ASSESSING THE HYDROLOGIC IMPACTS OF MILITARY MANEUVERS

by

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Abstract

Military land management is vital to the future health and usability of maneuver training areas. As land disturbance increases, runoff from the area also increases and may create significant erosion potential. Determining the relationship between what is safe training versus what is harmful to the environment can be done by determining runoff potential at different disturbance percentages given different training intensities.

Various studies have shown that soil density, soil structure, plant biodiversity, animal biodiversity, and many other essential ecosystem factors are greatly damaged by continuous training. These ecosystem factors influence runoff amounts and likewise erosion potential in that area. The primary factor examined in this study was the Curve Number (CN). Since military procedures do not have predefined CNs, representative CNs were created based off of CNs for agricultural use and supplemental research about training impacts on the land. Training intensity was broken into four classes: undisturbed, light use, moderate use, and heavy use. Five sample watersheds on Fort Riley were used as replications for the study. Disturbance intensity indexes were broken into 10% increments, and changes in runoff amount and peak rate modeled with TR-55.

Statistical analysis was done comparing watersheds, training intensities and disturbance percentages for different storm magnitudes to assess statistically significance of changes in runoff amount and peak rate. This analysis showed that runoff amount and rate were both significantly impacted at every 10% increase on disturbance percentage. Results also showed that at the lower disturbance percentage (less than 30%), runoff amount and rate were not significantly impacted by training use classes. From this it can be seen that even with very little training done to the land increased erosion can be expected.

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Dedication

To all of those who have supported me throughout this project, without whom I would not be here today.

Chapter 1 - Introduction

Gully erosion poses a serious threat to our armed forces because it produces training hazards and degrades the land's health, which then causes downstream problems and compromises the integrity of the land for future uses. Military vehicles that train under low visibility conditions have often been known to unwittingly run into gullies, severely damaging the equipment, and more importantly, the operators. In some cases, these gullies can be multiple meters in depth and even wider across.

Gully erosion is a direct result of increased runoff and occurs when the soil structure, vegetative cover, and/or surface storage is lost. Military maneuvers have been found to deteriorate all of these factors, with increased training intensity resulting in increased disturbance to the landscape. With this disturbance to the landscape, less water infiltrates into the soil and more water moves down the hillslope generating greater erosive potential.

In this study, the hydrology modeling tool Technical Report 55 (TR-55) was analyzed to see if it was sensitive enough to model changes in runoff generated by military training. Five watersheds were selected across Fort Riley for the study. Training was examined in four training classes: undisturbed, light use, moderate use, and heavy use. The amount of training that had been done in a particular class was defined by the disturbance percentage, which defined how much of the total watershed area had experienced training maneuvers. ArcGIS tools, various data layers, and on site data were used to create inputs for hydrological modeling.

Research Objectives

This study examined whether the widely used Curve Number (CN) Method could be adapted to predict useful runoff values from watersheds with differing military training intensities. Since runoff rates and volumes are highly correlated with erosion, the ability to accurately predict the magnitude of runoff events aids in linking military training to erosion potential and resultant gully formation. Main questions explored were if the CN Method was sensitive enough to catch the differences in runoff potential given typical training operations and at what disturbance percentages and training intensities this change in runoff was statistically significant. To simplify this process, the CN Method in conjunction with WinTR-55 was used to determine if the range of proposed CNs for military use could accurately differentiate between given runoff results. The main variable changing across the landscape for this study was CN based on percentage of land that had experienced differing degrees of training intensity. To represent this, four training classes similar to those used by Garten et al. (2003), were formed: undisturbed, light use, moderate use, and heavy use. Curve numbers were estimated by using known set CNs and modifying them based on research studies done on the military training areas. Where these changes in disturbance percentage were statistically different shows how much of the land can be trained on before an increase in runoff potential and gully formation can be expected.

Chapter 2 - Literature Review

Military Land Management

The Department of Defense (DoD) manages over 100 thousand square kilometers (25 million acres) of land, making it one of the largest land holders in the nation (DoD, 2006). On that land, there are over 425 military installations used for combat training, munitions testing, deployment of weapon systems, and much more. Of these lands nearly 50 thousand square kilometers (12 million acres) with 120 major installations are managed by the Army (Boice, 1996). Fort Riley alone encompasses 405 square kilometers (100,000 acres) of the DoD managed land (Dix, 2011).

There are two main purposes that DoD lands must strive to maintain: land for training and land for ecological function. In the DoDs 2011 Natural Resource Conservation Program (DoD, 2011), the DoD states that its conservation program activities must "…work to guarantee … realistic military training and testing and to sustain the long-term ecological integrity of the resource base and the ecosystem services it provides," pointing out the military's need to effectively manage its land resources for future training and ecological uses. Particularly they discussed four major stratagems for DoD land management:

1) Maintaining natural resources for testing, training, mission readiness, and assessing long-term, comprehensive, coordinated, and cost-effective range sustainability.
2) Protecting and enhancing resources for mission support, biodiversity conservation, and ecosystem maintenance services.

3) Managing areas for multiple uses when appropriate, such as military training, scientific research, education, and recreation.

4) Integrating conservation programs with mission activities, installation planning and programming, and other appropriate activities.

DoD installations are expected to operate according to Federal natural resources requirements, Executive Orders, and Presidential Memorandums, as well as taking ecosystem-based management approaches for its land (DoD, 2011).

Training land sustainability is threatened as the land is continuously disturbed, ITAM (Integrated Training Area Management Program), a program used by the U.S. Army at over 60 installations across the country, helps to monitor the impacts of training on military land. Boice, 1996 refers to five main practices ITAM uses to aid in military land management:

1) Monitoring changes over time in land and resource conditions.
2) Encouraging soldiers to practice environmental stewardship and wise tactical use of natural resources.
3) Rehabilitating land and controlling erosion for both training experience and resource conservation.
4) Integrating training mission requirements with natural resource conservation to optimize land use.
5) Managing threatened and endangered species.

If conservation practices are not used in training, the land quickly loses its ability to function as a natural training ground; ITAM helps to keep training land in its optimal conditions (Boise, 1996).

When considering ecosystem sustainability, soil erosion and endangered species management are two things that must be considered. The DoD National Resource Conservation Program (DoD, 2011) refers to soil erosion in stating that DoD installations must adhere to Non-Point Source (NPS) pollution laws, implement best management practices to minimize NPS runoff, and control soil erosion. From this it can be seen that military lands are held responsible for the amount of sediment that leaves training lands.

Boice, 1996 states that more than 200 of the military installations in the US provide habitat to at least one endangered species, particularly due to the fact that these areas include large, relatively undisturbed ecosystems that elsewhere have often been developed or otherwise disturbed. Boice, 1996 also states that the implementation of an ecosystem-based management plan will make managing endangered species much easier and cost effective for the DoD, since this type of plan is based on protecting existing plants and animals and their natural ecosystem, which then reduces the need down the road for restorative practices.

In Fort Riley's Integrated Natural Resources Management Plan, it is noted that poor grassland management promotes the invasion of woody plants.   This brush obscures weapon firing lines and reduces how well commanders can observe field maneuvers and firing exercises. These combined effects all lead to certain areas not being suitable for training procedures until restorative actions are taken (INRMP, 2010).

Maneuver Impact Area

The Army Training and Testing Area Carry Capacity Program (ATTACC) uses the Maneuver Impact Mile (MIM) to quantify training loads, which are based on mileage projections (US Army Corps of Engineers, 1999). MIMs are calculated by using a 'standard' vehicle assumption of an M1A2 Abrams tank as it travels one mile in an armor battalion field training exercise (Mendoza et al., 2002). The general equation for the MIM (Equation 6) as defined by Mendoza et al., 2002, shows that it is primarily a function of the number of vehicles active, the duration of the training event, and the mileage covered. There are also training severity factors and site specific inputs considered in the final calculation of the MIM.

Equation 1. Maneuver impact mile.

$$MIM = \sum_{E=1}^{e}\left[\left(\sum_{V=1}^{v}\left(Number_V * Mileage_V * VSF_V * VOF_V * VCF_V\right)\right) * Duration_E * ESF_E * LCF_E\right]$$

where:
MIM = normalized training load (maneuver impact miles)
E = event (dimensionless)
e = number of events (dimensionless)
V= vehicle type (dimensionless)
v = number of types of vehicles in event E (dimensionless)
Mileage = daily mileage for vehicle type V for event type E (miles)
Number = number of vehicles of type V (dimensionless)
VSF = vehicle severity factor for vehicle type V (dimensionless)
VOF = vehicle off-road factor for vehicle type V (dimensionless)
VCF = vehicle conversion factor for vehicle type V (dimensionless)
LCF = local condition factor for event E (dimensionless)
Duration = number of days for event type V (days)
ESF = event severity factor for event type V (dimensionless).

Non-Point Source Pollution and the Clean Water Act

Non-point source pollution is a common problem associated with military training land since the landscape can be highly disturbed during training exercises, similar to farming operations in some cases. The Clean Water Act (CWA) of 1972 established guidelines for pollutant discharge into water to maintain water quality standards for surface water; however, it did not originally include regulations for NPS pollution (EPA, 1972). It was not until 1987 that an amendment to the CWA expanded it to include a NPS management program which would be further developed state by state (EPA, 1987). For Kansas, NPS pollution refers to “the transport of natural or man-made pollutants by rainfall or snowmelt moving over and through land surfaces and entering lakes, rivers, streams, wetlands, or groundwater" (KDHE, 2010). For the Fort Riley location the primary mode of sediment transport is through water related erosion.

Sediment Loadings

A primary pollutant considered under the Clean Water Act is sediment. Sediment is a problem because it increases turbidity, carries many chemical pollutants, and disrupts hydraulic characteristics of the channels when it is deposited. Turbidity limits the ability of sunlight to penetrate the water, which then limits the photosynthetic capabilities of aquatic plants and algae. High turbidity can also degrade spawning areas for fish by silting in gravel beds. Suspended sediment is also considered a chemical pollutant because of the particulate organic carbon associated with it and because of the affinity of other chemicals to adhere to the soil particles. DDT and other chlorinated pesticides are common examples of chemicals that end up in the water due to their adherence to soil particles. These chemicals can then enter the food chain by fish directly ingesting the soil particles or bottom feeders ingesting it, which in turn are consumed by the fish, and accumulate on up the food chain ultimately to enter the human body (Ongley, 1996). High levels of sedimentation can disrupt navigation and increase flooding due to decreased storage capacity of the waterway (Ongley, 1996). Though sediment can be removed from water bodies by dredging, this is a very costly procedure ranging currently from \$20,000 to \$50,000 just for the mobilization and demobilization, and anywhere from \$5.00 to \$10.00 per cubic meter of soil removed after that, making avoiding the sediment loading in the first place optimal (Dredging Specialist, 2012).

Watershed Management and TMDLs

Fort Riley lies on the western side of the Kansas-Lower Republican Basin, with most of its runoff draining into Milford Lake (KWO, 2007). Milford Lake is a popular recreational site that was formed by the creation of the Milford dam in the 1960's to reduce the effects of flooding in the Fort Riley and Junction City areas (US Army Corps of Engineers, 2011). Milford Lake is approximately 16,318 acres (6,604 hectares) in size and is currently used for both flood control and recreation. According to the United States Environmental Protection Agency, Milford is in need of a TMDL for Dissolved Oxygen (U.S. EPA, 2010). Lack of dissolved oxygen is typically caused by excess vegetation, rotting vegetation, hot temperatures, and still water, commonly leading to fish kills (U.S. EPA, 2010). Milford Lake has very often and recently been under cyanobacteria (blue-green algae) alerts which directly result from excessive nutrients, such as nitrogen and phosphorus. Blue-green algae is a problem because of the toxins it can produce which endanger public health (FL Dept. of Environmental Protection, 2012). Suspended sediment in Milford has also been found to have increased from 1989 to 2009 by interpreting remotely sensed data (Milner, 2009). Many of these problems can be linked back to increased sediment loadings from runoff upstream, making controlling sediment loss at the source a vital priority.

