SOIL AND WATER MANAGEMENT

Content

Competency Areas

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CA 1: Basic Soil Properties

1. Know the five soil functions.

Soil is a complex matrix of solid materials and void spaces which perform numerous functions essential for life. The solid materials consist of a very intricate array or structure of mineral and organic materials, which interact with the air and water occupying the void (i.e., pore) spaces. The five soil functions include:

1) A Medium for plant growth or bio-materials production. The medium combines with other soil functions to anchor roots and allow for the transport of water and nutrients to the root/soil interface.
2) A Habitat for soil organisms, making up more than half of all "life" on the planet. Micro-organisms are responsible for most of the bio-chemical transformations in the soil medium whereas macro-organisms primarily affect physical soil transformations.
3) A Biochemical or nutrient reactor which absorbs, releases (i.e., desorbs), and transforms inorganic and biochemical compounds such as essential plant nutrients, pesticides, minerals, heavy metals, and numerous other compounds.
4) A Hydrologic buffer which stores (i.e., water holding capacity) and regulates the flow (i.e., drainage) of water in the landscape, allowing for the transport of various inorganic and biochemical compounds within and through the soil medium.
5) A Foundation for the physical support of structures including everything from plants to skyscrapers.

2. Understand the processes of soil formation in the Northeast.
  a. Know the five factors that determine soil formation.
  b. Describe glacial till, glacial outwash, lake and marine sediments, organic, and alluvial deposits.

a. The five factors that determine soil formation are: (1) parent material, (2) climate, (3) relief, (4) biota, and (5) time. Parent material has a significant impact on soil formation; northeastern soils are relatively young and un-weathered having developed from glacial parent material from the last ice age. Glaciations have had a great effect. This compares to soils developed from residual bedrock in un-glaciated areas that tend to be older and more highly weathered, which also relates to the time factor for soil formation. For biota, a good example is that some tree species, especially coniferous ones, release significant amounts of organic acids from their leaves upon decomposition. These acids can dissolve organic matter, aluminum and iron oxides and wash these down into the soil profile. Relief and climate both can have a large effect on erosion and deposition processes related to soil formation. Climate in the Northeast has high amounts of precipitation, which can result in leaching, leaving soils acidic.

b. There are three types of alluvial deposits: floodplains, alluvial fans, and deltas. A floodplain is part of a river valley that is inundated during floods. Alluvial fans are formed where streams exit an upland area into a much broader and flatter valley and sediment is deposited in a fan. Similar to floodplain deposition, coarse material is deposited first, and finer material settles further from the mouth of the valley and main channel. Deltas form as a result of deposition

of the finest material beyond floodplains. Deltas are found in oceans, lakes, and reservoirs near the mouth of the river and consist of clayey soils that are often poorly drained.
Two major effects of glaciation on our soils are: (1) the deposition of glacial till, transported and deposited beneath glaciers and left in place as glaciers melted and receded. The basic characteristic of glacial till is unsorted containing rocks, gravel, sand, silt and clay all mixed together. (2) the formation of glaciofluvial (lake and marine) deposits, which formed when the ice melted and the melting water deposited mostly gravel and sand in mounds (called kames), ridges (eskers), or flat-topped plains (outwash plains). Lakes formed in this period and sediment filled some of the lakes completely. Former lake sediments formed areas of lake plain soils mostly comprised of fine sand, silt and clays. Many shallow lakes filled in with vegetation forming various types of organic soils found throughout the Northeast

3. **Understand and be able to use soil survey information to:**
    a. **Determine soil series at any location**
    b. **Interpret soil properties and suitability for agriculture**
    c. **Determine land use and environmental implications**

a. Access the USDA Web Soil Survey website: https://websoilsurvey.nrcs.usda.gov/app/. Enter a location and then draw an 'Area of Interest' box around a field or group of fields. Click the 'Soil Map' tab at the top. Soil Series Symbols will be displayed, and additional information about that soil can also be found by clicking on the soil series name.
b. A general idea of the suitability of soils in your County can be obtained by clicking on the Soil Data Explorer tab in the Web Soil Survey once you have identified an Area of Interest (see above section). Then, click on the suitability's and Limitations for Use sub-tab, and the Vegetative Productivity option. You can then select from several options related to crop productivity and average crop yields through WSS.
c. Within the Soil Data Explorer tab in the Web Soil Survey (see above sections), you can also learn more about soil characteristics and appropriate land uses and associated environmental implications. This information can be found within the subtabs Suitability's and Limitations for Use, as well as Soil Properties and Qualities.

4. **Understand soil structure and its relationship to crop production and environmental protection.**

Soil structure is the arrangement of the soil particles (sand, silt, and clay) and the pore spaces between them, formed when individual particles bind together to form aggregates. Unlike soil texture (particle size distribution) soil structure can be improved over time with management practices. Adding organic matter, using cover crops, tilling less, and reducing compaction are a few management practices to improve structure. By building a healthy soil structure, farmers can improve drainage, reduce runoff, and achieve higher yields.

5. **Understand different types of soil organic matter, their dynamics, and roles with respect to soil chemical, biological and physical properties.**

Organic matter largely determines the quality of the soil for crop production. Typical mineral agricultural soils have organic matter contents of 1-6%. Organic matter consists of three distinctly different parts: living organisms, fresh residues, and well-decomposed residues (i.e., the living, the dead and the very dead organic matter). Living organic matter is composed of roots, fungi, bacteria, viruses, protozoa, algae, insects, earthworms, and animals. The living portion represents about 15% of the total soil organic matter. Living organisms play an important role in determining soil health. Roots stimulate soil aggregation and create pores in the soil. Most other soil organisms live off the "dead organic matter" and create "very dead organic matter", or humus. In the process, the living organisms recycle large quantities of nutrients and convert them to forms that are available or unavailable to plants. Humus is the product of the decomposition of "dead organic matter". Humus has cation and anion exchange capacity, and thus holds on to essential plant nutrients, storing them for slow release to plants. Humus improves drainage and hence reduces compaction of clay soils and improves water retention in sandy soils. Soil organic matter (SOM) is often grouped into active and passive pools, based on how quickly it cycles. The active pool is made up of fresh residues and microbial biomass that decomposes readily, strongly influencing nutrient availability. The passive pool is composed of older, more stabilized materials like humus that break down slowly and aid in carbon stores and structure.

6. Understand soil carbon dynamics and how organic carbon differs from organic matter.

Soil carbon dynamics describe how carbon enters, moves and is stored within the soil as organic materials decompose and transform over time. Soil organic matter is the fraction of the soil that consists of plant or animal tissue in various stages of breakdown (decomposition). Organic matter contains organic carbon, among other nutrients and elements. Typically, about 58% of the soil organic matter is soil organic carbon.

CA 2: Soil Hydrology

7. Understand the water budget for soil profiles characteristic to the northeast region.

- **a. Soil infiltration**
- **b. Evaporation and transpiration**
- **c. Percolation and leaching**
- **d. Runoff**
- **e. Soil water storage**

a. Soil infiltration

- Infiltration, the entry of water into soil, occurs as a result of gravity and soil water tension forces. Other terms describing infiltration are infiltration rate – the rate, or quantity of water per unit time, at which water enters the soil, and cumulative infiltration – the total quantity (depth) of water infiltrated with time. Soil may have a high infiltration rate, but if for example the water table is close to the soil surface, it will not have much cumulative infiltration.
- Soil infiltration is affected by soil surface conditions, subsurface soil conditions, and other influencing factors associated with weather and previous moisture conditions. Soil surface conditions can be predominant factors affecting whether infiltration will occur, and these include surface sealing, the prevalence of cracks and open pores, or the development of crusts and an impermeable layer. Bare soils may easily develop crusts, or heavily tilled and pulverized soil may destroy the pore size and ability to infiltrate water. Freezing weather creates an impermeable soil surface. Soils which are extremely dry do not conduct water very well, at least not until further wetting occurs, a dry soil surface may initially shed water.

- There are many factors related to subsurface soil conditions that ultimately influence soil infiltration. The most common factors are soil type (or more specifically the texture, structure, and size of soil pores), the existence of soil layers that conduct water differently, and the water content of the soil. Initial infiltration rates are higher when the soil is dry compared to when it is wet because the drier soil has more negative tension. As soil starts to saturate, the predominant force driving infiltration switches from soil tension to gravity. A good analogy is a dry paper towel versus one that is already partially wet. Because of this phenomenon, initial infiltration rates may be quite similar for sand and clay soils. However, once the soil becomes saturated the infiltration rate becomes steady, and this steady infiltration rate is much higher than those for clay soils.
- Special cases of high infiltration to be aware of are when a clay soil has extensive cracks or other soils form large macropores. Soil layers that conduct water at different rates will influence cumulative infiltration. A common example of this is when a plow pan is formed by tillage, causing a shallow compacted layer. Other natural soil layers that have a similar effect are fragipans and unfractured bedrock at shallow depth. Infiltration ceases in a soil that is already saturated due to the surface. Previously wet soils and the presence of a shallow water table will limit cumulative infiltration.
- A common approach to classifying a soil's overall infiltration is the Hydrologic Soil Group (HSG). Hydrologic soil groups are divided into four groups (A,B,C, and D) in which group A has the highest infiltration rate and cumulative infiltration, and group D the lowest.

b. Evaporation and Transpiration

- The combined processes of evaporation of water from soil surfaces and transpiration of water through plants is known as evapotranspiration. The primary factors that affect evapotranspiration, if water is readily available from soil and plant surfaces, are (1) solar radiation, (2) temperature, (3) humidity, and (4) wind.
- Solar radiation and temperature are the thermal sources that cause water to evaporate from the earth's surface. For a clear sky in the Northeast on the first day of summer, the maximum incoming solar radiation potential provides enough energy to evaporate about a half inch of water per day. However, some of this solar energy is absorbed and diffused by clouds (can be significant), some is reflected from soil, water, and plant surfaces (the albedo), and some goes into heating the atmosphere and the soil. Therefore, the potential evapotranspiration is about half to two-thirds the maximum, or generally around one-fourth inch of water per day when summer begins.
- Humidity and wind also influence evapotranspiration. High humidity has the effect of reducing the amount of evapotranspiration that occurs by decreasing the vapor pressure gradient. Similarly, if there is no wind, the water vapor is not transported away from the evaporating or transpiring surface and evapotranspiration is reduced. 'Potential' evapotranspiration refers to the evapotranspiration that would occur if there was ample water on the soil surface and for plants to transpire. 'Actual' evapotranspiration is the evapotranspiration that actually occurs considering a lower moisture content in the soil. The soil water availability (soil coefficient) and type of plant (crop coefficient) further determine the difference between the potential and actual evapotranspiration that occurs.

c. Percolation and Leaching

- Leaching is the removal of soluble material(s) from soil by the passage of water through it, known as percolation. Leaching depends on whether there is a soluble material dissolved in the soil water, and whether this soil water is moving, or percolating. Nitrate-nitrogen is more subject to leaching than ammonium-nitrogen because it is negatively charged. Different soil types have different percolation rates; more can be leached through a gravelly soil because of its higher percolation rate. Percolation and leaching can transport nutrients and other substances to groundwater or to tile drainage networks.

d. Runoff

- Surface runoff occurs when the rainfall rate is greater than the soil infiltration rate (infiltration-excess runoff), or when the soil becomes saturated (saturation-excess runoff). Runoff can happen very rapidly if there is no vegetation or surface depressions that help store it, and the soil surface is sloped. Small depressions on roughly tilled fields may hold considerable amounts of water, delaying the onset of runoff. A vegetative cover on the soil is especially important to intercepting and dispersing the raindrop impact energy of high intensity rainfall events and in slowing the movement of overland flow when it occurs, a thick vegetation mat or sod thatch can provide some water storage.
- Infiltration-excess type runoff rarely occurs on the coarser textured soils or in soils with extensive macropore development. Saturation-excess runoff is common in the Northeast and occurs in areas with shallow water tables or where soils have shallow impermeable layers. Unlike infiltration-excess, saturation-excess runoff occurs in localized areas of the landscape.
- Water that infiltrates and is in excess of the soils available water holding capacity can move laterally beneath the soil surface, especially on restrictive soil layers, and reemerge or 'exfiltrate' at lower elevations. The groundwater runoff can add to streamflow from watersheds and produce springs.

e. Soil water storage

- The soil water storage or soil water content can be quantified on the basis of its volumetric or gravimetric water content. The volumetric water content is the volume of water per unit volume of soil, expressed as a percentage of the volume. The volumetric water content is a convenient and useful way of expressing the soil water content for water budget purposes because the percentage is easily converted into a depth of water for some volume depth per unit area. The gravimetric water content is the mass of water per unit mass of dry (or wet) soil. Factors that affect soil water storage are: (1) the total porosity or void space, (2) the pore-size distribution and connectivity, and (3) the soil water pressure potential or energy status of the soil water.
- The total porosity or void space establishes the upper limit of how much water can be stored in a given volume of soil. When all the pores are filled with water the soil is saturated and cannot store any more water. Total porosity is a function of the soil's particle size, particle uniformity and packing or structure. Soils with good structure will have somewhat higher total porosity than soil that has been compacted (i.e., where the soil particles are forced closer together). Typical soil porosities range from 35-50%.

- Under saturated conditions, large pores drain more easily in response to gravity. When the soil is unsaturated, large pores are less subject to capillary (or matric potential) forces. The soil water characteristic (retention) curve defines the relationship between the soil water pressure potential (matric or suction potential) and the soil water content. This curve can be used to understand delineations between the three types of water contained within the soil: (1) gravitational water (water subject to drainage), (2) capillary water (water available to plants), and (3) hygroscopic water (water that is not available to plants).
- For water movement in soil, the water table is used as a convenient reference because below the water table the total porosity of the soil is saturated, and above the water table, the soil porosity is unsaturated. Below the water table, the pressure potential becomes positive, and above the water table the pressure potential becomes negative. This negative pressure in unsaturated soil is termed matric, tension or suction pressure potential so as not to confuse it with positive pressures. A tensiometer, equipped with a vacuum gauge, is used to measure the negative pressure potential exerted in unsaturated soil. Plants can extract (transpire) the soil water that is held at a negative pressure in unsaturated soil because the plant water energy status produced at the opening of the stomata in the leaves is more negative (around – 15 atmospheres or bars) in response to atmospheric conditions.

8. Know the relationship between the listed soil parameters and soil water content, soil water tension, soil pore size, plant growth and the fate and transport of nutrients and pesticides. Qualitatively understand how these parameters vary for different soil types.

