text{ cubic inches}$

1 cubic yard $= 3 \text{ feet} \times 3 \text{ feet} \times 3 \text{ feet} = 27 \text{ cubic feet}$

1 acre \cdot foot $= 43,560 \text{ square feet} \times 1 \text{ foot} = 43,560 \text{ cubic feet}$

b. Metric Units
Volumes in the metric system are given in cubic meters.

1 cubic meter $= 1,000 \text{ mm} \times 1,000 \text{ mm} \times 1,000 \text{ mm} = 1,000,000,000 \text{ cubic mm}$

1 cubic meter $= 100 \text{ cm} \times 100 \text{ cm} \times 100 \text{ cm} = 1,000,000 \text{ cubic cm}$

c. English to Metric Conversions

1 cubic meter $\cong 1.3079 \text{ cubic yards}$

1 cubic meter $\cong 35.3145 \text{ cubic feet}$

4. Mass
The mass of an object is often referred to as its weight though these are different concepts and quantities. Mass refers to the amount of matter in an object, whereas weight refers to the
force experienced by an object due to gravity. In other words, an object with a specific mass will weigh more on the Earth than the moon.

a. English Units
The avoirdupois pound is the primary unit of mass in the English system. Avoirdupois is a system of weight based on the 16 ounces per pound rather than the 12 ounces per pound in the troy system of weight.

1 ounce = 16 drams
1 pound = 16 ounces
1 hundredweight (short) = 100 pounds
1 hundredweight (long) = 112 pounds
1 ton (short) = 2,000 pounds
1 ton (long) = 2,240 pounds

b. Metric Units
The kilogram is the unit of mass in the metric system.

1 gram = 1,000 milligrams = 100 centigrams = 10 decigrams
1 kilogram = 10 hectograms = 100 decagrams = 1,000 grams
1 metric ton = 1,000 kilograms

c. English to Metric Conversions
The avoirdupois pound is defined as exactly 0.45359237 kg.

1 pound ≈ 0.4536 kilograms
1 kilogram ≈ 2.2046 pounds
1 metric ton ≈ 1.1023 tons (short)

5. Angular Measurement
In geometry, any horizontal or vertical angle is measured in degrees. These angles may be given in decimal degrees or degrees, minutes, and seconds.

1 degree = 60 minutes = 3,600 seconds
  e.g. 45.5555 degrees = 45°33’20”

The radian is another unit of measure for angles. By definition, a full circle has $2\pi$ radians or 360 degrees.

$2\pi$ radians = 360 degrees

1 radian = $\frac{360}{2\pi}$ degrees ≈ 57.2958 degrees
6. Temperature

a. English Units
The Fahrenheit scale, or degrees Fahrenheit (°F), is used in the United States to measure temperature. On the Fahrenheit scale, the freezing point of water is 32°F while the boiling point is 212°F at standard atmospheric pressure. The boiling and freezing points of water are exactly 180 degrees apart, making each degree Fahrenheit 1/180 of the interval between the two points.

b. Metric Units
The Celsius scale, or degrees Celsius (°C), is used in the metric system to measure temperature. On the Celsius scale, the freezing point of water is 0°C while the boiling point is 100°C at standard atmospheric pressure. The boiling and freezing points of water are exactly 100 degrees apart, making each degree Celsius 1/100 of the interval between the two points. The Fahrenheit and Celsius scales converge at -40° (i.e. -40°F and -40°C are the same temperature).

\[
(212 - 32)^\circ F = (100 - 0)^\circ C; \quad 180^\circ F = 100^\circ C
\]

\[
1^\circ F = \frac{100}{180} ^\circ C = \frac{5}{9} ^\circ C
\]

\[
1^\circ C = \frac{180}{100} ^\circ F = \frac{9}{5} ^\circ F
\]

c. English to Metric Conversions

\[
^\circ F = \frac{9}{5} * ^\circ C + 32
\]

\[
^\circ C = \frac{5}{9} * (^\circ F - 32)
\]

7. Pressure
Atmospheric pressure is the force per unit area exerted against a surface by the weight of the Earth’s atmosphere above that surface. Because there is less overlying atmospheric mass as elevation increases, pressure decreases with increasing elevation. The standard atmosphere (atm) is an international reference for pressure.

a. English Units
In the English system, air pressure is typically measured in inches mercury (inHg).

\[1 \text{ atm} = 29.2125 \text{ inHg}\]

b. Metric Units
Air pressure is measured in millimeters mercury (mmHg) or millibars (mbars) in the metric system, but may also be measured in pascals or kilopascals.

\[1 \text{ atm} = 101,325 \text{ Pa} = 1013.25 \text{ mbars} = 760 \text{ mmHg}\]
c. English to Metric Conversions

\[ 1 \text{ inHg} \times \frac{1,000}{39.37} = 25.40 \text{ mmHg} \]