Runoff

Surface runoff is one of the main causes of erosion, and it is influenced by evaporation, interception, infiltration, and surface storage (USDA, 2009). Evaporation refers to the process of liquid water being changed into a gas or vapor due to heat (USGS, 2009). Evaporation of soil water decreases the soil moisture content of the soil. Initial moisture condition of the soil, or how much water is present in the soil, is broken down into two critical levels of moisture content: field capacity and permanent wilting point. Field capacity occurs when the soil is holding as much water as is possible against gravitational forces; whereas permanent wilting point is on the other side of the spectrum and occurs when the soil is extremely dry and the only water present is unavailable to plants as they cannot exude enough pressure to remove it from the soil pores. Interception represents the storage of precipitation on plant and litter surfaces (Swank, 1968). Infiltration by definition is the rate at which water can enter a soil surface through soil pores, and it is highly dependent on initial moisture condition, soil porosity, soil pore size, and rainfall duration (Mishra and Singh, 2003). Soil porosity and pore size refers to the portion of soil not made up by solid material that allows for movements of fluids and gases through the soil profile. Soil porosity is the fraction of available space in the soil for fluid to the total volume of the soil, and is typically between 30-70%. Soil porosity changes if the soil is packed, its particle distribution changed, the shapes of its particles are altered, or due to cementing that occurs when clays and organic materials cement particles into aggregates (Nimmo, 2004). Porosity in itself is not a true indicator of a soil's infiltration capacities as many soils, such as soils with high clay content, may have very high porosities but very small pore sizes and therefore infiltrate water very slowly. The pore size of a soil type influences a fluid's ability to move throughout the soil via diffusion. The smaller the pore size the greater the tortuosity of the path the water must travel, so the slower the infiltration (Oxford and Oxford, 2010). As the duration of the rainfall increases, less storage is available so less water enters the soil profile. The three main types of runoff are surface flow, interflow, and baseflow. Surface flow refers to water from precipitation that flows along the surface of the watershed and exists in sheet, shallow concentrated, and channel flow conditions. Interflow is a type of subsurface flow that increases with increased infiltration capacity and eventually moves into a stream channel.

Baseflow occurs when water recharges via infiltration into the ground water table. This too eventually will enter a stream channel, but at a much slower rate than interflow (NRCS, 2004).

Runoff is also influenced by the soil's antecedent moisture condition (AMC). AMC is used to define soil moisture, which refers to how wet the soil is prior to a storm event. There are typically three AMCs: AMCs I, II, and III. AMC I refers to the most dry conditions where the most potential storage is available in the soil so maximum infiltration is possible. AMC III refers to wet soil moisture conditions where there is little storage with maximum runoff potential (Mishra and Singh, 2003). The National Engineering Handbook (NEH) (NRCS, 2004) suggests using five days prior to the storm event when determining how much antecedent rainfall is influencing the system. This is also known as the Antecedent Precipitation Index (API). Table 1 shows total five-day antecedent rainfall for the different AMCs based on the dormant versus the growing season (Mishra and Singh, 2003). AMCs can be determined by probes, with sampling, or with remote sensing technologies. The more water there is in the soil, the less available storage so likewise the higher the resultant runoff.

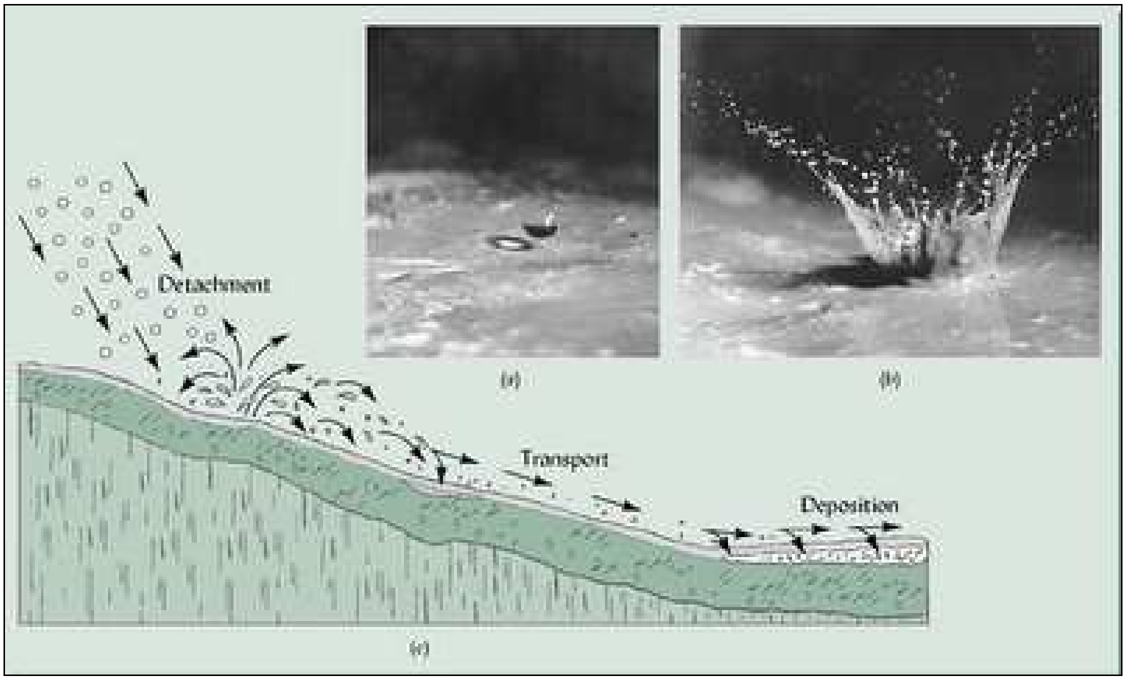
Table 1. Total 5-day antecedent soil moisture conditions for dormant and growing seasons, Mishra and Singh (2003).

AMC	Total 5-day antecedent rainfall (cm)	
	Dormant Season	Growing Season
I	Less than 1.3	Less than 3.6
II	1.3 to 2.8	3.6 to 5.3
III	More than 2.8	More than 5.3

Water Erosion

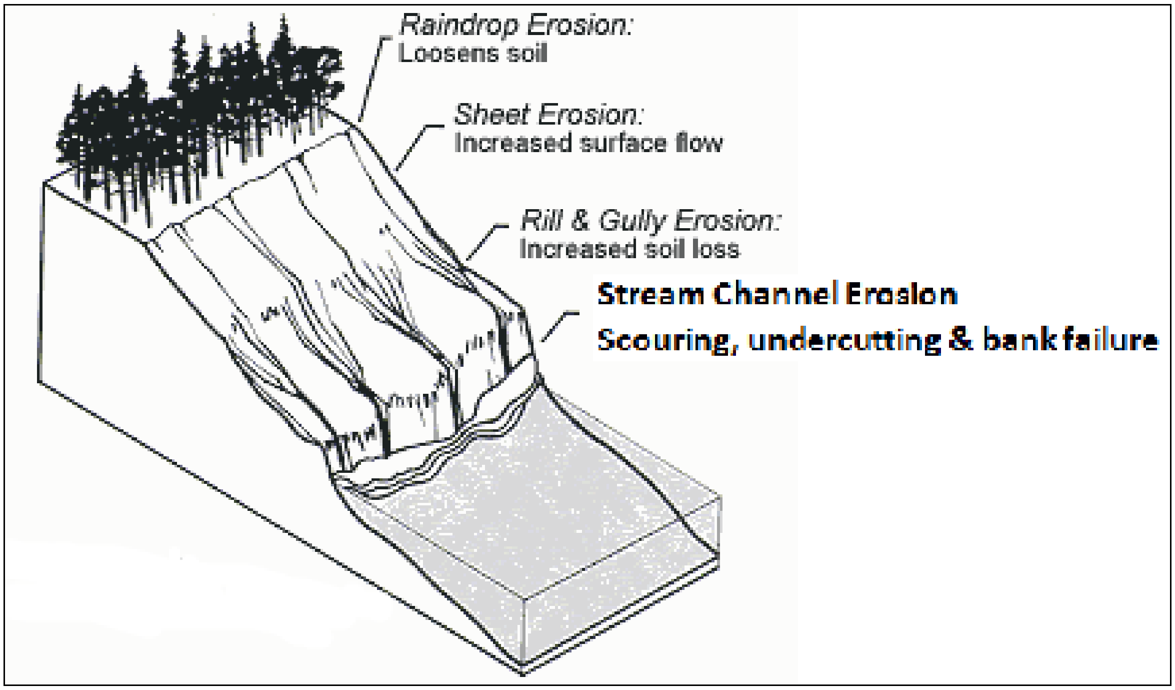
Water erosion can take several different forms: splash erosion, sheet erosion, rill erosion, stream channel erosion, and gully erosion. Splash erosion refers to the detachment of soil particles caused by the initial impact of water droplets as it falls on the soil surface. The main thing this does is to increase turbulence, or the amount of soil held in suspension, making more soil available to erode. Vegetative cover lessens the effects of splash erosion, but on bare ground this can lead to crusting and increased runoff (Ward and Trimble, 2004). Figure 1 shows how soil is detached via water droplets, transported down the hillslope, and then deposited when the water slows down and the soil particles can settle out.

Figure 1. Splash erosion mechanism from modified from Stitcher (2010) (a) raindrop just before impact with soil, (b) resulting splash and sediment disturbance, (c) process representation.



Sheet erosion is the relatively uniform removal of soil from a land surface (USDA, 2001). Sheet erosion results from increased surface flow and transports soil down the hillslope. Rill erosion further increases soil loss and takes the form of small eroding channels, usually only a few inches deep that can be erased by tillage but reform after heavy rain, especially with low vegetative cover conditions (USDA, 1997). Stream channel erosion refers to both sediment losses from the sides of the channel and sediment movement throughout the channel. This occurs through scouring, undercutting, and mass failures of the banks. Vegetation removal along banks is a primary factor in increasing stream channel erosion (Ward and Trimble, 2004). Figure 2 shows the different erosion processes.

Figure 2. Raindrop, sheet, rill/gully, and stream channel erosion processes modified from Dept. of Ecology, Washington (2010).



Gully Erosion

Gully erosion is the most dramatic form of water erosion and it is a common problem on Military land that can pose serious environmental and training threats. Gully erosion results in channels larger than those produced by rill erosion but with less sediment loss than rill erosion. Gully erosion refers to a highly visible form of soil erosion that experiences ephemeral flows during large rainfall events (Carey, 2006). Gullies are formed when concentrated flow moves at a velocity capable of detaching and transporting soil particles. Gullies are most commonly found when some part of the system has been disrupted; for example, if the overland flow is increased due to decreased infiltration. As time passes and more storm events occur, gullies may widen and deepen. Active gullies, ones where continued erosion is occurring, tend to have sheer vertical sides, while older gullies that have acclimated to runoff rates tend to stabilize toward oblique shapes which promote vegetation regrowth (Carey, 2006). Gullies are limited in depth by the underlying rock formations, so are typically less than 2 meters in depth, though can be as deep as 10 to 15 meters in certain regions (Carey, 2006). Typical gullies are linear incisions that cannot be removed during regular agricultural activities (Torri and Lorenzo, 2003). There are two main types of gully erosion: classic gully erosion and ephemeral gully erosion. Classic gully erosion is used to define channels that are too deep to cross with farm equipment. These are assumed to be permanent unless they are filled in with soil by human means. These gullies are known to subdivide the land and reduce land quality and value (Foster, 1986). Ephemeral gullies refer to gullies that form in natural waterways when they experience high concentrated flow. These waterways are where the majority of water and soil loss occurs from the area. Table 2 explains in further detail the differences between ephemeral and classical gully erosion.