- **a. Field capacity**
- **b. Permanent wilting point**
- **c. Available water capacity**
- **d. Total soil water storage capacity**
- **e. Drainable porosity**
- **f. Soil texture/structure**
- **g. Macroporosity/preferential flow**
- **h. Saturated and unsaturated flow**

a. Field capacity

The field capacity is the amount of water remaining in the soil a few days after having been wetted and after free drainage (the downward water flow due to gravity - the gravitational water) has ceased. The larger pores drain first, so gravity drainage if not restricted, may only take hours, whereas in clay soils (without macropores), gravity drainage may take two to three days. The volumetric soil moisture content remaining at field capacity is about 15 to 25% for sandy soils, 35 to 45% for loam soils, and 45 to 55% for clay soils.

b. Permanent wilting point

The permanent wilting point is the water content of a soil when most plants (corn, wheat, soybeans) growing in that soil wilt and fail to recover their turgor upon rewetting. The matric potential at this soil moisture condition is around -10 to -20 bars or commonly estimated at -15 bar. Most agricultural plants will generally show signs of wilting long before this moisture potential or water content is reached (more typically at around -2 to -5 bars) because the rate of water movement to the roots decreases and the stomata tend to lose their turgor pressure and begin to restrict transpiration. This water is strongly retained and trapped in the smaller pores and does not readily flow. The volumetric soil moisture content at the wilting point will have dropped to around 5 to 10% for sandy soils, 10 to 15% in loam soils, and 15 to 20% in clay soils.

c. Available water capacity

The total available water (holding) capacity (or capillary water) is the portion of water that can be absorbed by plant roots. It is defined as the amount of water available, stored, or released between in-situ field capacity and the permanent wilting point. The average amount of total available water in the root zone for various soil types is given in the table below.

Soil Type	Total Available Water	Total Available Water
	%	Inch/feet
Coarse sand	5	0.6
Fine sand	15	1.8
Loamy sand	17	2.0
Sandy loam	20	2.4
Sandy clay loam	16	1.9
Loam	32	3.8
Silt loam	35	4.2
Silty clay loam	20	2.4
Clay loam	18	2.2
Silty clay	22	2.6
Clay	20	2.4
Peat	50	6.0

Soil types with higher total available water content are generally more conducive to high biomass productivity because they can supply adequate moisture to plants during times of low rainfall. Sandy soils are more prone to drought and will quickly (within days) be depleted of their available water when evapotranspiration rates are high. Shallow rooted crops have limited access to the available soil water, and on sandy soils these crops are particularly vulnerable to drought periods. Irrigation may be beneficial on soils with low available water capacity.

d. Total soil water storage capacity

The total soil water storage capacity or total porosity refers to when all the soil pores or voids are filled with water. This occurs when the soil is saturated or flooded. Peat soil usually has the highest total soil water storage capacity of around 70 to 85% by volume. Sands and gravels will have the lowest total porosity of around 30 to 40% by volume. Total porosity for silt soils ranges from 35 to 50%, and clay soils typically range from 40 to 60%. When the total soil water storage capacity is reached, air is pushed out of the pores or void spaces and oxygen and other gaseous diffusion in the soil is severely restricted. Most agricultural plants cannot tolerate this condition very long as plant root respiration requires some oxygen diffusion to the roots. Root cells switch to anaerobic respiration, which is much less efficient than aerobic respiration. As anaerobic (reduced) conditions develop in the soil, nitrification ceases and denitrification is enhanced. Corn plants will quickly yellow in response to this saturated soil state as nitrogen becomes limiting. Prolonged anaerobic conditions in the soil starts to reduce manganese, iron (causing phosphorus to be more soluble), sulfur (producing hydrogen sulfide), and eventually methane gases.

e. Drainable porosity

The drainable porosity or effective porosity is the pore volume of water that is removed (or added) when the water table is lowered (or raised) in response to gravity and in the absence of evaporation. At its maximum, it's essentially the amount of water available, stored, or released between the total soil water storage capacity and the in-situ field capacity, and is generally referred to as gravitational water. Some average values for the drainable porosity on a volumetric water content percent basis are 2% for clays (with no macropores), 5% for clays with macropores, 7% for sandy clay, 10% for silt, 15% for sandy silt, 20% for fine sand, 25% for medium sand and fine gravel, 30% for coarse sand, and 20% for coarse gravel and pebbles.

Because at low matric pressure potentials big pores empty first, sandy soils will have a larger drainable porosity compared to a loam or clay soil. Macropores or good soil aggregation in loam and clay soils will increase the drainable porosity of these soils, facilitate the drainage removal of this excess water. Nutrients or pesticides dissolved or suspended in this readily drainable pore space will be carried along with this water, flowing to a tile drain or continuing downward to the water table via deep percolation if no drainage restriction exists. In large pores, nutrients that might otherwise adsorb to the soil particles (ammonium or phosphate) will bypass the soil because of limited time for contact and chemical reactions to occur with the soil surface area. Soils with a wide range of different pore sizes (sandy loams) or soils with mostly small sized pores are better at filtering nutrients and pesticides as they leach through the soil profile.

f. Soil texture/structure

The size and percentage of individual soil particles determine a soil's texture, but when the bulk arrangement of these particles is considered, the term structure is used. The clustering or aggregation of primary soil particles into compound particles of naturally formed peds or separate soil aggregates can greatly modify the textural influence on soil air and moisture relationships. The soil texture and structure determine the number and sizes of soil pores, which will influence the fate and transport of air (gas) and water exchange. A good example of structure's influence on water and nutrient movement is that a platy structure usually impairs permeability because the horizontal plates often overlap, but a blocky structure may lead to larger pore sizes than would be found between individual soil particles. The blocky structure effect on pore space is particularly important in clay soils and is generally what provides the drainable porosity. Sands are often considered structureless, because aggregation in sand occurs less frequently. The breakdown of structure by raindrop impact or tillage is what may lead to soil forming crusts or for puddling to occur. Root growth, the actions of microorganisms, and the availability of nutrients are all influenced by structural conditions. Soil structure can be modified naturally by soil organisms. The effect of worm burrows in forming macropores is perhaps best known because it can be easily visualized. Tillage implements also modify the soil structure within, and sometimes below (plowpan), their range of depth influence.

g. Macroporosity/preferential flow

Macropores or macroporosity commonly refers to soil pores through which water flows primarily in response to gravity. Macropores occur in coarse sands and gravels, cracking clays soils, or may form as the result of worm holes, other small burrowing microorganisms, decaying roots, and some tillage operations. When water flows rapidly in macropores, it is also termed preferential flow. The significance of macroporosity and preferential flow is that nutrients and other dissolved and suspended substances can be rapidly transported past the root zone without substantial filtration or other biochemical remediating interactions. Although the magnitude of macroporosity in soils is generally small (less than 5% of the total porosity), the environmental threat may be significant. Macroporosity is beneficial to air and water exchange, soil health, and provides more optimum conditions for plant growth, but can also lead to water quality impacts when dissolved and suspended materials are transported to tile drains or groundwater.

h. Saturated and unsaturated flow

Saturated flow and unsaturated flow are ways in which water moves through the soil, impacted by soil texture, structure, pore size, and organic matter. Saturated flow occurs when all soil pores are completely filled with water. When this occurs, gravity is the primary acting force upon water causing it to move through larger macropores rapidly. Unsaturated flow occurs when only part of the pore spaces contain water causing a much slower movement through micropores. This action is driven primarily by matric potential. In saturated soil conditions, soils with many macropores drain quickly increasing leaching and downward transport of nutrients and possible pesticides.

9. Understand how permeability and infiltration are affected by crusting and compaction, and how they are affected by soil type, precipitation, and management practices.

Permeability is the ease with which gases, liquids, or plant roots can penetrate or pass through a layer of soil. Permeability is a feature of the soil pore size and distribution. It is also a feature of the gas, liquid, or plant root in its ability to diffuse, flow, or penetrate through soil pores. As soil gases primarily move through the larger (non-water filled) pores, compaction (which compresses the larger pores first) can substantially diminish the soil's ability for gaseous exchange. Saturation of pores severely restricts gas permeability and exchange of soil air with the atmosphere.

Liquids differ greatly from air with regards to flow properties. Water is much denser than air, and is incompressible, so it is less sensitive to pressure changes in the soil. A change in barometric pressure or wind will affect gas exchange in the soil, without having much effect on water. Liquid manure is thought to move more quickly than water through soil via gravity because it has a higher density and the suspended organics alter its viscosity. Management practices which reduce the soil's permeability at the surface (makes soil pores smaller or causes them to be blocked or less connected) will reduce infiltrability. Practices such as heavy traffic loads or compressive tillage (plow, disk) which reduce pore size or connectivity at deeper depths may also reduce the soils overall permeability at deeper depths in the soil.

Management practices that reduce permeability often influence the ease with which plant roots can penetrate the soil and grow. Plant roots may have difficulty penetrating and thriving in compacted soils with smaller pores, not only because of changes in air-water relationships, but because of alterations to the soil's bulk density and soil strength. Compared to wheat or corn, tap rooted plants like alfalfa can exert greater root penetration forces to pass through compacted horizons, showing that plants also differ in their conductive ability to get through soil.

10. Understand how seasonal soil conditions and landscape position affect runoff and leaching.

Soil conditions change in response to seasonal changein precipitation and evapotranspiration. In the Northeast, the distribution of the annual precipitation is similar from month to month, but the evapotranspiration peaks in July and diminishes significantly in the colder months. During the months when the rainfall is higher than the evapotranspiration, soil gains water. When the rainfall is lower than evapotranspiration, soil water is extracted. As water content increases, there is a limit to how much water the soil can hold (field capacity). Any rain after the soil reaches field capacity will either drain or saturate the soil (if drainage is restricted). Although some surface runoff can occur anytime in response to large storms, most leaching and runoff (and tile drain discharge) begins after evapotranspiration ceases in the fall, and it peaks in late winter/early spring in response to all the additional water from snowmelt. Runoff starts to decrease in late spring with increasing evapotranspiration. Runoff and leaching are minimal during the late summer months because the soil water content is usually less than field capacity, and the soil can store incoming precipitation.

11. Know simple field methods to assess soil water conditions.

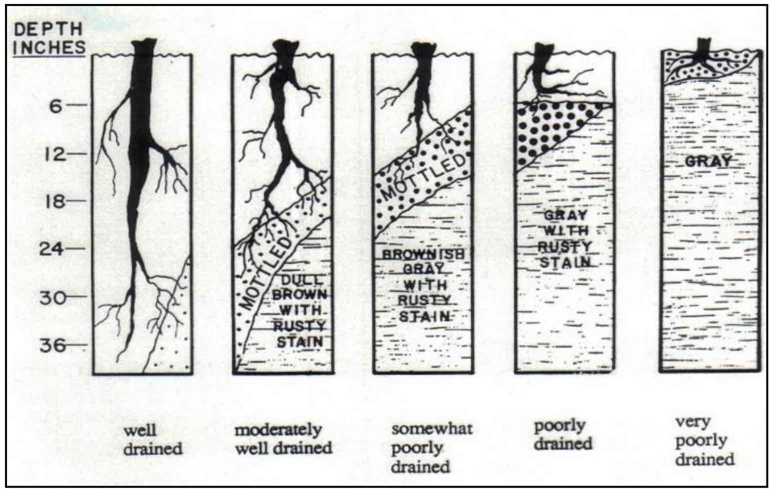
   a. **Observation/visual assessment**
   b. **Measurement devices**

One method to assess soil water conditions in the field is the “Feel” method. When the soil is wet, it will leave water on your hand (about field capacity). When the soil feels moist, it likely will be somewhere in the plant available water content range. Soil that feels dry is usually below the critical threshold of the readily available moisture content. For more detail on the “Feel” method: https://www.wcc.nrcs.usda.gov/ftpref/wntsc/waterMgt/irrigation/EstimatingSoilMoisture.pdf.
Other common tools for measuring and/or monitoring soil moisture include: (1) Tensiometer – a ceramic tipped probe attached to a tube filled with water that directly measures the matric (vacuum) tension or energy status of the soil, and then along with information about the soils characteristic curve, gives the volumetric water content, (2) Resistance (porous) blocks – made with gypsum or ceramic material that measures the electrical conductance of the soil, and then is calibrated to the matric tension or volumetric water content, and (3) Time Domain Reflectometry (TDR) – consisting of two or more probes inserted into the soil providing a measure of the volumetric water content. All of these tools are relatively inexpensive. Depending on the length of the probes, the TDR probes measure the soil water content over a slightly larger volume (rather than at a point) but may be subject to interference or inaccuracies in stony or high organic matter content soils.

CA3: Drainage and Irrigation

12. Understand the relationship between soil drainage class and crop productivity and know where to find this information.

The soil drainage class and some characteristic redoximorphic features associated with each class are depicted in the following figure (from Soil Survey). One characteristic feature in the figure is the depth of rooting that typically occurs in each drainage class, providing there are no other restrictions (i.e., compacted layer) to root penetration. For most common agricultural crops, a deeper and healthy root environment translates into higher biomass productivity. Studies in New York have shown 2- to 3-fold yield increases in corn and forage production on well drained soils as compared to those grown on somewhat poorly to poorly drained soils. Another major benefit of well drained soils is that the soil is more conducive to timely tillage operations without causing soil damage. This is particularly important in the Northeast, where the seasonal moisture distribution causes soils to be wet in the spring and fall, and the growing season is limited.



13. Qualitatively understand how hydrology and soil and landscape properties influence drainage class and drainage criteria.

The soil drainage classification is based on a variety of physical, chemical and biological indicators and interactions. The depth of the water table below the surface, the extent of the rise and fall (fluctuation) of the water table, and the duration that the water table is near the surface are important indicators. The water table may reach the surface of a well-drained soil, but if this happens very infrequently, it does not cause it to be a poorly drained soil. A very poorly drained soil classification arises out of the criteria that the water table remains close to the surface for the entire year. The 'average' depth and duration of the water table position below the surface increases for each better drained condition. High water table conditions are partly a function of the soil type (texture) but are also a function of the most restricting (impermeable) soil layer and the depth of this layer below the surface. For example, there are sandy soils that are classified as poorly drained due to a shallow restrictive layer. Similarly, poorly drained soils can also occur on the top of a hill due to the presence of some impermeable underlying layer. Redoximorphic features are also helpful in identifying drainage limitations of soils. Long-term anaerobic soil conditions reduce manganese and iron which results in grey/green/blue staining of soil peds as shown in the poorly drained classification. Where the water table rises and falls, the soil goes through brief periods of anaerobic and aerobic conditions respectively, which cause iron to oxidize and produce the red/brown/yellow/orange staining (mottles) on soil ped interfaces.