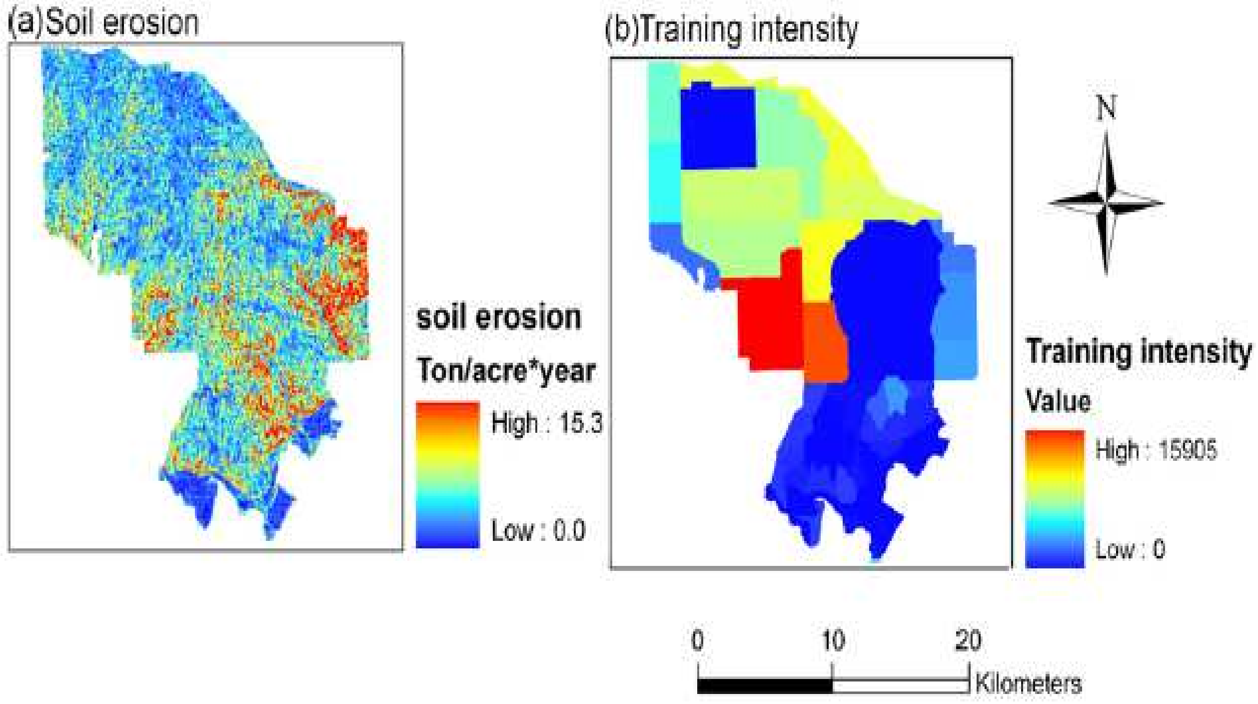
Table 2. Ephemeral and classical gully erosion characteristics, modified from Foster (1986).

Ephemeral Gully Erosion	Classical Gully Erosion
Ephemeral cropland gullies are temporary features, usually obscured by tillage; recur in the same location	Gullies are not obscured by normal tillage operations
May be of any size but are usually larger than rills and smaller than permanent gullies	Usually larger than ephemeral cropland gullies
Cross sections tend to be wide relative to depth; sidewalls frequently are not well defined; headcuts are usually not readily visible and are not prominent because of tillage	Cross sections of many gullies tend to be narrow relative to depth; sidewalls are steep; headcut usually prominent
Usually forms a dendritic pattern along depressional water courses, beginning where overland flow, including rills, converge; flow patterns may be influenced by tillage, crop rows, terraces, or other unnatural features	Tend to form a dendritic pattern along natural water courses; nondendritic patterns may occur in road ditches, terraces, or diversion channels
Occurs along shallow drainageways upstream from incised channels or gullies	Generally occurs in well-defined drainageways
Soil is removed along a narrow flow path, typically to the depth of the tillage layer where the untilled layer is resistant to erosion, or deeper where the untilled layer is less resistant; soil is moved into the voided area from adjacent land by mechanical action (tillage) and rill erosion, damaging an area wider than the eroded channel	Soil may be eroded to depth of the profile and can erode into soft bedrock

Current Gullies on Fort Riley

Soil erosion problems have been identified primarily in the east, south, and southwest parts of the Fort, with isolated areas of increased problems located in areas where regular training is known to be done (Handley, 2011). A comparison of erosion potential and training intensity for the Fort is shown in Figure 3 (Johnson, 2010). These images show that some of the areas with highest erosion potential are not from training areas. This is probably because of the land use in that area. To the southern portion of the fort there is a lot of developed area and agricultural land, while the impact zone lies to the east. The training intensities on Fort Riley vary by every publication, personal opinion, and on a much smaller scale than is depicted in Figure 3.b. Since training data is very difficult to procure, the probability that it is still the case is very slim.

Figure 3. Soil erosion (a) and training intensities (b) maps of Fort Riley, modified from Johnson (2010).



One difficulty associated with locating areas of high training intensity is the lack of training data and vehicle tracking information. In a study conducted by Haugen et al. (2003), various training exercises were monitored both spatially and temporally using Global Positioning Systems (GPSs) to determine how much land was disturbed, and given the varying speeds, the degree of disturbance that was done. Their findings gave impact factors relating increased speed and coverage area to greater land degradation, where higher speeds with shorter radii produced greater disturbance (Haugen et al., 2003).

Military Training and Soil Properties

Many research studies have been conducted on how military vehicles impact the landscape (Althoff et al., 2007; Althoff and Thien, 2005; Anderson et al., 2005, 2006; Foster et al., 2006; Haugen et al., 2003; Kun et al., 2009; Perkins et al., 2007; Wang et al., 2009). These studies examined how different soil types and conditions, vehicle types and maneuvers, and other factors influenced landscape changes. From these studies soil compaction generally tended to increase with increased training and vehicle size. Tracked vehicles typically caused less soil compaction than similarly sized wheeled vehicles since their weight was more distributed over the ground. Vegetation removal however was higher with tracked vehicles in most cases since the tracks dug into the surface more, particularly under wet conditions, creating more mixing in the top soil horizon. Loss of biological components such as small mammals, arthropods, and nematodes was also shown in areas where training had been done. The presence of these organism is an indicator of overall ecosystem health, so the further their numbers from natural conditions, the less healthy the landscape.

Vegetation Removal

Vegetation serves as a buffer between the soil and the forces that would erode it, such as water. When vegetation is removed, there is nothing to shield the soil and create the structure to hold the soil together. Anderson et al. (2005) researched how different levels of military training affected vegetative cover at Fort Hood, Texas. A site was monitored to determine changes in Cover factor (C factor), ground cover, and aerial cover both spatial and temporal. C factor refers to the different crop types and tillage methods used for an area, the lower the cover factor, the lower the potential soil erosion. During periods of high use of the land, noticeable declines in C factor were shown, but after troops were deployed and the training area was rested, C factors increased again. Trends for ground cover and aerial cover were relatively small, but portrayed a general decrease as disturbance increased. In addition, Anderson et al. (2005) examined the effects of training done during wet and dry periods. Training in wet periods was found to be much more destructive than training in dry periods, leading to greater vegetation loss. Similarly, when training was done under wet conditions, grass biomass was found to be reduced much more dramatically than when training was done under dry conditions, while more loss of forb biomass was found given dry conditions of training over wet conditions (Althoff and Thien, 2005). Vegetative cover was also proven to be highly influenced by training procedures by Perkins et al. (2007) who found high correlations between training intensity and ecological disturbance.

Vehicle type also impacts land disturbance. Tracked vehicles distribute the weight of the vehicle across the track's area so fewer ruts are formed. However, with wheeled vehicles, such as the Light Armored Vehicles (LAVs) studied by Foster et al. (2006), destructive disturbance was easily made with relatively low speeds due to their relatively short and narrow footprints.

This was particularly noticeable when turns of less than a 40 meter radius were executed. In this study, they also found that when such disturbances occurred, non-native species were much less disturbance resistant than native grasses and forbs. Once the native species were removed from the area due to intense disturbance though, the non-native species would move in and were easily destroyed by subsequent training (Foster et al., 2006). High-Mobility Multipurpose Wheeled Vehicles (HMMWVs) were also found be to less destructive than LAVs, particularly since the HMMWVs are a much lighter vehicle than LAVs (Liu, 2009). Vegetative cover and disturbance were also analyzed to determine how military training influenced them; vegetative cover was found be reduced and disturbance increased from pre-training conditions (Fang et al., 2005).

The type of training being done also greatly impacts the amount of disturbance. Some commonly used training procedures include zone reconnaissance, screen line, and area security. Of these, Haugen et al. (2003) found zone reconnaissance to be the most destructive toward vegetation. Zone reconnaissance includes the preliminary area exploration to determine information about the site so much more land is covered and therefore disturbed (Haugen et al., 2003).

Biological diversity, such as arthropods and nematodes has also been found to decrease as disturbance by training increased. Althoff and Thien (2005) compared the presence of native earthworms, exotic earthworms and arthropods given wet/dry and trained/controlled treatments for silty clay loam and silty loam on Fort Riley. The trained class being defined as just after a M1A1 Abrams tank had traveled over the area. In all cases where the organisms were found, their average values with the tank travel were all lower than in the untrained (control) area. For example, 31 native earthworms were found in the silt loam soil under wet and control conditions, whereas only 3 native earthworms were found under the wet plot with tank travel. This is important because the presence of these organisms is indicative of overall soil health (Althoff and Thien, 2005).

Soil Compaction

Soil compaction decreases pore space and, particularly with wheeled vehicles, is concentrated where the wheel or track of the vehicle travels on the soil surface (Althoff and Thien, 2005). Primary factors influencing the degree of compaction include the soil's mechanical strength, which is based off of such qualities as organic carbon content, soil texture, previous disturbance level of the soil, water content, and the loading that the soil receives from the vehicle based on its weight, dimensions, and velocity (Defossez and Richard, 2002; Anderson et al., 2005; Garten et al., 2003; Bhat et al., 2007). Each of the four soil hydrologic groups are impacted differently by compaction.

Soil hydrologic groups are based on saturated soil conditions, when the soil is not frozen, bare, and at the maximum swelling conditions of expansive clays. Group A soils infiltrate water readily, even when very wet. Group A soils have less than 10 percent clay content and more than 90 percent sand or gravel content. Some loams are included in group A, provided they have good aggregation, low bulk density, and/or greater than 35 percent rock fragments (NRCS, 2007). Group A soils do not compact easily due to the high sand and gravel contents. Therefore, group A soils that have more loam are more susceptible to compaction since this causes a loss of aggregation. Group B soils also have relatively high infiltration capacities when wet. These soils range from 10 to 20 percent clay content with 50 to 90 percent sand. Like group A, some loams are included in this class, provided they have good aggregation, low bulk density, or have more than 35 percent rock fragment content. Group B soils are more prone to compaction than Group A soils due to their higher clay percentages. When compacted, loams in this group also lose their aggregation, increasing their bulk density. Group C soils have fairly low infiltration potential when wet. These soils contain from 20 to 40 percent clay with less than 50 percent sand, with loam types in some soils. Clays are assumed to be well aggregated, with low bulk densities and greater than 35 percent rock fragment content (NRCS, 2007). Soil group D has the lowest infiltration potential when wet. Soils in group D have greater than 40 percent clay content and less than 50 percent sand (NRCS, 2007).

Compaction is similar to decreasing the soil's hydrologic group in a sense, because the soil steadily moves to being less aggregated, having lower infiltration capacity, and a higher bulk density. Soil types A and B with their high sand and gravel contents are less susceptible to compaction than soil groups C and D with their high clay percentages. Unlike sands and gravel, which do not adhere readily to other particles, clay particles with their small size and large specific surface areas easily adhere to other particles and each other, decreasing pore spaces and increasing bulk densities.

In a study conducted by Althoff and Thien (2005) on Fort Riley, KS, the moisture content of the soil under both wet and dry conditions was assessed to see how soil texture, bulk density, porosity, and other factors were influenced by varying degrees of training. Simulated training was done by M1A1 battle tanks passing in a figured-8 pattern five times over a set course. Two different soil types were assessed: silty clay loam and silty loam, because they represented the major soil types on Fort Riley, with three locations and three treatments for each plot. Under dry conditions (9% water content) the bulk density of the soil increased and the porosity of the soil decreased in trafficked areas for both soil types. Wet conditions (33 % water content) showed a much larger increase in bulk density with the silty loam soil while the bulk density of the silty clay soil under wet conditions slightly decreased. However, soil porosity was found to decrease for the silty clay soil as well, so the bulk density decrease may have been due to the shrink-swell properties of clay.

Perkins et al. (2007) also found landscape disturbance to be highly influenced by training procedures at Fort Benning, where mean soil pore sizes were found to decrease and soil bulk density to increase for training areas when compared to undisturbed areas. Compaction by military vehicles increased bulk density similarly to how agricultural vehicles increase the bulk density and create compacted layers (e.g. hardpan) beneath the soil surface. Hardpans are layers of soil that restrict root growth and infiltration capacity; this likewise increases the runoff potential of the soil (Raper et al., 2005).

Erosion Modeling

Modeling erosion can be done in many different ways. Some of the most common techniques involve using the Universal Soil Loss Equation (USLE) (http://www.ars.usda.gov/ Research//docs.htm?docid=10626) or the Revised Universal Soil loss Equation (RUSLE) (http://www.ars.usda.gov/Research/docs.htm?docid=5971) , the Water Erosion Prediction Program (WEPP) (http://www.ars.usda.gov/Research/docs.htm?docid=10621), or the Soil and Water Assessment Tool (SWAT) (http://swat.tamu.edu/) (Stone and Hilborn, 2000; Jones D. et al., 1996; Flanagan and Frankenberger, 2002; Gassman et al., 2006). All of these programs incorporate in some way the application of water as a driving force of erosion, but can be time and resource intensive. Because of the strong relationship between runoff and erosion, the doorway to using more user-friendly programs is opened to us, such as TR-55. By determining runoff for various watersheds, the areas of greatest potential for erosion can be determined.

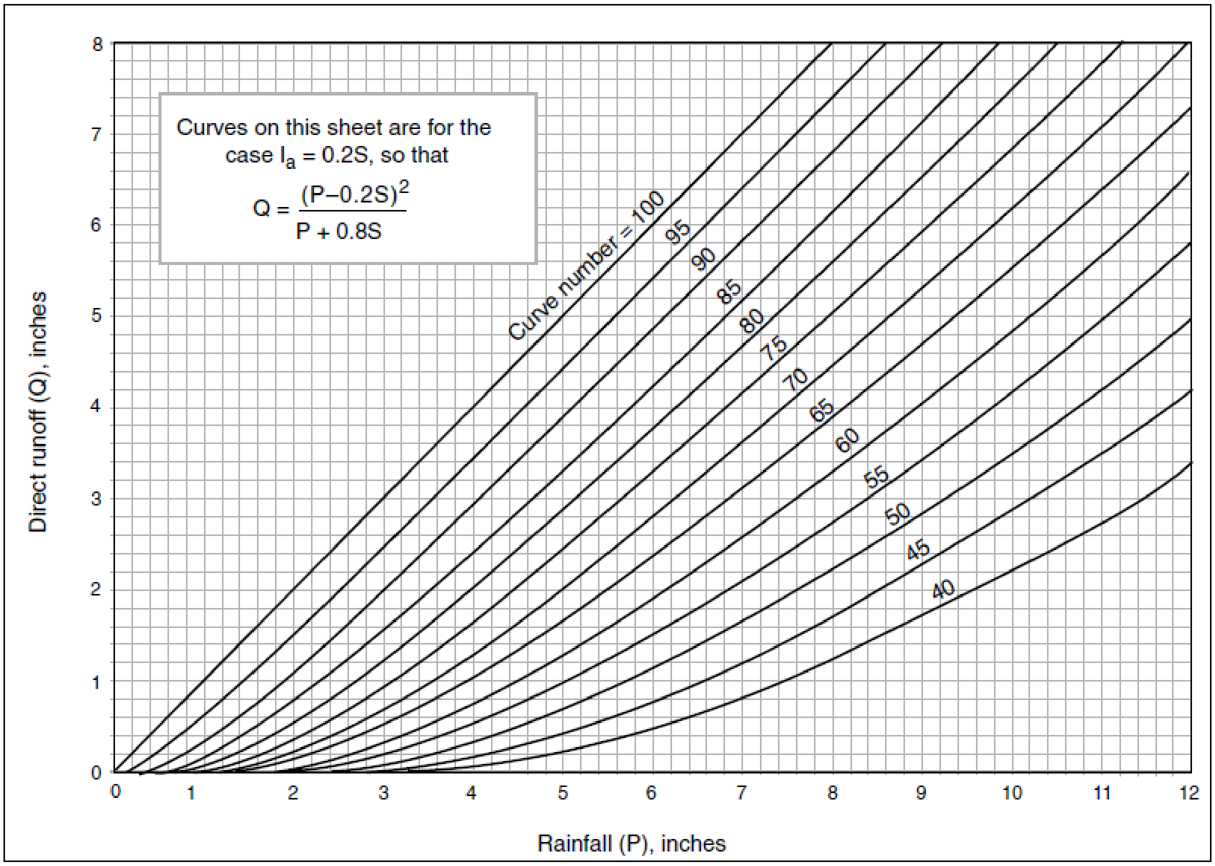
TR-55/20 and the Curve Number Method

WinTR-55 is a commonly used and relatively simple Windows based program developed by the Natural Resource Conservation Service (NRCS). TR-55 uses the widely accepted CN Method to predict runoff given different site specific information. TR-55 is primarily used for estimating runoff and peak discharge in urban settings with small watersheds ranging from 0.01 acres (0.004 hectares) to 16,000 acres (65,000 hectares) though it is applicable to other watersheds as well (USDA, 1986). It is commonly used to compare runoff rates given different stages of urbanization. As land is urbanized, runoff and peak discharge are typically increased due to increased impervious surfaces. Factors to be considered with TR-55 include CN, rainfall, time of concentration, drainage area, antecedent moisture condition, and any hydraulic structures. Runoff amount and peak discharge values have been found to be significantly accurate given that runoff is greater than ½ inch (1.27 cm) (LMNO Engineering, 1999). Additionally, TR-55 is commonly used because it is an empirical, lumped model with widespread use and acceptance, has enough simplicity to make modeling feasible on short time allowances, and works well for design storms (Dorsey, 2009). The SCS CN method itself has also been found to be very applicable given that the storage for a given watershed is less than or equal to twice the total rainfall amount, which is the case for the purposes of this study (Mishra and Singh, 2004).

The WinTR-55 program walks you through a number of steps to properly characterize a watershed. One of the first inputs is land use details, where CNs based on the land use categories, cover description, condition, hydrologic soil groups, and area of each of these are selected. Custom CN values can also be entered by using a user defined selection.

Land use categories within TR-55 are broken down into urban, developing urban, cultivated agriculture, other agriculture, and arid rangeland. The CN relates different land cover to its runoff potential: the higher the CN the greater the runoff potential. Figure 4 below shows how CN affects Runoff given different Rainfall events.

Figure 4. CN response to direct runoff from rainfall (inches), modified from USDA (1986).



Curves on this sheet are for the case $I_a = 0.2S$, so that

$$Q = \frac{(P-0.2S)^2}{P + 0.8S}$$

The CN Method approximates runoff using the following basic equation:

Equation 2. Runoff amount.

$$Q = \frac{\left(P - I_a\right)^2}{\left(P - I_a\right) + S}$$

Where:

Q= Runoff flow amount, in (mm)

P= Single storm event precipitation, in (mm)

Ia= Initial Abstraction, in (mm)

S= Storage, in (mm)

Storage (S), or the amount of water from precipitation that does not runoff the site, is a function based of the CN, where:

Equation 3. Storage.

$$S = (1000/CN - 10)n$$

S=Storage, in

CN= Curve Number

n= conversion factor for SI= 25.4 mm/in

CNs are determined based on site specific data in relation to hydrologic soil type, land covers, and percent impervious area. For a full list of set CNs see Appendix A, Figures 1, 2, and 3.

Time of Concentration data is another input section in TR-55 which calculates total travel time by summing values calculated from sheet, shallow concentrated, and channel flow. Time of concentration refers to how long water takes to move from the start (or some point of interest) to the end of the watershed. The time of concentration is typically equal to less than the rainfall duration. Time of concentration is found by determining the different travel times for the watershed and then summing them.

Equation 4. Time of concentration.

$$T_t = \frac{L}{3600V}$$

where:

T_t = travel time (hr)
L = flow length, **ft (m)**
V = average velocity, **ft/s (m/s)**
3600 = conversion factor from seconds to hours.

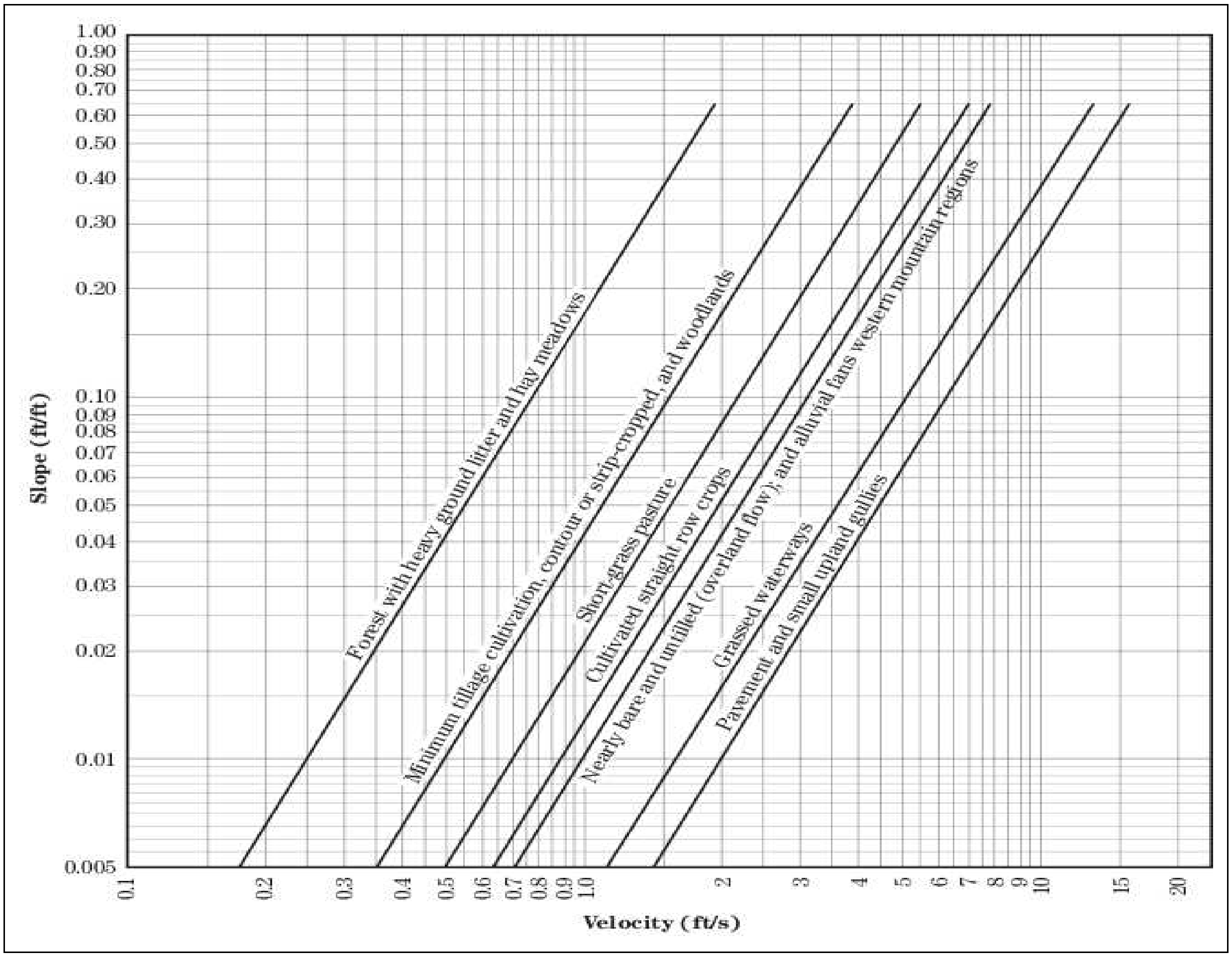
Flow type and velocity are the two main factors used to determine time of concentration. The three types of flow: sheet, shallow concentrated, and channel are determined by finding the slope, flow length path, depth of flow, channel shape and the roughness of the surface the water is passing over. Sheet flow refers to non-concentrated overland flow which rarely exceeds 30 meters in length. Some typical maximum sheet flow lengths for different land covers found by McCuen-Spiess (1995) are shown in Table 3 below. Range typically has much longer sheet flow than grass or woodland. The larger slope value of 0.05 is also associated with a longer sheet flow length.