14. Know the advantages and disadvantages of:

- **a. Surface drainage**
- **b. Subsurface drainage**
- **c. Random layout**
- **d. Pattern layout**

a. Surface drainage is the shaping, grading, or management of the land surface to provide gradual removal or diversion of water off the land surface. Surface drainage is accomplished by smoothing out small depressions or regrading an undulating land surface to a uniform slope and directing water to a natural or constructed channel or ditch. Advantages of surface drainage are to minimize the duration of ponded water that inundates crops and prevents cultural operations. Surface drainage is most advantageous on flat fields where slow infiltration, low permeability, or restricting soil layers prevent the ready infiltration of rainfall. A disadvantage of surface drainage is that it has a minimal effect on reducing the saturated subsoil occurring because of high water table conditions. Other disadvantages are that if the water is not removed in a controlled way, soil erosion may occur.

b. Subsurface drainage is the removal of drainable porosity water in the subsoil, with the aim of lowering the water table depth below the crop root zone. Subsurface drainage is usually implemented with the use of buried corrugated and perforated plastic pipe or clay conduits (both commonly called 'tile drainage'). Other less common approaches include mole drains, French drains, and deep open ditches., Once the water table drops to the same elevation as the drain, the drain will no longer flow. The primary advantage of subsurface drainage in the Northeast is the water table can be lowered so soils classified as poorly drained can be improved to respond more like well-drained soils, with the benefits of improved productivity and trafficability. A disadvantage of subsurface drainage is that it is often more costly to implement per unit area compared to surface drainage, especially for fine textured soils. Also, if water ponds on the surface because of surface sealing or a shallow compact layer (plowpan, fragipan), subsurface drainage is not effective in removing this excess water. The environmental disadvantages related to drainage implementation are the loss of wetlands and that drainage water may discharge unacceptable contaminants, such as nitrogen, phosphorus, and pesticides.

c. Topographically driven (random) layout of drainage systems refers to the irregular pattern in which surface and subsurface drainage systems are implemented into the landscape. A random layout mimics and takes advantage of natural drainage patterns, and thus surface ditches and/or subsurface drains are arranged in depressional topography to improve the wettest areas of the landscape. Random systems are well suited to undulating landscapes, where the higher areas of the topography are already adequately drained. Random systems are less costly to install per unit land area improved. A disadvantage of a random layout is that it may not adequately and uniformly drain the area.

d. Pattern layout of drainage systems have well-organized regular spacing of surface and/or subsurface drains across an entire field. Pattern layouts are well suited to long, uniformly sloping fields where the land slope is generally less than 5 to 8%. A pattern layout provides more uniform drainage improvements but will be more costly per unit land area improved.

15. Understand the potential impacts of the following factors affecting soil drainage and the installation of drainage systems:

- **a. Location of bedrock**
- **b. Soil type and texture**
- **c. Topography**
- **d. Organic soils**
- **e. Type of crop**
- **f. Outlet**

a. Bedrock that is massive and un-fractured creates an impermeable boundary which can restrict soil drainage. Soils that are shallow over this type of bedrock will saturate quickly, producing interflow and surface runoff. When this type of bedrock is within less than three feet of the surface, subsurface drains are ineffective and difficult to install. Surface drainage can be used to facilitate removal of ponding or shallow perched water, but benefits are marginal in fine-textured soils where the capillary tension sustains high water content. Shallow bedrock that is highly fractured does not necessarily restrict drainage and high-water tables are usually not present.

b. Soil type and texture influence drainage as the proportions of sand, silt and clay help determine how quickly and how much water will drain from the soil profile. Sandy soils with large particles and large pore spaces often drain rapidly, meaning subsurface drainage can be spaced further apart. Whereas clay soils containing small particles with small pores drain much slower, meaning that subsurface should be spaced closer together. Soil compaction reduces pore space in soils regardless of texture and will hinder drainage.

c. Slope tends to facilitate the overall drainability of soils as excess water has an opportunity to flow to lower elevations. Soils on convex type slopes are often better drained than those within concave slopes. The topography has a significant influence on the type of drainage systems and methods used because the installation of a drainage system by necessity must have a place to discharge the water that is collected. If free draining outlets cannot be found, the use of pumping systems may be the only alternative remaining to enhance soil drainage in low lying areas. Thus, topography determines the layout of a drainage system (i.e., interceptor, random, pattern), and the outlet situation (i.e., natural, constructed open ditch, or pump).

d. The internal drainability of deep organic soils (sometimes referred to as “muck soils”) is rarely a problem because of their prevalence for large pores and high drainable porosity. However, the larger difficulty with draining most organic soils in the Northeast is usually a result of their landscape position. Organic soils have mostly developed in low lying parts of the landscape where the natural drainage of excess water away from these areas is minimal. The installation of drainage systems in organic soils often requires constructing improved open channel outlets to remove surface and subsurface water, diverting water from entering upslope, and pump systems to isolate and dewater soil areas. Since organic soils are most often used and developed for growing high value agricultural crops, more intensive drainage systems are installed to reduce water stress risk. Drains are often installed at closer spacing to remove larger volumes of water in short periods of time.

e. The type of crop and its sensitivity to poor drainage conditions establishes the criteria of whether drainage improvements are needed, and to what extent. The rooting depth of a crop is one important factor, as shallow rooted crops may be able to withstand water tables closer to the surface. One crop may do well whereas another can’t compete. This is often observed when a mixed forage seeding of alfalfa, birdsfoot trefoil, and timothy are grown.

f. A soil may have a high drainable porosity, but its drainability depends on whether this gravitational water has a place to flow. Impermeable layers or a water table within the soil determine whether the drainable water will flow vertically downward, or laterally through the soil. In order for a subsurface drain to lower the water table in the soil, the outlet of the pipe or channel has to discharge to a water surface elevation that is below the elevation of the water table in the soil. If this cannot be achieved by gravity utilizing changes in topography, then pumps are required.

16. Understand the benefits and risks to the environment that are potentially inherent from a drainage system and potential for management of outlet/water control structures.

The major positive environmental effects and concerns with drainage implementation are:

- Increased productivity and value of land – wet soils can be used for more intensive land uses
- Improved trafficability, timeliness, and cost efficiency
- Reduced erosion – saturated soils cannot adsorb additional water so these may induce more surface runoff and erosion.

The major negative environmental effects and concerns with drainage implementation are:

- Land use conversion – wet soils and wetlands converted to agricultural land or other intensive (industrial, urban) land uses
- Habitat conversion – bio-diverse areas converted to mono-culture ecological systems (corn, soybean fields or houses and lawns)
- Water quantity manipulations – drainage water discharges may alter receiving stream hydrographs (i.e., extensive uncontrolled surface drainage may increase downstream peak flows and induce flooding)
- Water quality alterations – water discharged from drainage systems may contain undesirable concentrations of sediment, nutrients, and/or other contaminants that may enter receiving waters.

Potential for management of outlet control:

- Negative impacts from tile drainage can be mitigated to some extent flatter areas by controlling drain tile outlets and storing water back in the field during the non-growing season. Other outlet controls can route tile water through various treatment systems to remove nutrients that may be contained in tile outflows from cropland.

17. Understand the concept of hydric soils, hydric soil indicators, and the regulatory aspects associated with wetlands and the installation of drainage systems.

Hydric soils are defined as soils formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part. The hydric soil indicators may vary by region, but they generally must include observations of pronounced organic matter accumulation since plant decomposition is slower under saturated conditions. Mottled soil near the surface and color hue are key indicators. The very poorly drained and poorly drained soil drainage classifications usually fit the hydric soil delineation. The hydric soil component is a key criterion of wetland delineation for regulatory purposes, and the long-term indicator of the three delineation criterion components (the other two being hydrology and vegetation). The wetland protection rule requires permits be secured prior to draining and altering a delineated wetland. The Federal rule (implemented by the US Army Corps of Engineers) may be more stringent than state regulations, so it is best to check with both jurisdictions prior to implementing a drainage project on suspected wetland areas. Additionally, those growers who participate or plan to participate with USDA must meet the 1985 Food Security Act wetland conservation provisions which assist in protecting the values, acreage, and functions of the nation’s wetlands. The act requires permission to be obtained prior to completing certain activities otherwise USDA benefits could be jeopardized. The wetland conservation provisions of the Food Security Act help ensure producers will not farm converted wetlands or convert wetlands to enable agricultural production.

18. Explain the factors that influence the potential and actual evapotranspiration of crops.

The potential evapotranspiration, if water is readily available from soil and plant surfaces, is influenced by solar radiation (cloud cover), temperature, humidity, and wind factors. The actual evapotranspiration is also a function of the soil water content and the plant's ability to extract the soil water. In the same soil type, plants with deeper rooting depths will have more total water available. As the soil dries, plants have a more difficult time extracting the available water, so a soil coefficient is often used to adjust the potential evapotranspiration to obtain the actual evapotranspiration. Plants vary in their ability and sensitivity to access the total available soil water, so a depletion factor is assigned to arrive at the amount of readily available water. Crop coefficients vary by crop and maturity and are often used to adjust the actual evapotranspiration, relative to the potential, for soil water budget and irrigation scheduling purposes.

19. Understand the relationships of hydrology, the soil water budget, and crop water requirements as these pertain to irrigation system water requirements and the potential benefits of irrigation.

The soil water budget is similar to balancing one's checking account. Rain is a deposit to the soil water budget, and the actual evapotranspiration is a withdrawal. The field capacity water content sets the upper limit of plant available water that the soil can hold. If the rainfall exceeds the actual evapotranspiration, the soil water increases up to a maximum amount (i.e. field capacity). Water additions above field capacity become drainage water or runoff. When the soil water content is less than field capacity, the soil absorbs the rain, and the soil water content increases. When there is no rain, the evapotranspiration gradually depletes the soil water. This can go on for a while, until the plant's available water is gone, and then the plant starts to stress and stops evapotranspiring. Either rain or irrigation must occur at this time to replenish the soil water. In the Northeast, the annual or growing season irrigation system water requirements range from about 4 to 12 inches to offset the difference between the rainfall and actual evapotranspiration amounts. However, for crops with a low depletion factor (sensitive to soil water stress), are shallow rooted, and which are grown on sandy soils, these can rapidly deplete the readily available soil water during times of high evaporative demand. During mid-summer in the Northeast, the average weekly potential evapotranspiration demand is about 1 to 1.5 inches per week. Thus, for the more sensitive crops (potatoes, vegetables, dwarf rootstock trees), only a few days without rain or irrigation may be detrimental.

20. Know the various methods of irrigation and the advantages and disadvantages of each with respect to different soil conditions and crop types.

- **a. Drip irrigation**
- **b. Surface irrigation**
- **c. Sprinkler irrigation**
- **d. Subsurface irrigation**
- **e. Center pivot**
- **f. Lateral irrigation**
- **g. Traveler gun irrigation**

a. Drip/trickle irrigation systems are methods of micro-irrigation for specialty crops wherein water is applied through emitters to the soil surface as drops or small streams. The discharge rate of the emitters is low so this irrigation method can be used on all soil types. The placement of individual emitters can be such that individual widely spaced plants can be watered without watering areas in between, saving considerable water. The emitters can be spaced to water continuous row strips (line-source emitters). Emitters need to be positioned closer together on sandy soils to achieve sufficient lateral spread of the water.
b. Surface irrigation consists of a broad class of irrigation methods in which water is distributed over the soil surface by gravity flow. The irrigation water is introduced into level or graded furrows or basins, using siphons, gated pipe, or turnout structures, and is allowed to advance across the field. Surface irrigation is best suited to flat land, and medium to fine textured soil types which promote the lateral spread of water down the furrow row or across the basin. Surface irrigation is not well suited to root crops or in soils with water tables near the surface.
c. Sprinkler irrigation is a method in which water is sprayed or sprinkled through the air in rain like drops. The spray and sprinkling devices can be permanently set in place (solid set), temporarily set and then moved after a given amount of water has been applied (portable set or intermittent mechanical move), or they can be mounted on booms and pipelines that continuously travel across the land surface (wheel roll, linear move, center pivot). Sprinkler irrigation systems are adaptable to all soil types providing the application rate of the spray or sprinkler device is matched to not exceed the soil's infiltration rate and does not cause erosion. Seedlings and some crops may be sensitive to drop impact if drop size is not controlled, and the sprinkler drops may promote fungi and spread disease on foliage and fruit. Sprinkler systems can also be used for frost prevention, crop cooling, and fertigation.
d. Subsurface irrigation consists of methods whereby irrigation water is applied below the soil surface. The specific type of irrigation method varies depending on the depth of the water table. When the water table is well below the surface, drip or trickle irrigation emission devices can be buried below the soil surface (usually within the plant root zone). The buried drip/trickle method is best suited to medium and fine textured soils which promote the lateral spread of the irrigation water throughout the crop root zone, and it is well suited to all crop types. When the water table is close to the surface, sub-irrigation is the application of irrigation water below the ground surface by managing the water table level within or near the root zone.
e. Center pivot irrigation uses a long rotating pipeline that applies water uniformity as it sweeps around a central point. Known for its efficiency and uniformity, especially when equipped with drop nozzles or low-pressure applicators. Center pivots are well suited for medium to fine textured soils that benefit from controlled application rates and crops like corn and alfalfa. Advantages are low labor needs, adaptable to uneven terrain and good water use efficiency. Limitations include sandy soils where infiltration may be too rapid or irregularly shaped fields where the circular pattern may not cover some areas.
f. Lateral irrigation moves in a straight line across a field, allowing irrigation on rectangular fields more evenly. They are useful when field shape limits center pivot. Advantages include high water use efficiency and uniformity while disadvantages are higher labor demand, as well as guidance systems and water supply lines can be less practical on irregular shaped fields.

g. Traveler gun irrigation uses a large sprinkler that is mounted on a reel which moves across the field. This sprays water in a wide arc making the system flexible for irregularly shaped fields. Advantages include diversity, portability and relatively low labor while being able to irrigate an array of crops. Disadvantages include high application rates, potentially allowing for runoff and erosion.

21. Understand the sources of water for irrigation and how the quantity and quality affects irrigation methods.

The sources of water for irrigation can include surface water sources, groundwater sources, municipal water supplies, grey-water sources, and other agricultural and industrial process wastewaters. Surface water sources include 'flowing' water supplies (i.e., creeks, streams, canals) and 'standing' or stored water supplies (i.e., ponds, reservoirs, lakes). The distinction is important because this may affect the allowable rate of water withdrawal and which irrigation method may be more appropriate. For example, a flowing water supply may not have adequate flow when irrigation is needed most, and thus the amount of water that can be withdrawn at any given time may be limited. Water availability may also dictate that a more efficient irrigation method be used to prevent source depletion. A flowing water supply may carry sediments, and a standing water supply may contain algae that can clog drip irrigation emitters. Both types of surface water supplies are generally of poorer quality than groundwater supplies. Filtration is typically required of most sources when used with drip irrigation. Groundwater supplies may come from springs and wells, and although the quality is usually good, the available quantity that can be pumped at any time may limit the irrigation method. Municipal water supplies are good quality sources but are limited in the amount one can withdraw at any time. Tap size, usage fees, and water use restrictions must be considered, and backflow prevention of some type is required. The Food Safety Modernization Act focuses on the prevention of contamination to the U.S. Food Supply. This act can impact the irrigation method and source some farms utilize. To learn more, see: https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-final-rule-pre-harvest-agricultural-water.

22. Describe the components of irrigation scheduling and understand decision models with regard to irrigation.

Irrigation scheduling is a soil water budget accounting process to determine when irrigation is needed and the amount of irrigation water to apply. The important components of irrigation scheduling include:

- Rainfall amount
- Potential evapotranspiration amount
- Field capacity soil water content
- Wilting point soil water content
- Allowable crop depletion factor
- Crop rooting depth
- Time of planting

This information allows one to determine the readily available amount of water in the plant root zone, estimate the actual evapotranspiration depletion, and account for rain replenishment. The time of planting is important relative to the potential evapotranspiration amount and is used to account for the changes in root growth and crop canopy development (crop coefficient).

CA 4: Soil Health

23. Understand the concept of soil health and know and identify some indicators.

Soil health (also called 'soil quality') can be described as the capacity of a soil to function, within ecosystem and land use boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health. Soil health is an aggregate concept affected by chemical, physical and biological factors. Chemical indicators may include pH, cation exchange capacity (CEC), extractable P, K, and other macro and micronutrients. Physical indicators may include soil texture, surface and subsurface hardness, bulk density, aggregate stability, and available water capacity. Examples of biological indicators are soil organic matter, soil organic carbon, labile carbon, soil respiration, bioavailable nitrogen.

24. Describe different types of soil compaction and understand their agronomic and environmental implications.

a. Plow layer b. Subsoil c. Crusts d. Surface

a. A plow layer, sometimes referred to as a tillage pan, is created by repeated use of moldboard or disk plows at the same depth. The soil just below the tillage tool is compacted and becomes denser than the rest of the soil below or above it. Soil texture and soil moisture can impact the extent and severity of soil compaction. One of the consequences is inhibition of root penetration through the plow pan. A plow pan can inhibit drainage and cause problems with trafficability and aeration.

b. Subsoil compaction, also referred to as deep compaction, is caused by heavy machinery traffic at times when the soil is moist (in the plastic state). Subsoil compaction is primarily related to axle load. It negatively affects root penetration and water percolation. Deep compaction can be difficult and financially expensive to alleviate. Prevention is key.

c. Crusts, or surface sealing, are caused by the impact of raindrops on the soil surface. If the soil is unprotected and has poor aggregate stability, soil fines will disperse and fill surface pores. Infiltration capacity is reduced quickly and runoff results. Crusts can significantly harm germination of young seedlings which have trouble breaking through the crust.

d. Surface compaction can occur anywhere from the surface down to a normal tillage depth. Equipment traffic or livestock surface compaction results in reduction of pore space in the topsoil that increases risk of runoff, reduces aeration, and can cause planting problems and reduced root growth.

25. Understand the processes and management practices that cause soil compaction and their relative significance under Northeast conditions.

a. Equipment traffic and load distribution c. Tillage methods
b. Timing/frequency/intensity of tillage d. Livestock

a. Surface compaction is primarily caused by surface pressure, which can be the result of animal hoofs or equipment traffic. Typically, surface compaction can be alleviated by plant root growth and biological activity. Subsoil compaction is primarily due to axle loads. When axle load exceeds 10 tons the threat of subsoil compaction is great. If the load can be distributed over a larger footprint area or over multiple axles, subsoil compaction is reduced. Controlled traffic farming can also help reduce overall field compaction by confining all high-load wheel traffic to specific lanes in fields year after year.

b. When soils are tilled or trafficked in their plastic state, they are highly sensitive to compaction, while the soils are sensitive to rutting in their liquid state. In the friable state soils are less sensitive to compaction.

c. The moldboard and disk plows are the two tillage tools that pose the greatest threat to soil compaction as they are the most likely to cause formation of a plow pan. In-furrow moldboard plowing is the worst because, in addition to the tillage tool causing compaction, the wheels or animal hoofs cause direct subsoil compaction.

d. When animals repeatedly stand or walk on the same areas, gather around gates, feeders and water troughs, their weight compacts the soil. Rotational techniques and moving feed/water locations can help reduce the risk of compaction.

26. Understand the relation between soil compaction and the following factors. Understand each factor's relation to plant growth and important soil chemical and biological processes.

a. Aeration
b. Aggregation/structure
c. Runoff and erosion
d. Drainage

a. Soil compaction reduces pore volume, especially of the larger pores. This reduces air-filled porosity and aeration. This affects root function, because most crop roots will be negatively affected below 10% air-filled porosity. Poorly aerated soil leads to greater denitrification losses. Many aerobic soil organisms will be limited in poorly aerated soils.

b. Soil structure will degrade upon compaction. Soil bulk density will increase. Most damage is done when soils are trafficked or tiled in their liquid state, and most compaction occurs when soils are in the plastic state.

c. Runoff and erosion will increase as an effect of compaction because of the reduced pore volume and decreased infiltration and percolation.

d. Drainage will be compromised because of the reduced pore size and subsequent water percolation rate in compacted soils.

27. Understand variation in susceptibility to compaction among soil types due to:

a. Drainage
b. Texture

a. Poorly drained soil will be in the plastic state for longer periods during the year and therefore will be more susceptible to both shallow and deep compaction.

b. Soils with high clay content are highly sensitive to soil compaction. This is partly because they dry out slowly and this causes them to be in the plastic state for long periods of time. Clay particles also easily slide over each other causing them to pack more easily than sand or silt particles which are not plate-like.

28. Understand the effect of soil compaction on root and shoot growth and crop yield.

Root growth is restricted and shoot growth may be compromised in compacted soils. Seedlings will have difficulty emerging in compacted soils, while shoot growth will be reduced after emergence because of a reduced root system, nitrogen deficit due to denitrification, and inhibited root function due to lack of aeration. Crop yields can be reduced 50% in very severely compacted soils, but usually compaction losses will be hard to perceive because they are in the 2-5% range. Left untreated, compaction will continue to affect crop yields.

29. Understand appropriate use of a soil penetrometer and how to detect compaction layers.

Penetration resistance measured with a penetrometer is highly dependent upon soil moisture status. Use caution when using a penetrometer to assess compaction unless you know that locations being compared are at the same moisture content and of similar texture. A soil penetrometer is a diagnostic tool used to measure the depth and extent of soil compaction. The penetrometer usually comes with two cones depending upon the soil its being used in. The tool provides a PSI rating to measure resistance. The penetrometer is best used when the field is at field capacity.

30. Understand how compaction can lead to soil and water degradation. Understand the broader environmental consequences of soil degradation from compaction affecting:
   - **a. Energy requirements**
   - **b. Pesticide use**
   - **c. Runoff and water quality**

a. Energy requirements of tillage implements increase significantly due to compaction. The energy requirements to alleviate some forms of compaction such as deep compaction is very energy (fuel) intensive. The Revised Universal Soil Loss Equation (RUSLE2) can be utilized to quantify the estimated fuel usage associated with various farming operations.
b. Cros that are less vigorous, are more likely to suffer from weed infestations, disease pressure, and insect attacks, thereby increasing the need for pesticides. Surface crusting can inhibit water infiltration which can negatively impact effectiveness of some pre-emergent herbicides.
c. Compaction increases runoff and compromises surface water quality.

31. Describe approaches for remediation of soil compaction and understand when they are appropriate.
   - **a. Crop rotation**
   - **b. Deep tillage (subsoil compaction)**
   - **c. Organic matter additions and cover crops**
   - **d. Reduced tillage (plow layer compaction)**

a. Crop rotation can remediate some soil compaction depending upon the type, depth, and extent by integrating different root structures within the soil. Deep rooted crops and cover crops can help break through compacted soil layers improving aggregation and increasing organic matter. It is recommended to include a sod or deep-rooted crop every 3–5 years in row-crop systems
b. Deep tillage can help to remediate subsoil compaction and can break through plow pans. The benefits of deep tillage are usually short lived unless management adopts strategies to avoid or prevent further compaction. Deep tillage is only effective if the compacted layer is drier than the plastic state and will actually fracture.

c. Organic matter can improve the resistance of soil to compaction. Increasing the soil organic matter by reducing tillage and using high biomass crop rotations with cover crops can help create pathways for the roots of summer crops to follow. Increased soil organic matter levels improves aggregate stability which can help the soil be more resilient to compaction. The roots also make pores that improve infiltration and aeration.

d. Shallow tillage in the top 0-12 inches can help to remediate damaged/rutted soil and to address surface compaction. Special care should be taken to prevent recompacting the soil, since tillage also damages soil structure.

32. Understand how various practices influence soil organic matter/organic carbon.

- **a. Crop residue management**
- **b. Tillage system**
- **c. Cover crops**
- **d. Crop rotation**
- **e. Organic matter amendments**

a. Leaving crop residue on the surface is an effective way to build organic matter as residues supply a carbon source that soil organisms can utilize. Surface residues promote aggregation that helps stabilize organic carbon within the soil, improving soil structure, moisture retention and long-term organic matter levels.

b. Tillage intensity is one of the strongest drivers of soil organic matter (SOM). By RUSLE2 provides a Soil Tillage Intensity Rating (STIR) which can be used to evaluate the intensity of different tillage systems. When tilling, oxygen is introduced into the soil accelerating microbial decomposition of organic matter and carbon is released as CO_2. By using reduced or no till systems SOM is increased due to minimal disturbance protecting aggregates.

c. Cover crops can increase SOM and organic carbon. By adding biomass above and below (including root exudates) cover crop help feed soil microbes and build soil structure.

d. Crop rotation can improve soil organic matter by introducing various root systems and by improving microbial communities. Rotation of annual crops with sod crops builds soil organic matter more effectively than annual monocultures making rotation important.

e. Organic amendments such as manure or compost increase soil organic matter by adding carbon rich materials into the soil. These readily decomposable carbon and nutrient sources stimulates microbial growth and aggregation. RUSLE2 has a Soil Conditioning Index (SCI) tool built into it. The SCI helps to evaluate different conservation management systems and whether they will maintain, increase, or decrease SOM.

CA5: Soil Conservation

Erosion/Sediment Aspects

33. Explain the three stages of soil erosion by water and their relation to soil properties.

The three stages of soil erosion are: detachment, transport, and deposition. Aggregation affects this process: a well-aggregated soil is less sensitive to detachment and transport than a poorly aggregated soil. Soil with high infiltration will have less transport. Deposition occurs when the velocity and carrying capacity of runoff decreases. This may happen if soils change in slope or infiltration capacity.

34. Understand the main agronomic and environmental consequences of soil erosion and sedimentation.

Agronomic:

- Organic-matter rich surface soil is removed.
- Nitrogen, phosphorus, potassium, and other nutrients in mineral and organic form are lost from the field which can impact crop yields.
- Herbicides and other pesticides attached to soil particles will be removed from the field.
- Since silt particles are preferentially removed in erosion, the soil tends to either become more clayey or sandier.
- Soil depth is reduced, leading to reduced root volume and increased moisture stress.
- Rill and gully formation will make field work more challenging.
- Deposition can cause newly planted crops to be lost.
- Increased production costs

Environmental:

- Increased need for channel dredging.
- Adverse impacts on the recovery of underwater grass beds because the sediment reduces the amount of light reaching plants.
- Benthic (bottom-dwelling) organisms suffer increased mortality and reduced reproduction.
- Fish may be affected as increased sediment affects their feeding, clogs gill tissues, and smothers eggs.
- Increased turbidity may change the abundance of plankton, which can impact juvenile fish.
- Nitrogen and phosphorus are carried with the sediment, contributing to eutrophication, algae blooms, hypoxia, and overall water quality degradation.
- Persistent pesticides are potentially carried to surface water where they can enter the ecosystem.

35. Understand the different types of soil erosion by water and wind.

a. Inter-rill erosion
b. Rill erosion
c. Ephemeral gully erosion
d. Classic gully erosion
e. Streambank erosion
f. Wind erosion

a. Inter-rill erosion: The movement of soil by rain-splash and its transport by thin surface flow across the soil surface. The term sheet erosion is frequently used instead of inter-rill erosion, but it omits the concept of rain-splash effects.

b. Rill erosion: Erosion in small channels, they run parallel on a slope but may converge. Rill erosion usually less than 4” deep. Does not appear in the same location on the landscape from year to year.

c. Ephemeral gully erosion: Soil erosion that causes small gullies in the same flow area that can be obscured with tillage or other soil disturbance activities. Left untreated ephemeral gully could turn into classic gully erosion.

d. Classic gully erosion: Gullies created by runoff that can enlarge a channel progressively by head cuttings or lateral widening. Classic gully erosion is too deep for normal tillage operations to erase and often redefine a field boundary.

e. Streambank erosion: Erosion by rivers or streams cutting into banks.
f. Wind erosion: Detachment and transport of soil particles by wind.

36. Understand how soil types differ in soil erodibility (the soil K factor).

Soil texture, organic matter, and soil structure all affect erodibility. Silt is usually preferentially detached and transported because clay particles are highly cohesive, and (higher K value) sand particles are larger and heavier. Higher levels of organic matter cause soils to become less erodible due to the positive effect of organic matter on aggregate stability and soil structure.

37. Understand how climatic factors affect soil erosion.

Rainfall quantity and intensity are important. Greater rainfall amounts increase the potential for erosion if soils saturate and produce more runoff. Higher intensity rainfall also increases erosion, especially in soils with lower infiltration capacity.

38. Know how the topographic factors of slope and slope length affect water soil erosion.

Erosion increases with increasing slope and slope length because runoff energy and opportunity for concentration of low to occur are increased.

39. Explain the factors used in the Revised Universal Soil Loss Equation (RUSLE2).

The NRCS uses the Revised Universal Soil Loss Equation (RUSLE) or the Water Erosion Prediction Program (WEPP) to calculate soil loss by erosion as a function of 5 factors:

$$A = R \times K \times LS \times C \times P$$

where:
A = average annual soil loss (tons/acre/yr)
R = erosivity of rainfall
K = erodibility of the soil
LS = slope length/steepness (field measured)
C = cover management (i.e., plants, ground cover, soil disturbing activities, etc.)
P = support practices (i.e., contouring, strip cropping, etc.)

40. Understand how agronomic management practices can reduce erosion.

- **a. Vegetation type and growth stage**
- **b. Filter strip, buffer strip, riparian areas**
- **c. Tillage and crop residue management**
- **d. Crop rotations**
- **e. Cover cropping**

a. Perennial vegetation typically helps reduce potential for erosion compared to annual crops because soil is continually protected by the living vegetation and increased root biomass helps prevent detachment. Soils are especially susceptible to erosion early on as until rainfall is intercepted by the growing season by plant canopy thereby reducing the rainfall velocity impact on the soil surface. Cover can reduce raindrop impact. Closely spaced crops such as wheat tend to provide quicker soil cover than widely spaced crops such as corn.
b. Filter strips, buffer strips, and riparian areas can be effective for reducing transport of eroded soil from reaching an adjacent water body by slowing runoff and encouraging soil deposition.