Table 3. McCuen-Spiess sheet flow length limitation criterion, modified from USDA (1986).

Maximum sheet flow lengths using the McCuen-Spiess limitation Criterion			
Cover type	n values	Slope (m/m)	Length (m)
Range	0.13	0.01	23
Grass	0.41	0.01	7
Woods	0.80	0.01	4
Range	0.13	0.05	52
Grass	0.41	0.05	17
Woods	0.80	0.05	9

Shallow concentrated flow occurs after sheet flow as water collects in swales, small rills and gullies. Flow depths for shallow concentrated flow usually range from 0.1 to 0.5 feet (0.03-0.15 meters). Figure 5 below illustrates how the velocity of the flow increases as the slope increases for different land cover types. Forests typically show the lowest velocity of shallow concentrated flow and then as cover decreases the velocity of flow increases, leaving the highest velocities to areas with no cover, such as pavement or asphalt.

Figure 5. Shallow concentrated flow velocities given varying land cover types and slope, modified from USDA (1986).



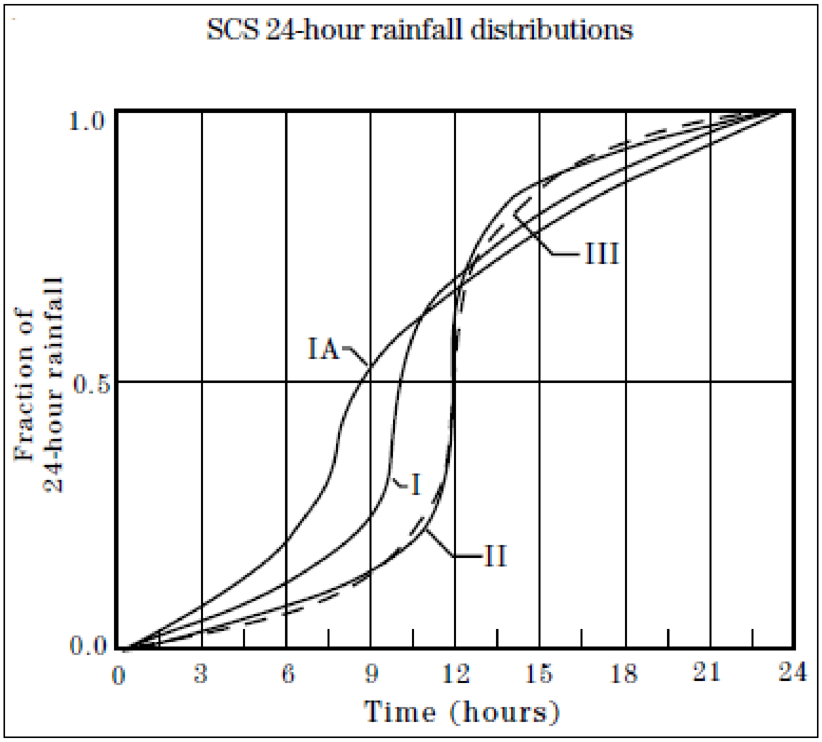
Following shallow concentrated flow, open channel flow occurs. Open channel flows have depths of flow greater than shallow concentrated flow and channels are mapped or able to be viewed from aerial photography.

The drainage area refers to how much land is included in the watershed and is typically determined from topographic maps. Depending on the size of the area being studied, the area may be broken down into smaller subwatersheds to help better characterize the flow.

Data on hydraulic structures in the watershed can also be added and includes such things as dams and reservoirs which alter the natural hydrologic cycle that are in the watershed.

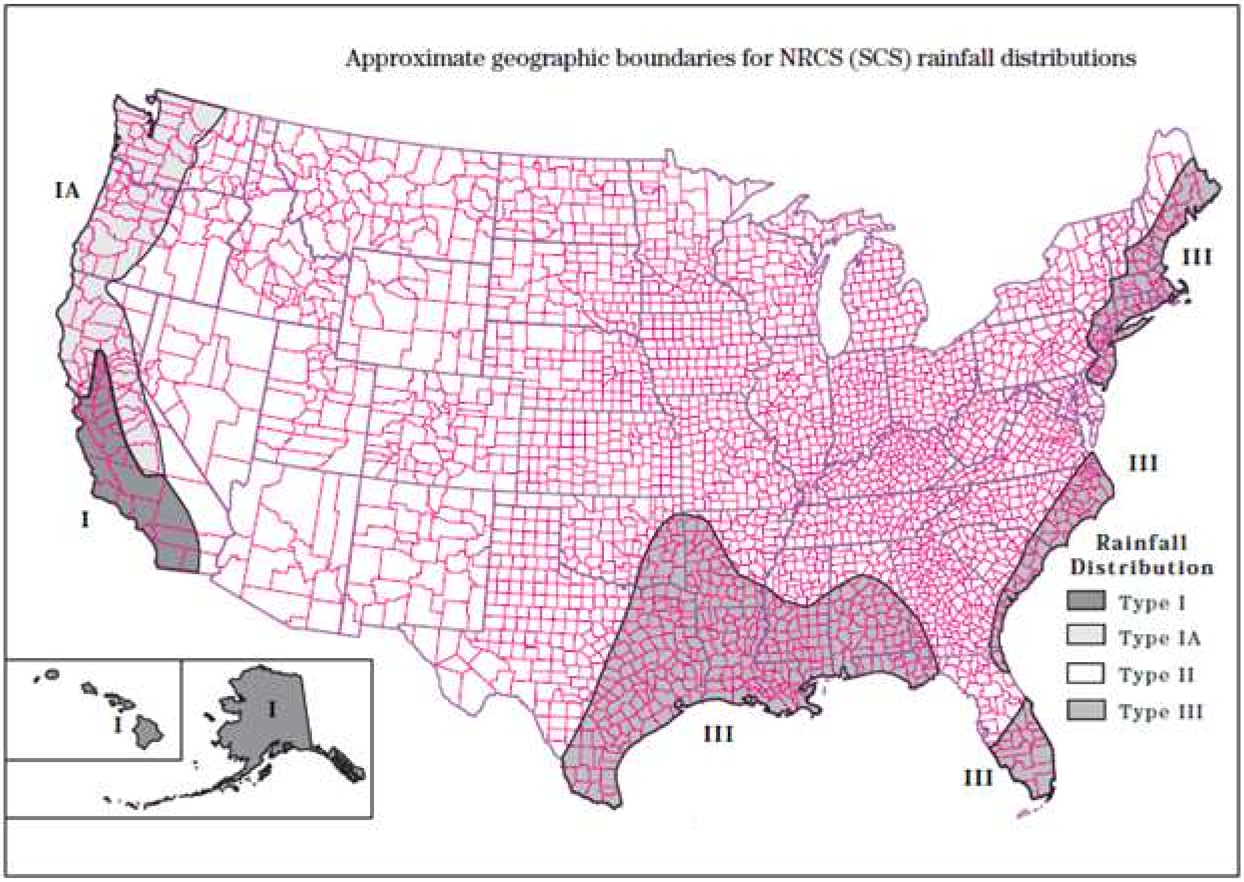
TR-55 also allows the user to define rainfall distribution and storm types. Typically NRCS storm data is used for the site, but custom inputs can be made. Four regional rainfall time distributions are used in TR-55 over a 24-hour storm period (Types I, IA, II, and III) that break up rainfall based on its rate throughout the storm period. Figure 6 shows the differences between the different storm distributions.

Figure 6. SCS 24-hour rainfall distributions, modified from USDA (1986).



Riley County has a type II rainfall distribution, in which the highest rate of rainfall is between the 10th and 11th hour of an assumed 24-hour storm (USDA, 1986). Rainfall distribution types can be defined based on the rainfall distribution map created by the NRCS shown in Figure 7.

Figure 7. Rainfall type distribution map, modified from USDA (1986).

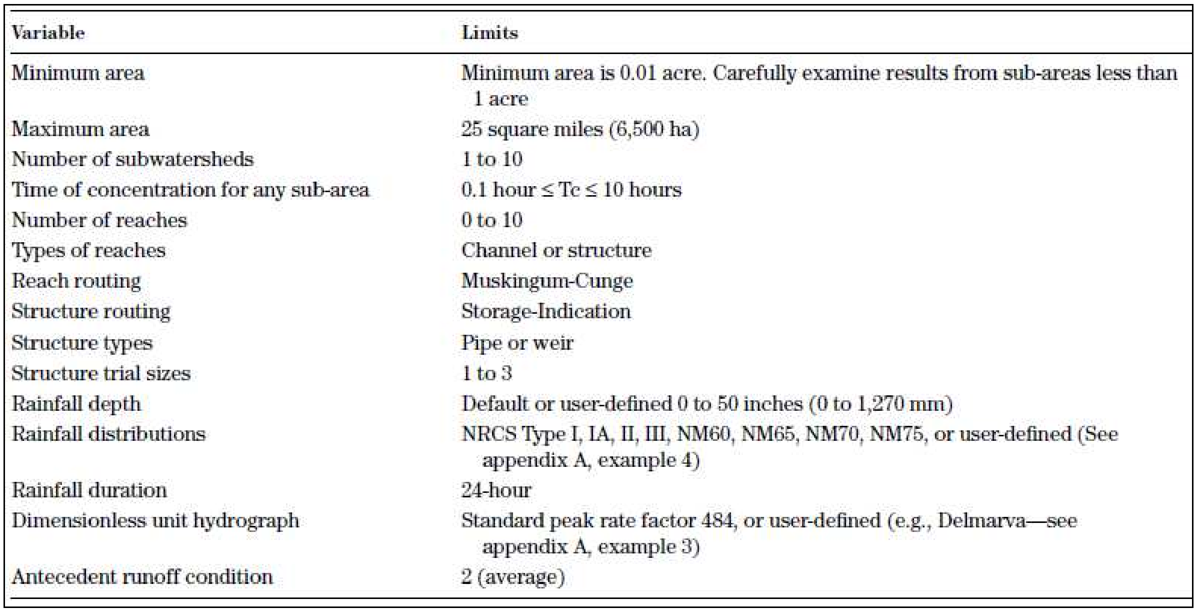


Once all input has been determined, peak discharge and hydrographs can be generated with TR-55 for different storm events using two different methods: the Graphical Peak Discharge Method and the Tabular Hydrograph Method. Results provide peak flow rates from the subareas, reaches, and outlet in cubic feet per second.

Limitations of TR-55

TR-55 is a simplified program used to expedite the watershed modeling process; because of this assumptions have been made which limit the customization of certain parameters. In addition, up-scaling of data from TR-55 from individual watersheds to the entire site may not result in completely accurate results; this is particularly a problem when small-scale assessments are done (Anderson et al., 2005). Table 4 below summarizes the main variables limited by the WinTr-55 program and the range of changes that may be applied to them.

Table 4. WinTR-55 limitations, USDA (1986).



Variable	Limits
Minimum area	Minimum area is 0.01 acre. Carefully examine results from sub-areas less than 1 acre
Maximum area	25 square miles (6,500 ha)
Number of subwatersheds	1 to 10
Time of concentration for any sub-area	0.1 hour ≤ Tc ≤ 10 hours
Number of reaches	0 to 10
Types of reaches	Channel or structure
Reach routing	Muskingum-Cunge
Structure routing	Storage-Indication
Structure types	Pipe or weir
Structure trial sizes	1 to 3
Rainfall depth	Default or user-defined 0 to 50 inches (0 to 1,270 mm)
Rainfall distributions	NRCS Type I, IA, II, III, NM60, NM65, NM70, NM75, or user-defined (See appendix A, example 4)
Rainfall duration	24-hour
Dimensionless unit hydrograph	Standard peak rate factor 484, or user-defined (e.g., Delmarva—see appendix A, example 3)
Antecedent runoff condition	2 (average)

Many watershed characteristics are simplified with TR-55 and were outlined as follows (Virginia Dept. of Conservation and Recreation, 2012).