Filter strips are narrow bands of grass or mixed vegetation along field edges. Buffer strips are typically wider than filter strips, including trees and shrubs providing a greater area of protection. Riparian buffers are vegetative areas among streams and rivers that help stabilize stream banks, reducing erosion and filter runoff before it enters a waterway.

c. Clean tillage leaves the soil unprotected by burying all crop residue. Leaving more residue on the surface will help prevent raindrop impact and detachment of soil particles.
d. Crop rotation can help control erosion when perennials and annuals are rotated. Diverse crop rotations also help build soil health and structure and improve infiltration, further decreasing risk of runoff and erosion. Strip cropping is the growing of alternate strips of crops susceptible to erosion with strips of erosion resistant crops.
e. Keeping soil covered in the fall and winter helps protect it from erosion. Mulch left by a cover crop can also help prevent erosion during the growing season and build soil organic matter.

41. Understand the basic approaches to structural soil conservation practices. These are engineering practices.

- **a. Grass/rock-lined waterways**
- **b. Diversions**
- **c. Ponds, surface inlets, and water and sediment control basins**
- **d. Drop structures**

a. Grassed or rock-lined shaped or graded channel with either suitable vegetation or erosion resistant lining (i.e., rock) that conveys surface runoff at a non-erosive velocity to a stable outlet. They are often placed where gully erosion has occurred on a regular basis.
b. A diversion is a channel usually constructed across the slope with a supporting ridge on the lower side to convey surface water to a stable outlet.
c. Surface inlets allow movement of surface runoff water into underground tile drains and discharge into surface waters. WASCOBs (water and sediment control basins) are short earthen dams built across a drainage that trap sediment and water. WASCOBs include a surface inlet which conveys runoff water to a stable outlet.
d. Hydraulic structures for safely transferring water in a channel to a lower-level channel without causing erosion.

42. Understand the purposes of tillage.

Tillage can be defined as any mechanical manipulation of soil. The goal of tillage is to provide a suitable environment for seed germination, root growth, moisture control, and weed control. Tillage may also be done to incorporate nutrients or alleviate soil compaction concern.

43. Describe the basic components and role of tillage systems and understand their agronomic and environmental benefits.

- **a. Plow-till**
- **b. No-till**
- **c. Reduced-till**
- **d. Ridge-till**
- **e. Zone/strip-tillage**
- **f. Vertical-tillage**

Primary tillage is usually the deepest operation in the system, which loosens and fractures the soil to reduce soil strength, invert and cover previous crops or weeds and to bring or mix residues and fertilizers in the tilled layers. Secondary tillage is used to kill weeds, cut and cover crop residues, incorporate herbicides, and prepare a seedbed.

a. Plow-till
Typically consists of primary tillage with a moldboard plow, followed by one or more passes with a disk and another type of harrow. The moldboard plow is the best weed controlling tillage tool. It inverts the soil, incorporating and covering residue, fertilizer or manure. However, the plow-till system is one of the more soil degrading tillage practices because of its aggressive disturbance and reduction of mulch cover. This system uses the most fossil fuel for field operations and takes the most labor.

b. No-till
No full-width tillage is performed from the time immediately following harvest or termination of one cash crop through harvest or termination of the next cash crop Crops are direct seeded with a no-till planter or drill, and weeds are controlled without tillage. Manures and fertilizers are applied to the soil surface or may be injected with low-disturbance injectors. If left at the surface, ammonia volatilization and odor are a concern. No-tillage systems conserve soil and build soil organic matter. They also have a beneficial effect on soil organisms. Fossil fuel use for field operations is low as well as labor needs. Odor from manure, planting issues through heavy residue, and weed control are the greatest challenges with this system. Even crop residue spread at harvest is extremely critical for success with no-tillage.

c. Reduced-till
A type of full-width conservation tillage. Common tillage tools used with this system are chisel plows, disk harrows, and field cultivators. Erosion control is much better than that obtained with moldboard plowing, but not as great as that obtained with no-till. Organic matter content is typically higher than with moldboard plowing, but lower than with no-till.

d. Ridge-till
A tillage system in which no tillage is done from harvest until planting, except for nutrient injections. Crops are grown on preformed ridges. The ridges are usually formed in the previous crop with in-row cultivators. Ridge tillage is a way to reduce use of in-crop herbicide inputs, and it is a form of precision traffic because all traffic takes place between rows. Manure is typically not incorporated, which increases ammonia volatilization losses and odor nuisance. Organic matter content is typically similar to mulch-till systems, and erosion control is good due to the high residue cover after planting. All crops need to be planted on the same row-spacing, and equipment needs to be redesigned to run between the ridges.

e. Zone/strip-tillage
A system that is similar to no-till, except narrow tilled zones are formed either during planting or before planting for seed placement. The major benefit of zone tillage over no-tillage is the faster emergence of early planted summer crops such as corn. Zone tillage takes more tractor power, and equipment costs are higher than with no-till. Erosion control is excellent as there is no full

width tillage performed. Some zone/strip till systems can meet the NRCS standard for No-Till as there can be very little soil disturbance.

f. Vertical-tillage

Vertical tillage is a reduced-till system specifically designed to manage crop residue and condition the soil whilst minimizing creating horizontal compaction layers. Basic components include shallow cutting residue disturbing only the top 1-3 inches and a roll basket that helps level the surface. The goal is to manage residue, improve the seedbed and reduce compaction while minimizing depletion of soil structure.

44. Understand adaptability of tillage systems to common soil types in the Northeast based on:

- **a. Texture**
- **b. Drainage class**
- **c. Climate**

a. Light-textured soils benefit from no-till and heavy crop residue cover because of its moisture savings. Heavy clay soils dry out slowly in the spring and may cause corn to emerge slowly in no-tillage with heavy crop residue cover. Mulch-till, ridge-till or zone tillage may be the optimum choice, although some attachments on the planter may achieve satisfactory results in no-tillage as well. On steeply sloping soils erosion is more likely and therefore greater residue cover is more important. Stony soils are most suitable to no-tillage crop production.

b. In general, the better drained a soil is, the more suitable it is to high-residue or no-tillage farming. In well-drained soils moisture conservation is a benefit, and soil warming is generally not a big problem. In poorly drained soils, excessive moisture does not evaporate under a mulch layer, and early warming of the soil may be problematic, especially for corn production and other early planted crops, but not for fall-seeded crops or crops planted later than corn. High residue systems are more challenging on poorly drained soils but can be implemented successfully with some planting equipment modifications and proper planning of crop rotations.

c. High residue and no-tillage systems tend to have slower soil drying and warming in spring and are therefore more challenging in the northern parts of the Northeast.

45. Understand the adaptability of tillage systems to various cropping systems.

- **a. Livestock-based systems**
- **b. Conventional cash grain systems**
- **c. Low-input and organic cash grain systems**

a. Livestock-based systems

The following applies primarily to dairy and beef farms, while hog and poultry farms usually only produce grain (see next section).

- <u>Residue return</u>– Many times all above-ground biomass is removed in hay, silage, or straw. Therefore, care needs to be taken to return organic material (manure) to the soil, grow cover crops, and minimize further organic matter losses through intensive tillage.
- <u>Crop diversity</u> – Many crops can be grown for forage, and therefore, there is much opportunity to increase crop diversity. Maximizing crop diversity and soil cover can be used to great

advantage in permanent no-tillage systems due to the time savings, soil erosion control, and soil improvement.

- Soil compaction – Manure application and timely harvest operations during fall, winter, and spring when soils are still wet can pose a significant compaction risk. It is important to respect principles of compaction avoidance. If compaction is caused, surface or deep tillage may be required to alleviate its effects.
- Soil erosion – It is important to maintain living vegetation on the land to protect the soil from erosion and compaction and to take up nutrients that may be released when organic matter from manure applications is decomposing. Cover crops can be established during fallow periods, which can help protect the soil from erosion until the planting of the next crop.
- Soil warming – Cool soils may be a concern with no-till systems when corn is planted into a high residue cover that remains from the previous corn grain harvest. In this case, zone/strip-tillage may be a practical alternative. In most other cases, soil warming in the spring is of minor concern.
- Weed control – It is important to manage weeds with crop diversity in permanent no-tillage systems. If perennial weeds get established and become a problem, early fall applications of burn-down herbicides may be needed, or tillage may be required. Plow tillage is the best weed control option besides herbicides to control perennials and many annuals. Ensuring weeds don't go to seeds and reducing weed seed spread by cleaning equipment can help to reduce weed pressures.
- Nutrient management – Some nitrogen from manure will volatilize if it is not incorporated immediately after application or injected. The same holds for odor control.

b. Conventional cash grain systems, primarily limited to corn, soybeans, and small grains.

- Residue return - With the exception of small grains, most residue is left in the field, which helps with organic matter conservation, erosion control, and moisture control. The return of crop residues to soil can compensate for some of the organic matter losses due to tillage.
- Crop diversity – Crop diversity may be low, as in continuous corn or corn-soybean systems. This poses a problem for soil quality and successful no-tillage, which may then need to be addressed by tillage. In the latter case, reduced-till is preferred over plow-till to limit soil impacts. Zone tillage can be used for corn if early soil warming is a concern (after corn grain).
- Soil compaction – Same as above in Livestock-based systems.
- Weed control – Same as above in Livestock-based systems.
- Nutrient management – Urea fertilizers are subject to volatilization similarly to manure (see a above). Anhydrous ammonia needs to be injected with low disturbance knives, and secondary tillage may be required prior to planting.

c. Low-input and organic cash grain systems

- Residue return – Similar to above systems.
- Crop diversity – Often crop rotations are more diverse than on other cash grain farms. Permanent no-till is possible in low-input systems with high crop diversity, but not on organic grain farms due to weed control problems. Some organic farms are No-Tilling certain crops within their overall crop rotation.

- Soil compaction – Same as above systems. In organic systems, farmers may attempt to plow as shallow as possible to reduce tillage intensity, which may result in shallow soil compaction.
- Soil erosion – A significant threat if plow tillage is used. The effects of plow tillage need to be compensated by return of crop residues, cover crops, composts and manure additions to maintain soil quality.
- Soil warming - Not usually a major issue on these farms.
- Weed control – The major reason to do tillage, especially in organic systems. Plow tillage is the best weed control but may be alternated with less intensive tillage such as reduced-till or occasional no-till, even on organic farms. Organic farms may also perform in-row cultivation on row crops to reduce weed pressures.
- Nutrient management – Often manure is applied to supply nutrients (for manure management, see livestock-based systems above). If compost is applied, ammonia volatilization is not of concern in the field, and no incorporation is required. Organic farms often use imported chicken manure to help supply the crop with the fertility it needs.

46. Understand the relation between tillage practices and:

a. Residue cover
b. Soil roughness
c. Soil health
d. Residue fragility and persistence

a. Almost every tillage pass reduces residue cover. It is possible to estimate the effect of a tillage system on residue cover based on the percent cover after harvest, overwinter residue decomposition, and estimates of percent cover remaining after different tillage operations. Residue cover is critical in helping to reduce soil erosion especially after crop planting.
b. The soil surface can be smoothened by soil tillage. However, subsequent traffic creates more soil roughness after tillage, and the danger of rut formation is greater on a previously tilled soil than a long-term no-tillage soil.
c. Soil tillage degrades soil quality because of its negative effects on soil structure leading to soil erosion, oxidation of soil organic matter, reducing surface residues, collapsing of soil pores, and limiting nutrient and water infiltration.
d. Fragile and non-fragile residue are terms used to distinguish the different decomposition rates of crop residues. Fragile residue decomposes more quickly and is from crops such as soybeans, canola, dry beans, and potatoes. Non-fragile residue is more persistent and is from crops such as corn, alfalfa, and small grains.

47. Understand the relation between tillage systems and:

a. Soil structure and compaction
b. Runoff and erosion
c. Nutrient cycling and pest management
d. Infiltration and percolation

a. Tillage generally destroys soil structure. Soil compaction is created below various tillage tools (i.e., plows, disks, powered rotary tillers), but it can also be alleviated by other types of tillage tools (i.e., subsoilers, chisels) if performed appropriately. Types of compaction include both surface and subsurface. There are many different ways to detect compaction from visual observations to tools such as penetrometers.

b. Soil tillage increases runoff and erosion because of its effect on residue cover and soil aggregation. In certain cases where compaction is present, soil tillage may increase infiltration and reduce erosion. The goal of soil management should be to avoid relying on a cycle of tillage to remediate compaction caused by tillage.
c. In the absence of tillage, herbicides are needed to control weeds in permanent no-till. However, herbicides are only one tool in the box of weed control. Judicious use should be made of different herbicide modes-of-action, timing of applications, crop rotations, crop vigor, nutrient placement, mowing, reducing weed dispersal, etc., instead of relying on herbicides alone for weed control.
d. Crop residue cover helps improve infiltration by reducing soil sealing and crusting. Percolation is improved when a well-developed, continuous macro-pore system is present, as in no-till.

48. Understand the concept of soil tilth and the roles of soil texture, organic matter, structure/aggregation, and bulk density as they affect tilth.

Soil tilth refers to the physical condition of the soil in relation to plant growth. Tilth tends to decrease with particle size (sand>silt>clay), and organic matter content. Soils with good tilth have high aggregate stability, and low bulk density.

49. Understand the relationship between soil consistency and tillage conditions, the "Ball Test", and the effects of soil freezing.

A "Ball test" is used to determine if conditions are right for tillage and traffic across a field. The test involves taking a fistful of field soil and trying to mold it into a ball. When a ball can be formed, the soil is in a plastic state and sensitive to compaction. If the ball breaks into smaller pieces, the soil is in a friable state, indicating the soil can be driven on and is suitable for tillage. Thus, the "Ball test" is a simple and effective way to gauge soil moisture and field accessibility.
Soils with high clay content tend to be in a plastic state much of the year if conditions are moist (as judged with the 'ball test') which makes tillage operations challenging. One strategy to address this is to do primary tillage on these soils in the fall and let the freezing-thawing action crumble the clods, followed by secondary tillage in the spring to prepare a seedbed. This is a way to avoid cloddy seedbeds in the early spring. Fall tillage, however, will lead to increased erosion potential.

CA6: Watershed Hydrology

50. Define a watershed and describe its main functions.

A watershed, drainage basin, or catchment is an area of land from which surface runoff (and subsurface stream recharge) flows to a common discharge outlet. Watersheds can be of various sizes from a small location within a single field to very wide geographic watersheds spread over multiple states. The main functions of a watershed are the collection and redistribution of water. A watershed's development and basic features result from climate and geologic interactions over long time periods.

Characteristics features of watersheds are:

- Boundary (topographic divide between other watersheds).

- Outlet and base (common discharge point and type of termination).
- Size and Shape (total area, and its general extent and arrangement).
- Elevation and Gradient (elevations of boundary and outlet and distance between).
- Aspect and Orientation (watershed slope and direction it faces).
- Drainage network (pattern of runoff concentration and streamflow).
- Soils and Geology (soil types, parent materials, arrangement, bedrock and aquifers).
- Land Use and Vegetation (rural, urban, industry, agriculture, and forestry).
- Cultural Activities (settlement, history, heritage, and recreation).

51. Understand the major inputs and outputs of water in a watershed.

a. Precipitation
b. Storms
c. Infiltration and percolation
d. Storage
e. Vegetation
f. Base Flow
g. Storm Flow
h. Runoff
i. Evaporation and Transpiration

Soil Hydrology, the components of the hydrologic cycle and the water budget for the soil profile can be extrapolated and applied to watersheds. In watersheds, the spatial distribution of elevations, soils, geology, vegetation, and land use interact with the hydrologic cycle, causing variations with how water collects, drains, and is redistributed within soil associations and throughout the landscape. See also CA2.

a. Precipitation: Precipitation often varies across a watershed, and the spatial variation tends to be greater in watersheds with significant topographic relief.
b. Storms: Classified as frontal, convective, and orographic. Frontal storms occur as warm or light air masses meet cold or heavy air masses. This is the dominant type of precipitation that occurs in the Northeast, generally producing the low intensity, long duration rainy days. Convective storms occur as a result of air expanding when heated by solar energy, and the lighter air moistened with evapotranspiration rises, cools, and condenses. In the Northeast, this produces summer thunderstorms, often delivering high intensity but short duration rains. Orographic storms occur as wind forces warm, moist air masses to rise over hills and mountains.
c. Infiltration and percolation: Infiltration and percolation can vary substantially across a watershed. Generally, infiltration and percolation tend to be higher in soils that are higher in elevation. However, there are numerous exceptions to this because of the variation in soils, soil layering and geologic material.
d. Storage: (Depression, Detention, Channel, Groundwater, Retention) – refers to the locations in the watershed where surface runoff or excess drainage water is held, at least temporarily. Depression storage is the water stored in field surface depressions and therefore not contributing to surface runoff. Detention storage refers to the water in excess of the depression storage which is temporarily stored somewhere in the watershed while enroute to streams. Wetlands are a good example of detention storage. Channel storage is the water temporarily stored in channels while enroute to an outlet. The drainable (porosity) water that percolates and reaches groundwater will also be stored if the water table is below the

elevation of an adjacent stream. Retention is the precipitation on an area that does not escape as runoff. Essentially, it's the difference between the total precipitation and total runoff.

e. Vegetation: Plays an important role in the amount of retention, both in terms of interception and transpiration. Transpiration by vegetation is the primary component of retention. However, interception, the amount of precipitation caught by vegetation canopy, and that which is evaporated directly back to the atmosphere, is also important. A tall dense alfalfa canopy can intercept about 0.20 inches of rain, and under the right conditions it can evaporate directly with little of this ever hitting the ground.
f. Base Flow: Occurs when the water table rises above that of an adjacent ditch or stream. When this occurs, the hydraulic head of the water table begins to exceed that of the adjacent stream, and the groundwater flows to recharge the stream. In a perennial stream (always flowing), base flow is a continuous process of transferring temporarily stored groundwater into surface water.
g. Storm Flow: Most often considered to be the direct surface water runoff that flows to a stream following a precipitation event. The water quality of the storm flow and the base flow is usually quite different. An ephemeral stream is one that flows only during and immediately after a rain event, carrying only surface water runoff with no base flow contribution. The term concentrated flow path is often used in reference to a channel carrying only storm flow.
h. Runoff: Runoff varies from point to point in a stream within a watershed. The relative proportions that the different sources of runoff (surface, subsurface) contribute to a stream can vary as one traverses the stream. Therefore, the water quality of a stream can vary substantially from one location to another across a watershed. Land use can greatly impact the different components of runoff, and subsequently the water quality of the stream(s) within the watershed. Large areas of impervious surface will increase the surface runoff component by reducing the opportunity for infiltration, percolation, and storage.
i. Evaporation and Transpiration: Varies spatially in watersheds with respect to the extent of open water, types of vegetation, and impervious surfaces. Even more importantly, evaporation and transpiration vary seasonally throughout the year, causing major shifts in retention and runoff.

52. Explain the pollutant delivery process and describe the relationship of nutrient budgets and total maximum daily loads (TMDL) to non-point source pollutant loading.

Pollutant delivery requires a pollutant to be 'available' when water is moving over or through the soil and landscape. Nutrient pollutants (i.e., nitrogen and phosphorus) can be lost to surface runoff and water percolating through the soil. The degree to which these nutrient pollutants are available and able to be transported depends on what form they are in and the soil characteristics. For example, phosphorus often adsorbs to fine-textured soil, but if the soil has lots of macropores water can percolate rapidly and limit adsorption. The importance of nutrient budgets is to minimize nutrient pollutant availability when water is flowing over or through the landscape. When nutrients are applied in excess of crop nutrient requirements, the opportunity increases for pollutants to be transported with moving water. The off-site transport and diffuse loss of pollutants from storm water runoff (from agriculture and other sources) is termed nonpoint source pollution. The total maximum daily load (TMDL) is the maximum amount of a pollutant that a water body can receive and still meet water quality standards. Federal and state regulatory agencies establish the maximum allowable point and nonpoint source loading for water bodies based on hydrologic characteristics, ability to process the incoming pollutants, and designated uses. Nutrient budgets or developing and implementing Comprehensive Nutrient Management Plans (CNMP's) is way for to minimize the off-farm loss of excess available nutrients to reduce nutrient pollutant loads, limit nonpoint source pollution, and achieve TMDL targets.

53. Describe the main agricultural point and non-point sources of contaminants in a typical rural watershed in the Northeast.

The main agricultural point or concentrated sources from livestock-based systems are barnyards, feedlots, silage storage and milkhouse wastewater discharges. For conventional cash grain production systems, the point sources arise from fertilizer, pesticide and fuel storage areas. The main non-point sources of contaminants from agricultural operations are crop fields.

54. Understand and describe aquifers (confined, unconfined) and the geologic conditions that affect water yield from wells.

Aquifers are geologic formations that store groundwater in the saturated pores of these sediment or rock formations and are sufficiently permeable to transmit economic quantities of water to wells or springs. Aquifers consist of two types, confined and unconfined, as distinguished by differences in their hydraulic behavior. A confined aquifer has an upper, and perhaps lower natural soil or rock layer boundary that does not transmit water readily, and thus, the stored water is confined within the permeable layer materials. A well that is drilled into this type of aquifer, and where the hydraulic head pressure is adequate to raise the water past the upper confining boundary and to the surface is commonly referred to as an artesian or flowing well. An unconfined aquifer is one where the upper boundary consists of a relatively porous natural material that transmits water readily, and the water table is free to rise and fall with recharge or withdrawal of water. When water is withdrawn (pumped) from an unconfined aquifer, the water table is drawn down.

55. Understand the concepts of pumping and drawdown in wells, the cone of depression, and well capture zones.

When wells are pumped, the water level in the casing is lowered (drawn down) relative to the water level in the aquifer. This drawdown causes stored water in the aquifer to flow towards the well. The cone of depression refers to this drawdown, because the water level surface in the aquifer material exhibits a conical shape with increasing distance in all directions away from the well. The capture zone of a well refers to the area on the surface under which water drains towards a pumping well. Essentially this area extends up-gradient from the well to the point where the groundwater slopes in another direction. The importance of defining the extent of the capture zone is that activities on the land surface that overlie the capture zone may eventually pollute the well. Shallow unconfined aquifers are particularly vulnerable to contamination because there is no restricting soil layer above these aquifers to divert leached pollutants.

56. Understand the relationship between geologic conditions and the potential for groundwater and surface water contamination.

Soil layering and varying subsoil geologic conditions will significantly affect water movement. Layers that are permeable allow water to flow in any direction. However, layers that are impermeable impede water movement, and the flow of water is then redirected through more permeable layers. The depths, separation distance between layers of differing permeability, and the slope of impermeable layers all affect water movement and the direction in which it moves. Groundwater is most easily contaminated when the soil is permeable to great depths. The deep unconsolidated permeable materials of alluvial valley-fill are where leaching of nitrate and soluble pesticides can most often contaminate the groundwater. In contrast, an impermeable layer just below the surface, such as in soils with fragipans, impedes downward water movement, and excess water is forced to move laterally (interflow). This can lead to saturated areas (seep) and the runoff from this may cause surface water contamination.

57. Understand recharge areas for groundwater and surface water.

Deep permeable soil deposits facilitate deep percolation and provide areas for groundwater recharge. Soils with shallow impermeable layers or drainage restrictions recharge surface water.

58. Understand and apply the concepts of hydrologically sensitive areas and critical management zones at the field, farm, and watershed levels. Be able to give examples.

Hydrologically sensitive areas (HSA's) are areas in the landscape where there is a high hydrologic risk for water, and pollutant movement off-site. Examples of HSA's include:

- Impervious Uncontained surfaces (barnyards, bunker pads).
- Relatively impermeable (crusted or frozen soil, soil with shallow hardpans or fragipans) and erosion prone (low permeability, sloping) soils.
- Saturated soils (poorly drained soils, variable source saturating areas, seeps).
- Flood plains (especially those that flood frequently).
- Flowing surface water areas (perennial and intermittent streams, concentrated flow paths).
- Groundwater recharge areas (highly permeable soils, sinkholes, shallow soil over Karst – a special type of landscape that is formed by the dissolution of soluble rocks, including limestone and dolomite).

59. Understand key processes that occur in wetlands and riparian buffer zones and their role in a watershed with respect to downstream water quality.

Wetlands are areas of wet soil (hydric soil) that are inundated or saturated under normal circumstances and would support the prevalence of hydrophytic vegetation (plants adapted to survive in low soil oxygen environments). Key processes that occur in wetlands are to slow the transport of water and provide surface water storage, resulting in the retention and removal of suspended and many dissolved pollutants. Wetlands are quite effective at removing suspended and particulate materials, such as phosphorus bound to soil particles, but are less effective at retaining dissolved phosphorus. Riparian buffer zones are areas of land immediately adjacent to water bodies but are generally not saturated like wetlands. Riparian buffers may also serve to infiltrate incoming surface runoff, facilitating the removal of suspended and some dissolved pollutants that readily absorb to soil. When streams flood, water flowing into the riparian buffer may also be cleansed as sediments, nutrients, and other pollutants are retained in the buffer.

60. Understand the multiple-barrier concept in watershed protection.

The multiple barriers concept is a strategy applied to minimize the occurrence, availability, and transport of pathogens to surface and groundwater. It consists of four major barriers: (1) imports and bio-security to reduce occurrence of unwanted pathogens; (2) animal health and hygiene to minimize the spread and availability of pathogens; (3) waste management to contain and further reduce availability; and (4) land application beneficial management practices to reduce transport and off-site exports.

61. Be able to identify impaired water bodies, the causes listed for the impairment and understand the implications for agriculture.

   a. **Clean Water Act: Total Maximum Daily Loads (TMDLs)**
   b. **303(d) listing of impaired waters**
   c. **Implications in the Clean Water Act for addressing items in a TMDL report that may involve agriculture.**

As part of the Federal Clean Water Act Section 303(d), EPA requires state environmental agencies to periodically assess and report on the quality of waters in their state, and to identify and develop a list of impaired waters. Where agriculture is listed as the cause of the impairment, Federal and State agency programs working with agriculture will give priority in directing resources to conservation efforts in those watersheds to address water quality concerns.

CA7: Non-Point Source Pollution

62. Distinguish between agricultural non-point source (NPS) pollution and point source pollution and the extent and importance of each.

Non-point source (NPS) pollution is pollution that has no well-defined source, such as that originating from diffuse land surface areas. Agricultural non-point sources include things like soil erosion and runoff and leaching losses of nutrients, pathogens, Biological Oxygen Demand (BOD) and pesticides from cropped land or pasture. Agricultural NPS pollution can also include spray drift from pesticide applications, causing odor issues or damage to non-targeted plant foliage. Sediment from soil erosion and other non-agricultural source losses constitutes the largest non-point pollutant loading on a mass basis and is the most frequently cited cause of surface water quality impairment. Phosphorus and pathogens (fecal-type coliforms, *Cryptosporidium*, *Giardia*) are also frequently the cause of surface water impairments. While elevated levels of nitrates (above the MCL of 10 ppm) are frequently found in groundwater, with some vulnerable areas reporting 10 to 20% of wells exceeding the MCL. The percentage of wells exceeding the MCL for nitrate is generally higher in intensively farmed agricultural areas but can also be high in densely populated urban areas where septic systems are used on permeable soils. Pathogens and pesticides can potentially be detected in groundwater in agricultural areas.

Point source pollution is the pollution of surface or groundwater supplies at well-defined locations. Agricultural point sources of pollution include:

- Nutrients, pathogens, and BOD losses from unmanaged barnyards, manure pits pile areas, and other livestock facility storage and processing operations (silage leachate and from feed storage, milkhouse wastewater discharges) on livestock operations
- Nutrient and pesticide losses from fertilizer and pesticide storage and rinsing areas
- Petrochemical losses from fuel storage areas and machine shop facilities

63. Describe the main sources of agricultural (NPS) pollution and their origins.

a. Nitrogen
b. Phosphorus
c. BOD (Biological Oxygen Demand)
d. Sediment
e. Pesticides
f. Pathogens
g. Silage leachate
h. Chemicals and toxins
i. Processing wastewater
j. Antibiotics

a. Nitrogen: Sources are from runoff, tile discharge and leaching losses originating from fertilizer and manure applications. The timing, form, rate, and placement of nitrogen application (4R) are critical factors in controlling NPS pollution.

b. Phosphorus: Sources are from eroded soil (as particulate P), soluble P in runoff and tile discharge, and from suspended and dissolved organic P in manure runoff and tile discharge. High P concentrations can be found in runoff, and in some cases, tile drain discharge, especially when rain follows shortly after surface manure applications and soils have well-formed macropores or cracks.

c. BOD (Biological Oxygen Demand): Sources are the loss of land-applied nutrients sources (i.e., manure), runoff from untreated concentrated nutrient sources (i.e. silage leachate), and direct discharge of waste water.

d. Sediment: Sources are primarily erosion from cropland, especially when there is no vegetative cover on the fields. Sediments may also originate from laneways, field roads, and non-vegetated surface drainage ditches.

e. Pesticides : Sources are pesticide runoff and leaching, especially when rain occurs shortly after pesticide application. Pesticide drift may also find its way back into surface waters.

f. Pathogens: Sources are calf housing areas and manure applications, especially when the manure is applied to the surface and rain causes runoff. Surface water and tile drain discharges are usually more impacted than groundwater, but groundwater may also be affected when manure is applied to coarse-textured soils, or to shallow soils overlying fractured bedrock.

g. Silage leachate: Sources are from inadequate treatment runoff from silage storage facilities. Silage leachate contains substantial BOD, as well as nutrients horizontal & vertical silos, Ag bags, etc.

h. Chemicals and toxins: See section e. Pesticides.

i. Processing wastewater: Sources are the uncontrolled loss or inadequate treatment and disposal of these wastewaters from livestock facilities (i.e., milkhouse drains).

j. Antibiotics: Main sources are through livestock manure and wastewater. Unmetabolized antibiotics are excreted used as manure which can then runoff into streams and water ways.