1) TR-55 simplifies the relationship between rainfall and runoff by assuming that all initial abstraction is done before runoff begins, and uses “S” to represent potential maximum storage from soil and cover conditions.

2) Initial abstraction represents many different processes in TR-55, including interception, initial infiltration, surface depression storage, evapotranspiration, along with other watershed factors.

3) Runoff from snowmelt or from frozen ground is not considered in TR-55s runoff calculations.

4) If runoff is less than 1.27 centimeters, the runoff CN is very inaccurate.

5) SCS runoff procedures do not apply to subsurface flows or high water conditions

6) If sheet flow lengths are longer than 300 feet, Manning’s kinematic solution should be used to calculate time of concentration.

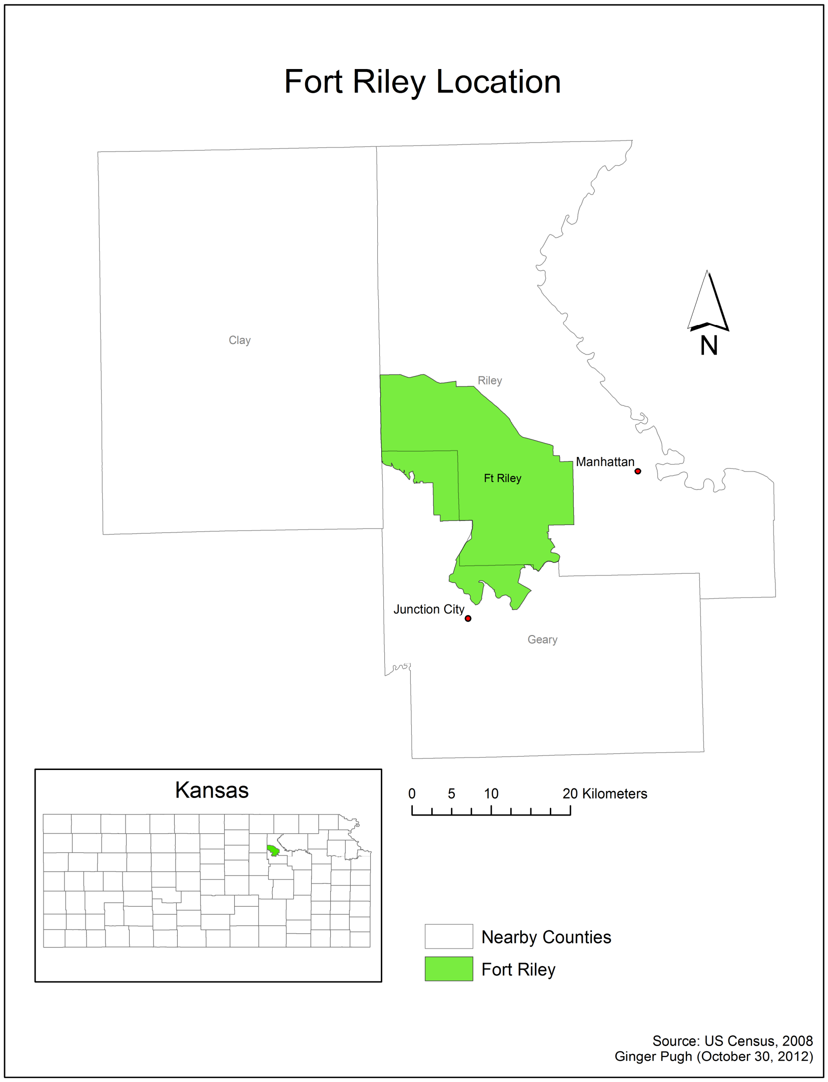
7) TR-55 has a minimum time of concentration of 0.1 hour.

Chapter 3 - Materials and Methods

Site Description

The study site for this project is the Fort Riley military installation located between Junction City and Manhattan, Kansas, at latitude 39.083N and longitude -96.807W (Figure 8). Fort Riley, which was built in 1853, encompasses approximately 412 square kilometers and receives active year-round training.

Figure 8. Fort Riley location, U.S. Census (2008).

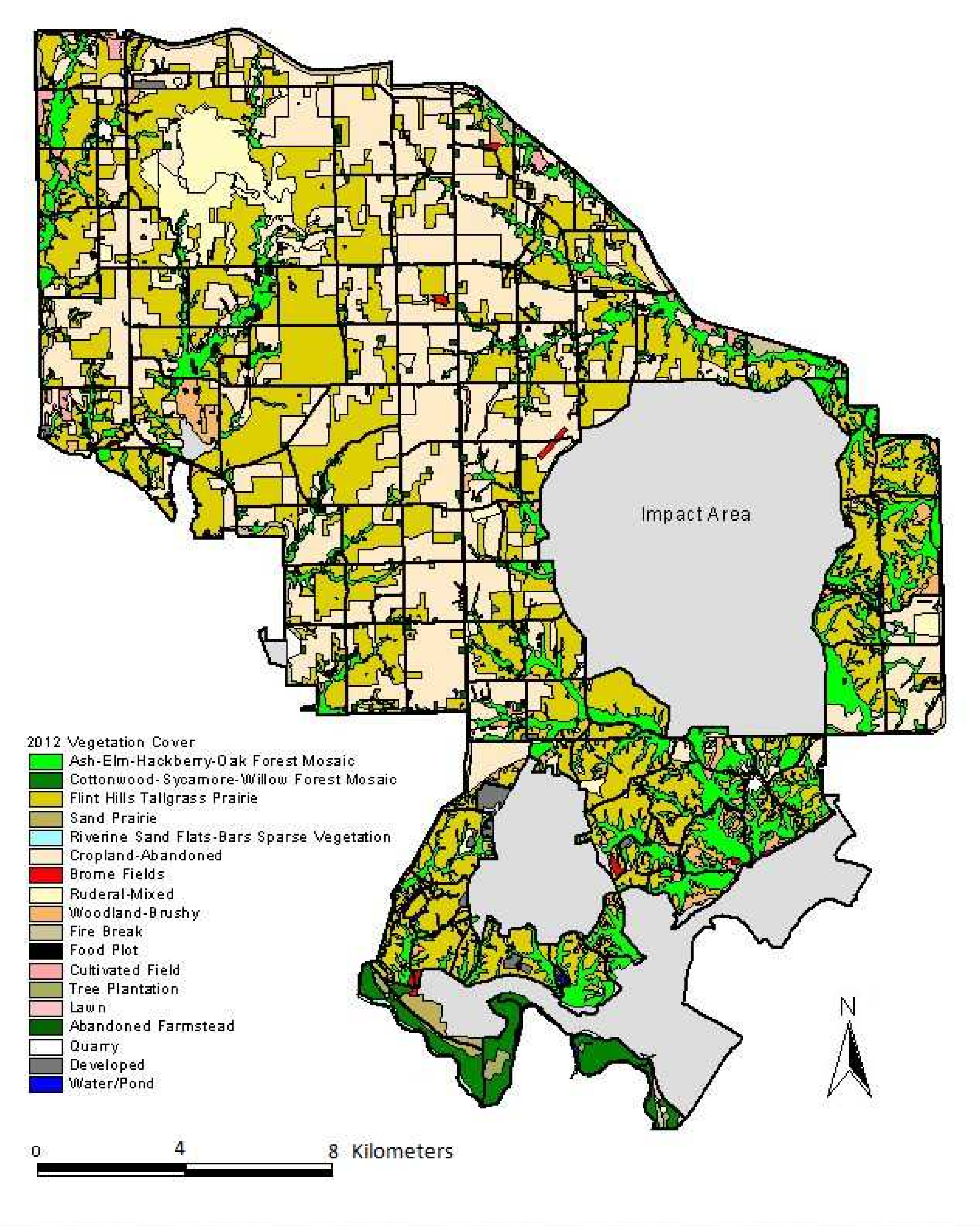


Source: US Census, 2008
Ginger Pugh (October 30, 2012)

Land Use and Land Cover

Land uses on Fort Riley range from urban uses to reverted agricultural land or prairie used for maneuver training, which can have extensive land disturbance or be relatively undisturbed (Wang et al., 2009). Fort Riley lies in the Flint Hills ecoregion, with dominant vegetation types being tallgrass prairie, abandoned cropland and deciduous forests (Figure 9) (Delisle et al., 2012). The grasslands are approximately 34% with low-human impacts, and 66% with high-human impacts, predominately from training-related procedures (Freeman, 2004).

Figure 9. Fort Riley land cover assessment, from Delisle et al. (2012).

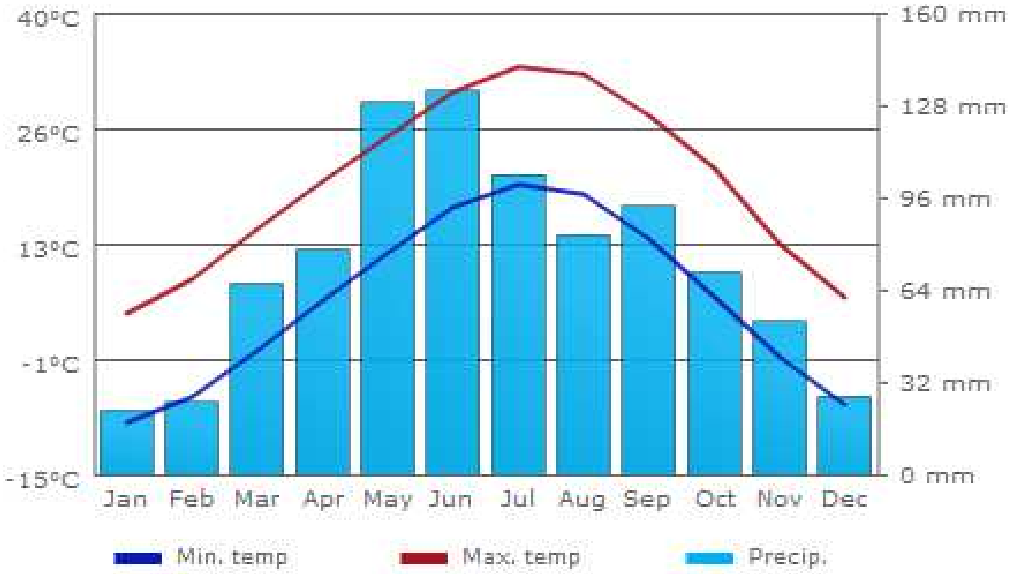


Primary vegetative cover types on Fort Riley are grasslands and forestlands. The grassland areas on the Fort make up about two-thirds of land area of the Fort, and consist of approximately 40% native tallgrass prairies and 60% reclaimed agricultural land once used for grazing and row-crop agricultural practices or highly disturbed grassland (US Army, 2011). Native grasses such as big bluestem *(Andropogon gerardii)*, little bluestem *(Schizachyrium scoparium)*, indiangrass *(Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and sideoats grama (*Bouteloua curtipendula*) are the most common types of native grasses found on the Fort. Lands that have been reclaimed from agricultural practices or have been severely disturbed tend to have concentration of native grass species and more invasive grasses and forbs. Forestland consists primarily of cottonwood *(Populus deltoides*), hackberry (*Celtis occidentalis*), green ash (*Fraxinus pennsylvanica*), red mulberry (*Morus rubra*), sycamore (*Platanus occidentalis*), American elm (*Ulmus americana*), bur oak (*Quercus macrocarpa*), chinquapin oak (*Quercus muehlenbergii*), black walnut *(Juglans nigra*), bitternut hickory (*Carya cordiformis*), and honey locust (*Gleditsia triacanthos*). Most forestland is located along the Kansas and Republican Rivers, or in the vicinity of other small waterways. Tree cover seems to indirectly reduce the amount of training done in an area, depending on what types of training are taking place. Shrubland areas are also becoming more popular on the Fort due to reduced burning and grazing (US Army, 2011). Dense tree or shrub cover is more difficult to navigate through than open rangeland so may prove less desirable for training. Military disturbance percent by landcover type is approximately 7.5% for woodland and shrubland, 21% for large forested areas, and 33% for rangelands (Milchunas et al., 1999). The amount of forested and shrubland in the watersheds of interest were relatively small and so were not considered in the analysis

Climate

Yearly precipitation for Riley County is approximately 86 centimeters (KSU, 2011), slightly lower than the US average, with mean rainfall per month peaking at around 120 mm in May and June, the beginning of the growing season, and falling down to a minimum rainfall of around 30 mm during the winter months. Temperatures reach their maximum, 33º C, during July and August and hit an average minimum of nearly -10 º C from December through January (U.S. Climate Data, 2012). Figure 10 below shows the trend for precipitation and minimum and maximum average temperatures for the nearby city of Manhattan, KS.

Figure 10. Climate graph for Manhattan, KS, modified from U.S. Climate Data (2012).



The area is in the Type II rainfall distribution region, which refers to a rainfall distribution where the storm starts out with a slow rainfall rate, reaches its maximum rate during the middle of the storm, then slows down as the storm ends (USDA, 1986).

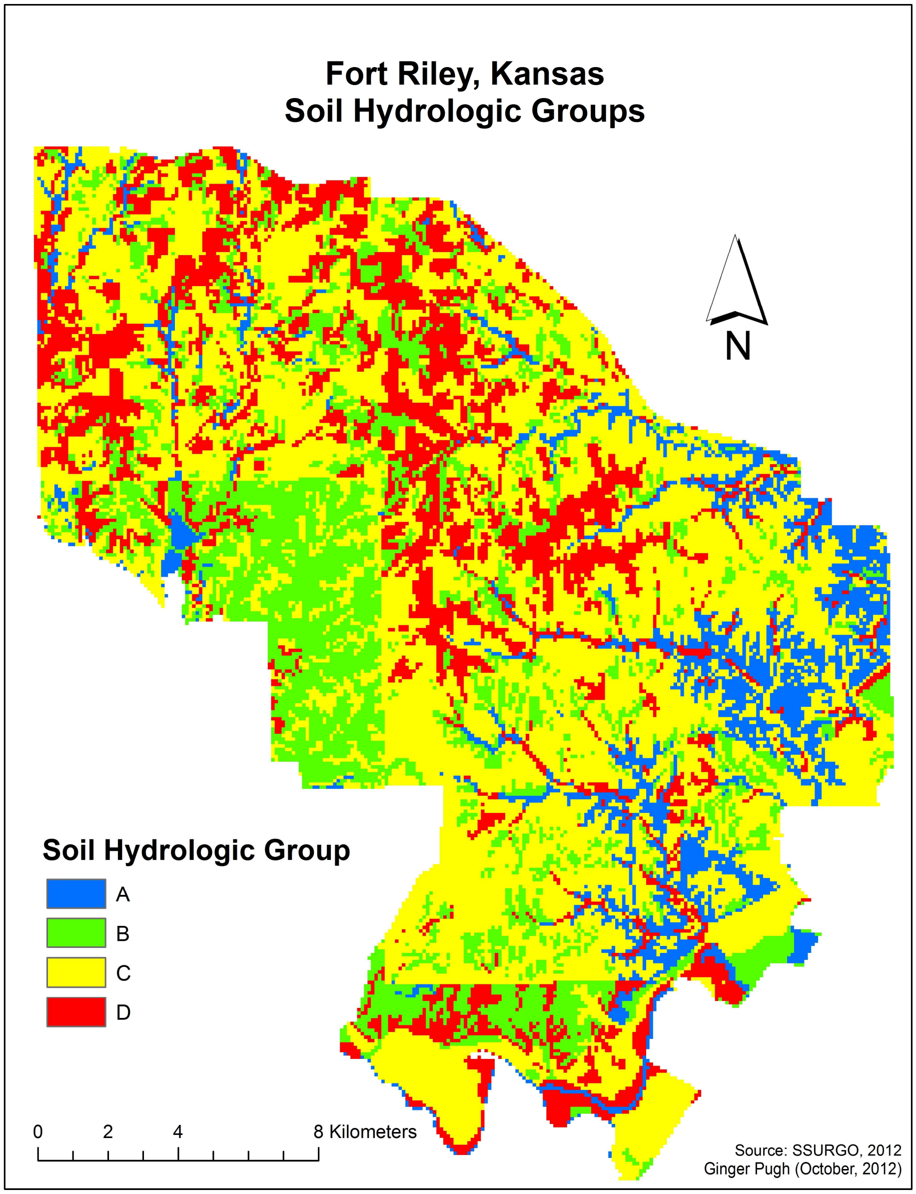
Topography

Fort Riley is located in the Osage Plains portion of the Central Lowlands physiographic province. The terrain ranges on the south side of the Fort from alluvial bottomland flood plains and rivers to broken and hilly transition zones in the central and eastern parts, then to high upland prairies on the north and western sides. Along the west side of Fort Riley lays the Great Plains and to the east the Ozark Plateau. The high upland prairies alternate between layers of Permian limestone and shale, with very gentle slopes below rolling plateaus. A small, inactive fault line is located on the northeast portion of Fort Riley near Tuttle Creek Lake which provides the potential for earthquakes in the region (US Dept. of Ag-SCS, 1975).

Soils

Predominant soil types on Fort Riley include silty clay loams and silt loams (USDA, 1975). By examining Soil Survey Geographic Database (SSURGO) maps, it can be seen that the areas where most of the training is done on the Fort primarily have soil types in the C and D hydrologic groups, with the majority of the areas having C type soil (Figure 12). C and D soils are highly susceptible to runoff and compact very easily compared to type A and B soils.

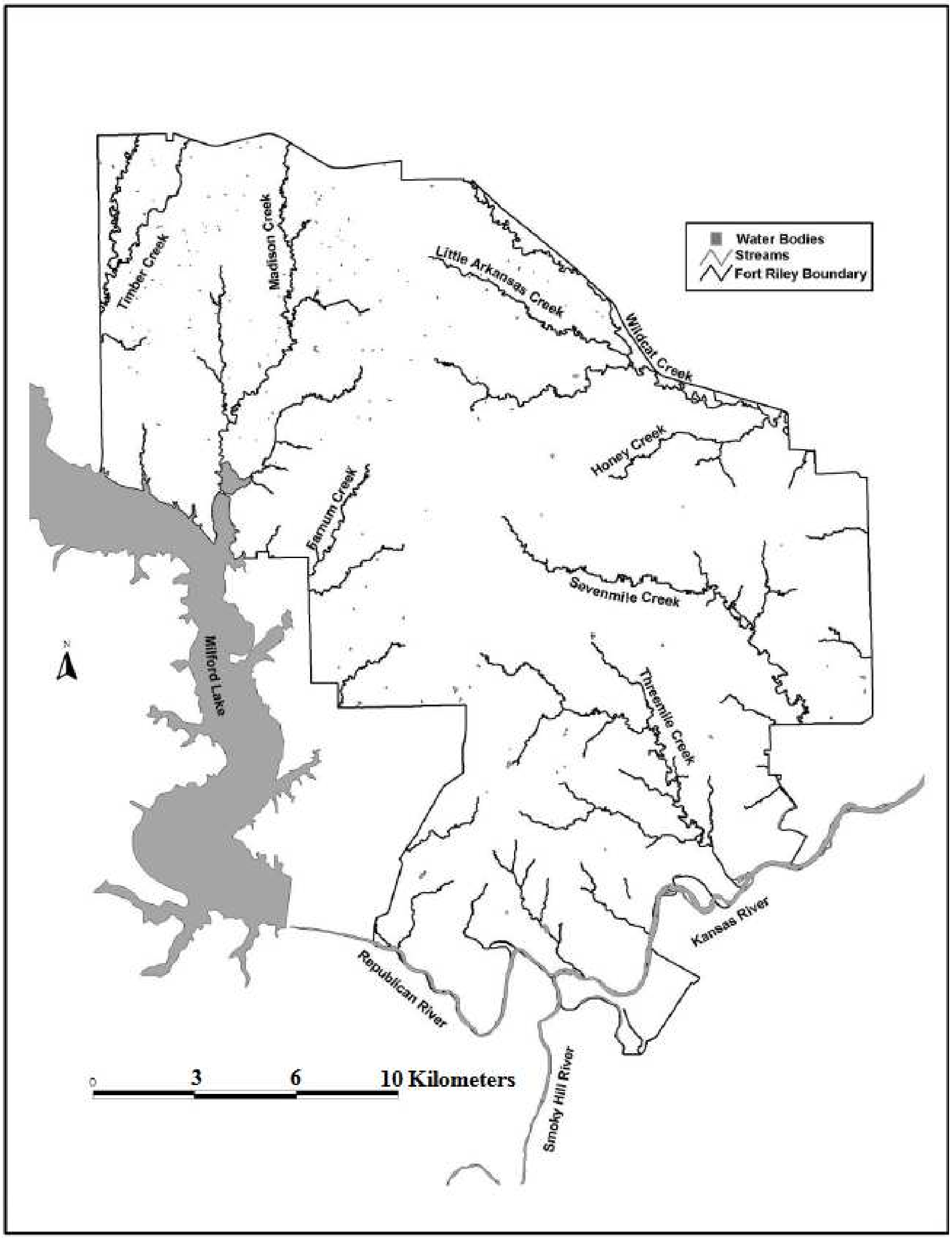
Figure 11. Fort Riley, KS Soil Hydrologic Groups, SSURGO (2012).



Hydrology

Fort Riley is crisscrossed by intermittent streams, with the Kansas and Republican Rivers running along the Southern border (Figure 13). Primary streams that training areas drain into include: Little Arkansas Creek, Honey Creek, Wildcat Creek, Madison Creek, Timber Creek, Farnum Creek, Sevenmile Creek, and Threemile Creek. Increased flow in these waterways has commonly resulted in downstream flooding which is a major concern for highly populated areas such as the city of Manhattan.

Figure 12. Fort Riley waterways, modified from DoA (2011).



Hydrologic Modeling

In order to determine just how runoff is affected by military training induced landscape changes, TR-55 was used to model watersheds on Fort Riley with different training intensities to bertter understand the impact of training on hydrologic function. Many different models are currently available to predict runoff, each with differing degrees of accuracy, complexity and cost. TR-55 was considered for this study because it has been widely accepted in terms of accuracy, is much less complex than other modeling programs, and is freeware (Dorsey, 2009; LMNO Engineering, 1999; Mishra and Singh, 2004; USDA, 2013).