64. Understand the environmental impacts of the various agricultural contaminants listed above on the quality of surface water and groundwater as it relates to their various uses.

- Nitrogen - causes eutrophication and hypoxia (low dissolved oxygen and dead zones primarily in bays and estuaries) in surface waters, and nitrate enrichment in groundwater. Elevated concentrations of nitrate or ammonia in surface water also affect aquatic organisms. High nitrate concentrations in drinking water can affect both humans and animals, causing oxygen deficiencies in the blood (methemoglobinemia).
- Phosphorus – causes eutrophication (mainly in ponds, lakes and reservoirs) and hypoxia in coastal waters.
- BOD - causes depletion of dissolved oxygen in surface water which may kill fish and other aquatic organisms and can deplete oxygen in soil-water affecting plant growth.
- Sediment - causes turbidity of surface waters which affect aquatic habitat, results in sedimentation in ponds, lakes and reservoirs, and increases treatment costs of drinking water supplies.
- Pesticides - cause loss of aquatic life and exceedance of drinking water standards. Atrazine, simazine, metolachlor, and alachlor are often present in surface runoff, tile drain discharge, and groundwater.
- Pathogens - cause impairment of recreational and drinking water, leading to problems with animal and human health when coming into contact or consuming the contaminated water.
- Silage leachate - causes depletion of dissolved oxygen because of high BOD, and ammonia-nitrogen and phosphorus enrichment of water.
- Process wastewaters - cause turbidity, depletion of oxygen and nutrient enrichment of receiving waters. Milkhouse wastewater contains suspended milk solids (i.e., BOD) and is mostly enriched with dissolved phosphorus. Barnyard runoff is similar to silage leachate but generally has slightly lower concentrations.

65. Identify basic water quality indicators and explain their significance.

Water quality indicators consist of physical, chemical, and biological parameters. Water that looks turbid and colored (containing total suspended and/or dissolved solids materials) is deemed unfit for drinking and can inhibit photosynthesis of aquatic vegetation. Turbidity may indicate inputs of BOD (reducing oxygen content) or phosphorus (causing eutrophication – a process of nutrient enrichment that also leads to anoxic conditions). Suspended materials may also be indicators for the presence of total (or fecal and E. coli) coliform inputs (potentially pathogenic organisms to humans that limit use for recreation and drinking). The absence of certain aquatic macroinvertebrate (biological) organisms (i.e., mayflies, caddisflies, riffle beetles), or the presence of midges, horsefly, and tubificid worms, is often an indication of nutrient enrichment in streams.

66. Understand the concept of best management practices for NPS pollution control.

Best or beneficial management practices (BMP's) are techniques recognized to be most effective and practical means to reduce surface and groundwater contamination while still allowing the productive use of resources. It's important to note that a BMP may not always be the best available technology (BAT) for containing, treating, or reducing a pollutant from water, because the BAT may be impractical and prohibitively expensive. By definition, a BMP also would not be one that restricts or prohibits the productive use of resources.

67. Know some appropriate beneficial/best management practices for agricultural NPS and point source pollution control in a given farming system.

Examples of structural BMPs for addressing NPS soil erosion were listed in Item 42. Some examples of nonstructural (cover crop) and management measures (crop rotations) to address NPS soil erosion are listed in Item 41. With regards to point sources, some structural BMPs would be diversions for diverting uncontaminated water away from barnyards or vegetated treatment areas for treating the contaminated runoff from the barnyard. Nonstructural and management measures would include recycling flush water and feed management to reduce the volume of contaminated water released or the concentration of contaminants in barnyard runoff. See https://www.nrcs.usda.gov/resources/guides-and-instructions/conservation-practice-standards for a suite of BMP's commonly applied to farming systems

68. Understand the importance of federal, state, and local laws and regulations related to NPS and point source pollution control.

- **a. Clean Water Act**
- **b. Safe Drinking Water Act**
- **c. Coastal Zone Management Act**
- **d. Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)**
- **e. Local regulations**

a. Clean Water Act

The Clean Water Act (CWA), first promulgated in 1972, is the primary federal law in the United States governing water pollution. The Act is the cornerstone of surface water quality protection and addresses aspects of both point and NPS pollution. For a summary of what the CWA contains and for more information see https://www.epa.gov/laws-regulations/summary-clean-water-act

b. Safe Drinking Water Act

The Safe Drinking Water Act (SDWA), originally passed by Congress in 1974, is the principal federal law in the United States that ensures safe drinking water for the public. The Act sets forth primary and secondary drinking water quality standards and oversees states, localities, and water suppliers who provide public drinking water. The primary drinking water standards include maximum contaminant level (MCL) or concentration thresholds set to protect human health. Secondary standards are generally related to drinking water aesthetics or are ones where MCL's have yet to be established regarding impact to human health. See https://www.epa.gov/sdwa for more information.

c. Coastal Zone Management Act

The Coastal Zone Management Act (CZMA), adopted in 1972, has the objective of controlling nonpoint sources of pollution that affect coastal water quality. In this regard it serves to protect bays and estuaries, including those in the Great Lakes. The nonpoint source measures of control are inextricably linked to agricultural operations in watersheds which discharge to coastal waters

(Susquehanna River - Chesapeake, Hudson River - Long Island Sound). More information on the CZMA impacting agriculture can be found at https://coast.noaa.gov/czm/act/.

d. Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
The Federal Insecticide, Fungicide, and Rodenticide Act, first enacted in 1947, established the federal government's control on pesticides. The Act establishes a system of pesticide regulation, sales, distribution and uses to protect applicators, consumers, and the environment. The Act established the registration of pesticides and pesticide applicators, and provides for oversight on intended uses, appropriate dosage, and material hazards specifications. More information can be found at https://www.epa.gov/enforcement/federal-insecticide-fungicide-and-rodenticide-act-fifra-and-federal-facilities

e. Local regulations
State and local laws have evolved to promulgate the federal laws, and in most cases follow the rules and recommendations established by federal law. Specific details regarding state and local laws are best determined by contacting state and local agencies.

CA8: Concentrated Source Pollution

69. Understand the advantages, disadvantages, and situational appropriateness of various options for handling agricultural process waste waters.
   - **a. Septic systems/leach fields**
   - **b. Vegetative treatment areas**
   - **c. Aerobic lagoon**
   - **d. Bark mound/Bark beds**
   - **e. Constructed wetlands**
   - **f. Spray irrigation**
   - **g. Aerobic septic system**
   - **h. Inclusion in liquid manure handling system**

a. Septic systems/leach fields
Septic systems and leach fields are typically low in cost but are not generally suitable for treating large volumes of milking center or other process waste waters. Leach fields are easily clogged with overflow of suspended milk solids. Depending upon the soils (i.e., high water table, high permeability, etc.) over which the leach fields are installed, additional water quality concerns can be generated.

b. Vegetative treatment areas
Vegetative treatment areas are more costly but are reasonably effective in treating processed wastewaters, providing certain design and maintenance criteria are met. Some examples of these criteria include settling and screening out solids and large organic debris, using effluent distribution methods that provide sheet flow across the entire filter area, sizing the filter area appropriately based on hydraulic loading and nutrient loading and removal criteria, and locating the treatment area on suitable soils that can absorb, adsorb, and process the nutrient loads. Milking center wastewater treatment through a vegetated filter area is highly dependent upon the number of animals being milked. Operations with a lot of animals can generate a lot of milking center waste which a vegetated filter area may not be able to adequately handle and treat.

c. Aerobic lagoon

The advantages of an aerobic lagoon are to provide storage and disposal flexibility, they may use less land around the facility for treatment, there may be opportunities for liquid recycling, wastewater treatment becomes a part of the nutrient management plan when the effluent is removed, and they often entail lower labor needs and operating costs. Disadvantages of an aerobic lagoon are offensive odors may occur, aeration may be necessary, and frequent emptying of effluent (depending on size).

d. Bark mound/Bark beds

Organic filter beds are suitable for small wastewater volumes and are quite effective at removing nitrogen. However, they may release phosphorus as the organic filter media decomposes. The main disadvantage is the cost is generally prohibitive to treat large runoff volumes and the organic media beds need to periodically be replaced as they decompose.

e. Constructed wetlands

The advantages of constructed wetlands are they are capable of providing a high level of treatment, inexpensive to operate and largely self-maintaining, and can handle variable loads .The disadvantages are the direct inflow of concentrated process wastewaters may kill vegetation (hydrophytic plants are quite sensitive to high ammonia levels), and large influxes of runoff may temporarily reduce treatment capacity. Furthermore, they can potentially harbor mosquitoes and generate offensive odors and are often more expensive to construct than other treatment options.

f. Spray irrigation

The advantages of spray irrigation are that large wastewater volumes are easily handled and distributed over large areas, and it can provide crop nutrients as part of a nutrient management plan. The disadvantages of spray irrigation, especially in the Northeast, are the wastewater likely needs to be stored for application during dry periods, and it may be difficult and not acceptable to use during winter periods. Spray irrigation systems also require pumps, a network of pipes, and pumping energy inputs.

g. Aerobic septic system

The aerobic septic system is similar to a regular septic system except that the effluent is decomposed and treated aerobically rather than anaerobically. An advantage of an aerobic septic system is the treated effluent is of better quality for land application or disposal to the leach field, so a leach field is less likely to plug. Some disadvantages of the aerobic septic system are that it is more expensive to construct than a traditional septic system, and it is not generally practical for large wastewater volumes.

h. Inclusion in liquid manure handling system

When processing wastewaters are added to the liquid manure handling system, which most often uses the aerobic lagoon approach discussed in C above, the lagoon needs to be increased in size to handle the additional wastewater volumes.

70. Describe the potential pollution impacts of silage leachate.

Silage leachate is acidic (pH around 4), and contains high concentrations of BOD, ammonia-N, phosphorus, potassium, and organic carbons. Silage leachate is one of the most environmentally contaminating wastes produced on a livestock farm if it's not contained, treated, and disposed of properly. Silage leachate is corrosive to steel and concrete, which further complicates managing this waste.

71. Explain management factors that reduce or prevent the potential of stored silage to leach.

Humid climatic conditions exasperate the production of silage leachate. On an equal mass basis, grass ensilage produces more fermentable leachate than corn because of the finer chop size and higher moisture content at harvest. However, compared to corn, grass ensilage is usually put into storage at a denser pack during summer months, so less total leachate runoff tends to escape during rain events. Management factors to reduce leachate volume and runoff from silage bunkers are to harvest crops at maturity and drier moisture content, avoid filling during rainy periods, and to cover the bunkers as quickly as possible.

72. Understand the various methods to manage and treat high and low flow silage leachate.

Low volumes of highly concentrated leachate (low flow) should be collected and diluted prior to land application. Directing the low flow to the manure lagoon for later spreading is recommended. Silage leachate that has been diluted with storm water runoff (high flow) can be either added to the manure storage lagoon, or when concentrations are acceptable, the wastewater can be diverted to appropriately designed vegetated treatment areas or applied directly to crop fields through irrigation.

73. List management and environmental objectives for improving a farmstead with respect to surface drainage in animal operations.

The primary management objectives for improving a barnyard are to enhance livestock health and to make the care and feeding operations more efficient. Environmental objectives are to reduce offensive odors, improve facility aesthetics, and to minimize any off-site loss of contaminants that may impair water quality.

74. Understand why excluding clean water is important and describe methods of excluding outside (clean) water from barnyards and other livestock areas.

Excluding clean water from barnyards and livestock areas reduces the volume of water that needs to be captured or treated. Typical approaches to excluding clean water include the collection and diversion of rainwater from roof areas and the diversion of adjacent (upslope) in-coming runoff water around the barnyard, feedlot, and other feed and manure storage areas.

75. Understand advantages and disadvantages of various barnyard surfaces.

Depending on soil texture, earthen barnyards can become muddy and create water quality and animal health issues. They also can contaminate underlying groundwater. Smooth concrete surfaces are more costly and produce more contaminated runoff but are easy to clean. Slightly roughened minimally sloping concrete is best for animal footing but is more difficult to keep clean.

76. Explain establishment and/or maintenance requirements of barnyards and barnyard runoff treatment options.

Barnyards should be constructed and established so that cleaning can be easily and efficiently accomplished. Barnyards that are cleaned frequently improve animal health, are easier to clean, and reduce concentrations of contaminants in runoff. Barnyards are sloped to runoff collection infrastructure, and concrete curbs are usually installed to which cleaning equipment can push against. Barnyard runoff treatment options are to collect and transfer the effluent to a manure storage lagoon or transfer the runoff effluent to a vegetated treatment area. Considerations should be given to limiting the size of barnyards, eliminating them altogether, or placing a roof over them to minimize the amount of contaminated runoff water that is generated.

77. Compare and contrast AFO and CAFO requirements and regulations.

The EPA defines Animal Feeding Operations (AFOs) as agricultural operations where animals are kept and raised in confined situations. An AFO is a lot or facility (other than an aquatic animal production facility) where the following conditions are met:

- Animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and
- Crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

The AFOs that meet the regulatory definition of a concentrated animal feeding operation (CAFO) are regulated under the NPDES permitting program. The NPDES program regulates the discharge of pollutants from point sources to waters of the United States. Under regulations, CAFOs are point sources, as defined by the CWA [Section 502(14)]. To be considered a CAFO, a facility must first be defined as an AFO, and meet the criteria established in the Regulatory Definitions of Large CAFOs, Medium CAFOs, and Small CAFOs.

a. Large Concentrated Animal Feeding Operation (Large CAFO)

An AFO is defined as a Large CAFO if it stables or confines as many or more than the numbers of animals specified in any of the following categories:

- 700 mature dairy cows, whether milked or dry;
- 1,000 veal calves;
- 1,000 cattle other than mature dairy cows or veal calves. Cattle includes but is not limited to heifers, steers, bulls and cow/calf pairs;
- 2,500 swine, each weighing 55 pounds or more;
- 10,000 swine, each weighing less than 55 pounds;
- 500 horses;
- 10,000 sheep or lambs;
- 55,000 turkeys;

- 30,000 laying hens or broilers, if the AFO uses a liquid manure handling system;
- 125,000 chickens (other than laying hens), if the AFO uses other than a liquid manure handling system;
- 82,000 laying hens, if the AFO uses other than a liquid manure handling system;
- 30,000 ducks (if the AFO uses other than a liquid manure handling system); or
- 5,000 ducks (if the AFO uses a liquid manure handling system)

b. Medium Concentrated Animal Feeding Operation (Medium CAFO)

The term Medium CAFO includes any AFO with the type and number of animals that fall within any of the ranges listed below and which has been defined or designated as a CAFO. An AFO is defined as a Medium CAFO if the type and number of animals that it stables or confines falls within any of the following ranges:

- 200 to 699 mature dairy cows, whether milked or dry;
- 300 to 999 veal calves;
- 300 to 999 cattle other than mature dairy cows or veal calves. Cattle includes but is not limited to heifers, steers, bulls and cow/calf pairs;
- 750 to 2,499 swine each weighing 55 pounds or more;
- 3,000 to 9,999 swine each weighing less than 55 pounds;
- 150 to 499 horses;
- 3,000 to 9,999 sheep or lambs;
- 16,500 to 54,999 turkeys;
- 9,000 to 29,999 laying hens or broilers, if the AFO uses a liquid manure handling system;
- 37,500 to 124,999 chickens (other than laying hens), if the AFO uses other than a liquid manure handling system;
- 25,000 to 81,999 laying hens, if the AFO uses other than a liquid manure handling system;
- 10,000 to 29,999 ducks (if the AFO uses other than a liquid manure handling system); or
- 1,500 to 4,999 ducks (if the AFO uses a liquid manure handling system); and

Some state water quality control authorities may further define or designate certain operations regardless of the animal numbers as CAFOs under state authorities.

CA9: Conservation Planning

78. Understand how policies, procedures, technical guidance, and programs at the federal, state and local level fit together in the conservation planning process. Understand the key elements of the planning process.

The National Environmental Policy Act (NEPA) requires agencies of the Federal Government to utilize a systematic, interdisciplinary approach which will ensure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making which may have an impact on man's environment. The United States Department of Agriculture - Natural Resources Conservation Service (NRCS) developed the 9-Step Conservation Planning Process that enables the agency to meet this NEPA help requirement. The NRCS completes a site-specific Environmental Evaluation (EE), commonly referred to as a CPA-52, during the planning process which incorporates environmental considerations throughout planning, installation, and operation for all actions where NRCS may have control. The NEPA requires NRCS take into account the effects of its actions on all aspects of the environment. Conducting the EE coincides with the 9-step planning process and is not considered a separate activity once the actions have been decided and planned. The9-Step planning process thus establishes a framework in the spirit of NEPA for planning and applying conservation practices/systems which will encourage productive and enjoyable harmony between people and their environment.

79. Explain how federal, state, and local programs support implementation of conservation plans.

Technical and financial assistance is offered to farmers in a voluntary, cost-share driven incentive environment through conservation programs offered by federal, state, and/or local governments. Such programs utilizing public tax dollars are designed to provide public benefits through improved soil, water, air, and plant quality, improved energy efficiencies, and improved wildlife habitat. While they do not typically provide complete cost-share to implement planned conservation practices, they do cover a percentage of the installation cost. Long term operation & maintenance of the conservation practice(s) is the responsibility of the client. When farmers implement conservation plans through participation in voluntary conservation programs, they share in the public's environmental desires and bolster their environmental stewardship. Technical assistance for the conservation plan development and the design of conservation practices is brought to bear by NRCS and Soil and Water Conservation District (SWCD) employees, as well as certified Technical Service Providers (TSP) from the private sector. These individuals provide expertise from discipline areas such as agronomy, animal science, engineering, forestry, and wildlife. TSPs work on behalf of the customer to offer planning, design, and implementation services that meet NRCS criteria. A portion of TSP fees are offset through cost sharing available through federal and state conservation programs. Leveraging federal and state conservation programs at the local level is a very effective strategy to provide a significant amount of the financial assistance that a farmer needs to install the planned conservation system.

80. Understand the NRCS 9-Step Planning Process, including identifying resource concerns, planning criteria, and client objectives, and other state planning tools.

The USDA-NRCS developed and uses a three-phased - nine-step conservation planning process. The planning process integrates economic, social, and ecological considerations to meet private and public needs. The objective of the conservation planning process is to help the client make sound management decisions and prevent the degradation of Soil(S), Water(W), Air(A), Plant(P), Animals(A), and Energy(E) resources, while acknowledging related human (H) considerations. The acronym commonly used for describing this is "SWAPAE+H". The conservation planning process is based on a desired future condition that is desired by the client. It is a dynamic process and steps may be repeated. For more information, see the NRCS "National Planning Procedures Handbook (NPPH): https://directives.nrcs.usda.gov/sites/default/files2/1712930121/33148.pdf. The NPPH provides the following steps of conservation planning:

1. Phase I – Collection and Analysis
   - Step 1 – Identify Problems and Opportunities - Identify existing resource problems and concerns and potential opportunities in the planning area.

- Step 2 – Determine Objectives - Identify and document the client's objectives.
- Step 3 – Inventory Resources - Inventory and document the natural resources and their current onsite and offsite conditions and effects, as well as the economic and social considerations related to the resources.

2. Phase II – Decision Support
   - Step 5 – Formulate Alternatives - Formulate alternatives that will achieve the client's objectives, address identified natural resource concerns and take advantage of opportunities to improve or protect resource conditions and demonstrate a variety of technical and economic implementation strategies.
   - Step 6 – Evaluate Alternatives - Evaluate the alternatives to determine their effects in addressing the client's objectives and the identified natural resource concerns and opportunities. Evaluate the projected effects on social, economic, and ecological concerns. Special attention must be given to those ecological values protected by law or Executive order.
   - Step 7 – Make Decisions - The client selects their preferred alternatives and works with the planner to schedule the conservation system and practice implementation.
3. Phase III – Application and Evaluation
   - Step 8 – Implement the Plan - The client implements the selected alternatives. The planner or technical expert provides the land manager with detailed practice implementation requirements, including component plans and engineered designs. Additional inventory, analysis, and surveying activities may be needed in this step to complete implementation requirements. Conservation staff will also provide practice layout, construction inspection, and certification. The land manager directs the implementation of each practice.
   - Step 9 – Evaluate the Plan - Evaluate the effectiveness of the plan in solving the resource concerns and work with the client to make adjustments as needed.

81. Be aware of the uses of the following USDA NRCS references:

a. Field Office Technical Guide (FOTG)
b. National Handbook of Conservation Practices (NHCP)
c. National Planning Procedures Handbook (NPPH)
d. Agricultural Waste Management Field Handbook (National Engineering Handbook Part 651)

a. Field Office Technical Guide (FOTG)

The Field Office Technical Guide (FOTG) is the primary technical reference for NRCS. It is also the umbrella document for NRCS Technical Releases and References. The FOTG is available on-line and is known there as the electronic FOTG or eFOTG. Each state is required to maintain their own FOTG. The FOTG is divided into five sections:

Section 1 – General Resource References

Section 1 contains general resource information such as maps and other references. Section 1 also contains various resource assessment tools.

Section 2– Natural and Cultural Resources Information

Section II contains detailed information about resources such assoil, water, air, plant, and animal resources. It also includes information about Cultural Resources and Threatened and Endangered Species integration into the planning process.

Section 3 – Resource Concerns and Planning Criteria

Section 3 contains detailed information about NRCS Planning Criteria, which establish standards for resource conditions that help provide sustained use.

Section 4 – Practice Standards and Specifications Supporting Documents

Section 4 contains the NRCS Conservation Practice standards, specifications, guidelines, statements of work, and implementation requirements (IR)

Section 5 – Conservation Effects

Section 5 provides background information on how conservation practices affect each identified resource concerns.

b. National Handbook of Conservation Practices (NHCP)

- The NRCS is the lead USDA agency for providing conservation technical assistance and planning on privately owned lands. The National Handbook of Conservation Practices (NHCP) establishes national standards for conservation practices commonly used to address natural resource concerns and opportunities. Conservation Practice standards are technical documents and are conservation program neutral. Each NRCS State office localizes the Field Office Technical Guide (FOTG) to its geographic area and establishes quality requirements for applying conservation practices within its area of responsibility.
- National conservation practice standards should NOT be used to plan, design, or install a conservation practice or system of practices. Use the standard developed by the state in which you are working to ensure that you meet all state and local criteria which may be more restrictive than the criteria found in the national version of the practice standard. In addition, each state determines which National conservation practice standards are applicable in their state. If you are unsure which state level standard you are looking at, check the bottom right corner of the standard which will identify the state abbreviation and release date.
- Conservation practice standards are updated approximately at least every 5 years to align with advancements in farming and ranching techniques used throughout the world and with changes in technology as documented by research, conservation field trials, and accumulated experience. Practice standards need to be reviewed and maintained continuously to stay current with rapid changes in technology and to ensure that they address multiple resources.
- National policy and practice standards are developed to protect the landowner, conservation contractors, Soil and Water Conservation District (SWCD) employees, NRCS employees, and private sector planners assisting clients with the 9-step planning process. They help to maintain credibility, public trust, and provide consistency across county boundaries.
- The following definitions help to clarify the different documents that are found in the NHCP or Section 4 of the FOTG. Conservation Practice Standards
- Provides the minimum acceptable level of quality that is required to plan, design, install, operate & maintain the practice for the entirety of its lifespan. Conservation Practice Specification
- Site-specific instructions that establish the technical details and workmanship required to install the practice according to NRCS requirements. Conservation Practice Overview

- The conservation practice overview sheet contains a photograph of the installed practice, plus a definition or description of the practice, where it is commonly used and a brief description of the conservation effects of this practice when it is properly applied.
- Conservation Implementation Requirements (IR)
- The conservation practice Implementation Requirements ("IRs") provide detailed requirements for the design, installation, and checkout for the conservation practice,
- Statements of Work
- The Statements of Work outlines the deliverables required to document the design, installation, and checkout for the applicable conservation practices.

c. National Planning Procedures Handbook (NPPH)
(see PO 87 – Understand the NRCS 9-Step Planning Process and other State planning tools).

The purpose of this handbook is to provide guidance on the planning process the Natural Resources Conservation Service (NRCS) uses to help develop, implement, and evaluate conservation plans for individuals, and area wide conservation plans or assessments for groups. NRCS provides conservation planning and technical assistance to clients (individuals, groups, and units of government). These clients develop and implement plans to protect, conserve, and enhance natural resources (soil, water, air, plants, animals and energy) within their social and economic interests.

Planning involves more than considering individual resources. It focuses on the natural systems and ecological processes that sustain the resources. The planner strives to balance natural resource issues with economic and social needs through the development of conservation management systems (CMS). Resource Management System (RMS)An RMS is a combination of conservation practices and resource management activities that treats all identified SWAPAE+H to a level that meets or exceeds the planning criteria in the FOTG. The conservation planning process helps the planner and client accomplish the following:

- Help protect, conserve, and enhance natural resources.
- Design alternatives that meet local resource quality criteria for identified resource issues.
- Include the consideration of human concerns toward achieving sustainable agriculture.
- Consider the effects of planned actions on interrelated geographical areas (i.e., looking off-site, beyond the planning unit boundary).
- Consider and explain the interaction between biological communities and society.
- Focus on ecological principles.
- Consider the effects and interactions of planned systems and practices on natural resources, as well as economic and social considerations.
- Assist with development of plans, regardless of scale, which will help achieve the client's and society's objectives.
- Identify where knowledge, science, and technology need to be advanced.

Planning is complex and dynamic. Successful planning requires not only a high level of knowledge, skills, and abilities on the part of the planner, but also the exercise of professional judgment. To gain or maintain knowledge, skills, and abilities, this handbook can be used as a training tool by less experienced planners and as a reference tool by experienced planners.

d. Agricultural Waste Management Field Handbook (National Engineering Handbook Part 651)
This is a publication that provides planning, design, implementation, and operation and maintenance information for conservation systems that include Agricultural Waste. The Agricultural Waste Management Field Handbook can be accessed at https://directives.sc.egov.usda.gov/directive/24). It is developed and maintained by NRCS.

82. Understand the roles and responsibilities of the local, state, and federal conservation agencies.
   a. USDA Farm Service Agency (FSA)
   b. USDA Natural Resource Conservation Service (NRCS)
   c. Environmental Protection Agency (EPA)
   d. Cooperative Extension Service (CES)
   e. Soil and Water Conservation District (SWCD)
   f. State Environmental Regulation Agencies
   g. State Departments of Agriculture

a. USDA Farm Service Agency (FSA)
The Farm Service Agency (FSA) administers and manages farm commodities, credit, conservation, disaster and loan programs as laid out by Congress through a network of federal, state, and county offices. These programs are designed to improve the economic stability of the agricultural industry and to help farmers adjust production to meet demand. Economically, the desired result of these programs is a steady price range for agricultural commodities for both farmers and consumers. State and county offices directly administer FSA programs. These offices certify farmers for farm programs and pay out farm subsidies and disaster payments.

b. USDA Natural Resource Conservation Service (NRCS)
Since 1935, the Natural Resources Conservation Service (originally called the Soil Conservation Service; http://www.nrcs.usda.gov/about/) has provided leadership in a partnership effort to help America's private land owners and managers conserve their soil, water, and other natural resources. NRCS employees provide technical assistance based on sound science and suited to a customer's specific needs. The agency provides financial assistance for many conservation activities through Federal conservation programs. Participation in these programs is voluntary These conservation programs are funded through the Farm Bill and p NRCS offices are located in nearly every county across the United States as well as some U.S. territories.

c. Environmental Protection Agency (EPA)
The EPA leads the nation's environmental science, research, education, and assessment efforts. The mission of the EPA is to protect human health and the environment. Since 1970, EPA has been working for a cleaner, healthier environment for the American people and: (1) develops and enforces regulations; (2) gives grants; (3) studies environmental issues; (4) sponsors partnerships; (5) teaches people about the environment; and (6) publishes information.

d. Cooperative Extension Service (CES)

Cooperative Extension is a key outreach system of the land-grant universities in the northeastern US. Many of the states in the northeastern US have county-based or regional Cooperative Extension Systems. See the websites of the land-grant universities for more information.

e. Soil and Water Conservation District (SWCD)

Soil and Water Conservation Districts are government entities that help control the use of land and water in U.S. states and insular areas. There are more than 3,000 in the United States. Depending on the state, they may also be known as soil and water conservation districts, soil conservation districts, resource conservation districts, or other similar names.

f. State Environmental Regulation Agencies

Each state has a state environmental regulation agency. As an example, the New York State Department of Environmental Conservation (DEC) was created with the mission to "To conserve, improve and protect New York's natural resources and environment and to prevent, abate and control water, land and air pollution, in order to enhance the health, safety and welfare of the people of the state and their overall economic and social well-being." Maine, Massachusetts and New Jersey have a Department of Environmental Protection. New Hampshire has a Department of Environmental Services. Connecticut has a Department of Energy and Environmental Protection. Rhode Island has a Department of Environmental Management. Like New York, Vermont also has a Department of Environmental Conservation. For more information, see Health and Environmental Agencies of U.S. States and Territories | US EPA.

g. State Departments of Agriculture

The Northeast Association of State Departments of Agriculture includes the New England states, New York and Pennsylvania. A listing of departments can be found here: NEASDA - NASDA.