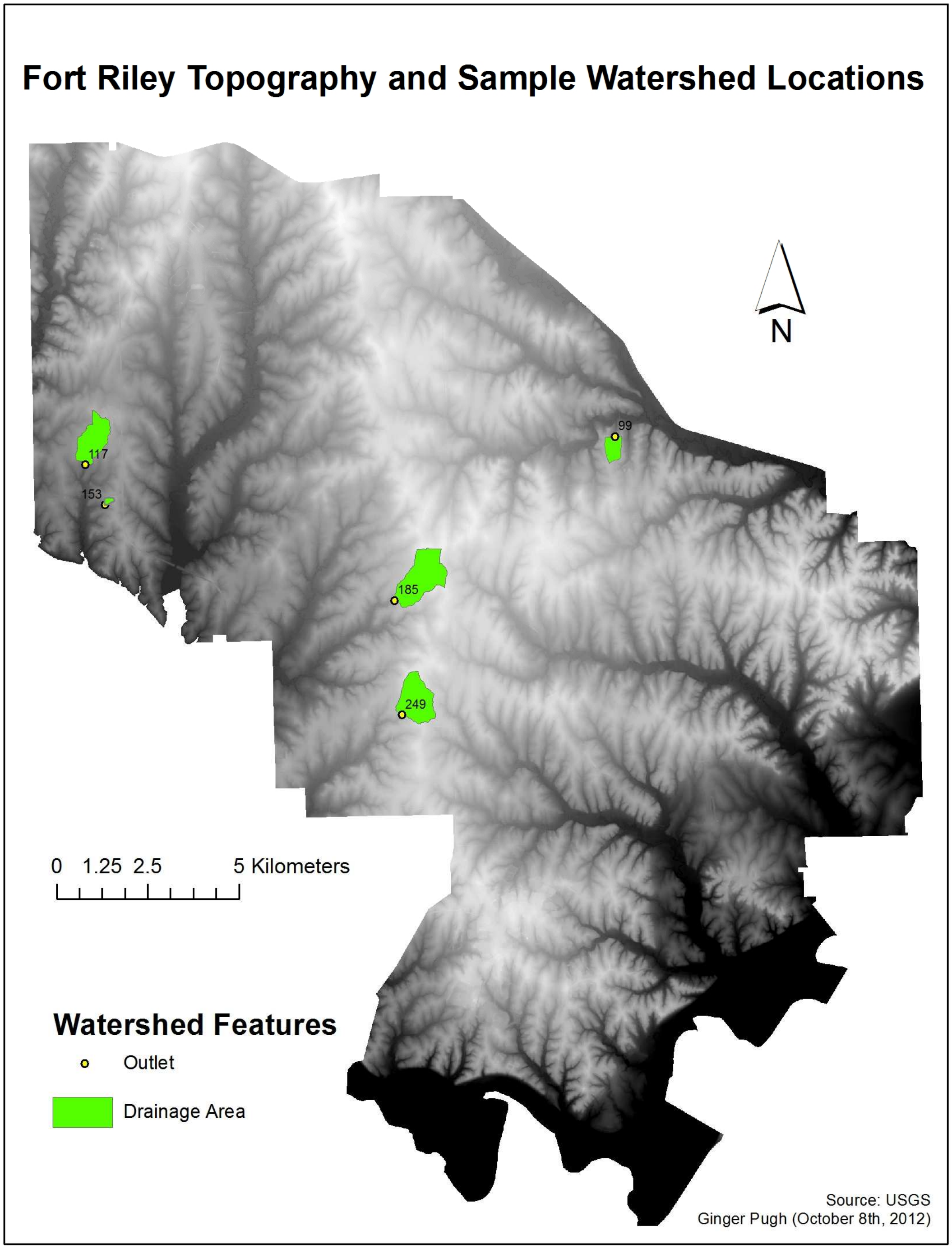
Model Inputs

In order to model runoff from military training lands, the following primary inputs had to be determined: watershed selection and areas, military CN, stream data, land use and soil data, and storm data. Data required to gather the inputs for TR-55 included: NRCS CN tables (USDA, 1986), Fort Riley boundary shapefile (Kansas Data Access Center, 2012), three-meter digital elevation model (DEM) of Fort Riley (USGS, 2012), land use data (USGS, 2012), and soil data (SSURGO, 2012). Also, as mentioned earlier data was also collected from on-site measurements and observations.

Watershed Selection

Five watersheds were selected for comparison in this study based on their accessibility, range of observed training damage received, and their general size being around 1 km^2 or less (Figure 14). Pour points for each watershed were based off of GPS coordinates taken at observed outlets for each watershed; these points were also where an ISCO water sampler was placed on each site for monitoring flow depth. Watersheds were then delineated using the hydrology tools in the ArcMap 10 Toolbox (Figure 1, Appendix B). Each watershed size varied based on delineated area, each is organized by training area and code in table 5 (Muluken Muche, unpublished data, 2012. Manhattan, KS: Kansas State University, Department of Biological and Agricultural Engineering).

Figure 13. Fort Riley watershed locations and topography (USGS, 2012).



Source: USGS
Ginger Pugh (October 8th, 2012)

Table 5. Watershed areas delineated from ISCO locations using a 3-meter DEM.

Training Area	Watershed Code	Total Area (km²)
52	99	0.27
56	117	0.81
64	153	0.05
65	185	1.33
90	249	1.01

The five selected watersheds on Fort Riley were selected to use as replications for the runoff data generated by TR-55. Generally, the land cover types were approximately the same, but slopes, time of concentration details, and areas varied from watershed to watershed. Initially, watersheds were modeled with ArcGIS for use in a pairwise comparison by Muluken Muche (unpublished data, 2012. Manhattan, KS: Kansas State University, Department of Biological and Agricultural Engineering) though the actual selection of the sites was severely limited based on accessibility. Watersheds selection was based on the observed drainage area and location and selecting a pour point on site to use in remodeling the actual watersheds.

Subwatershed Delineation

Subwatersheds were created for each watershed based on the stream network for channel flow created from the three-meter DEM. Each watershed was subdivided into as many as different subwatersheds, the maximum number of subwatersheds that can be modeled in TR-55. The smaller watersheds (Figure 15) had fewer subwatersheds than larger watersheds (Figures 16). Figure 2 in Appendix B shows an example subwatershed delineation done through ArcMap and Appendix B Figures 3 through 7 show delineations for each watershed.

Figure 14. Subwatersheds generate with ArcMap 10 for a smaller watershed (WS 99).

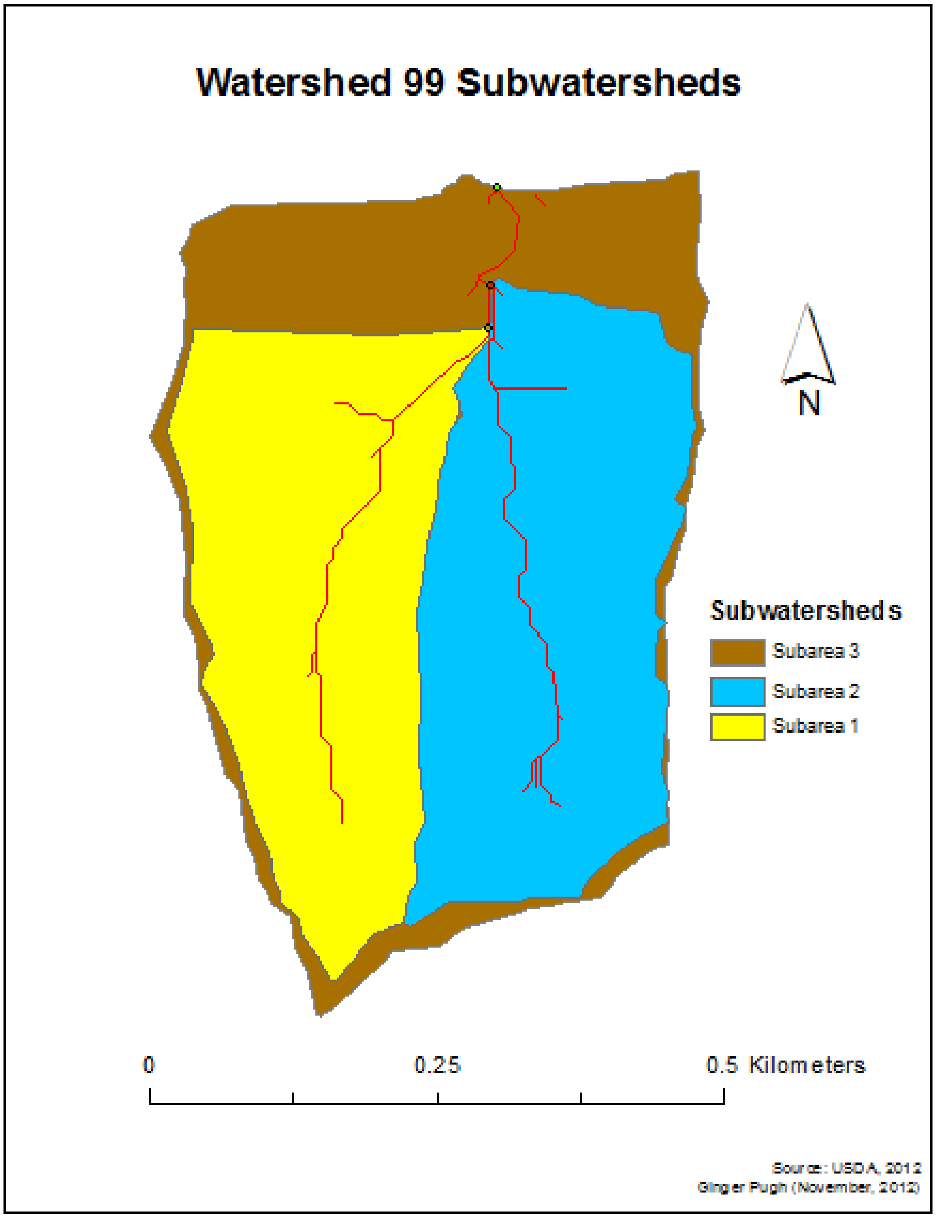
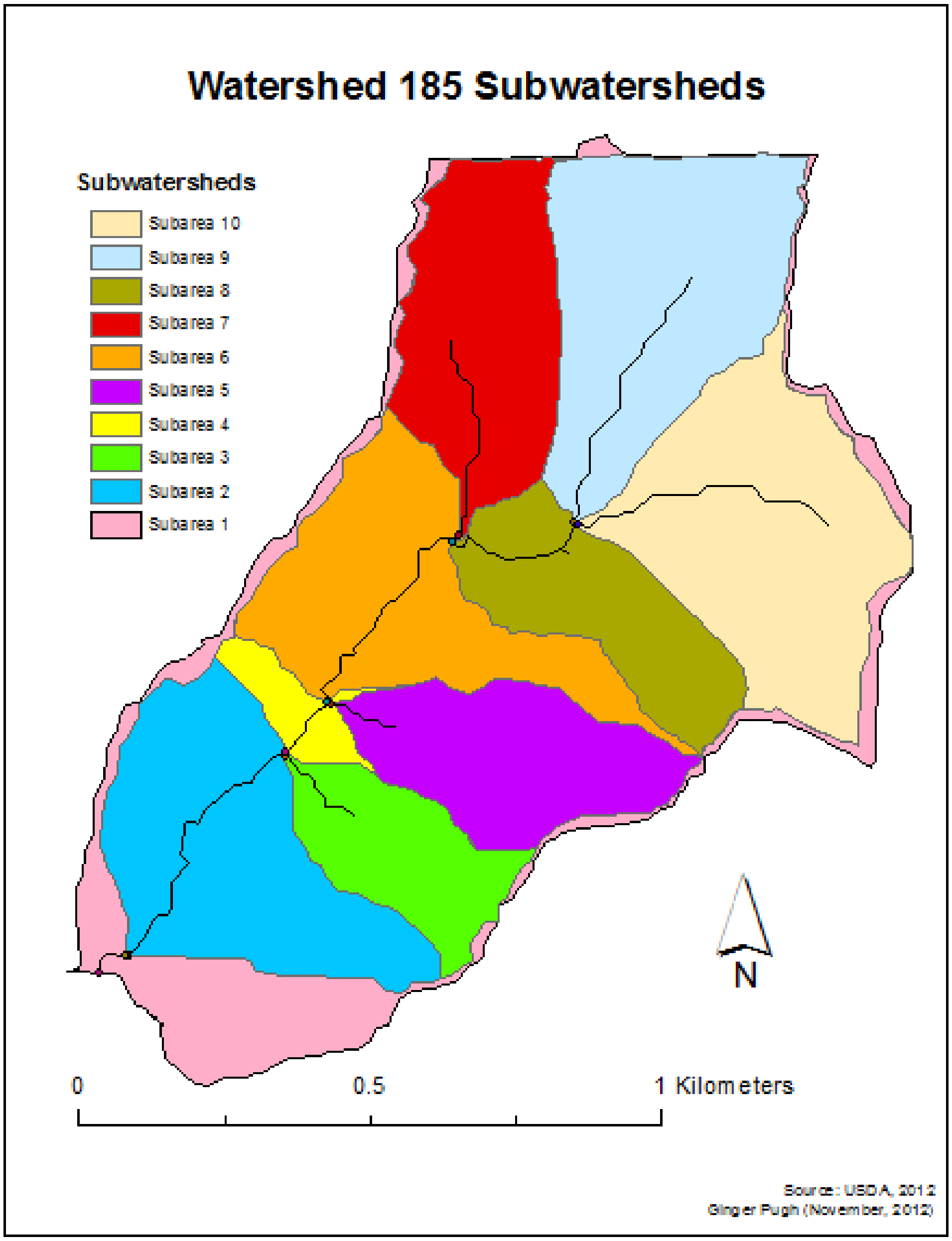


Figure 15. Subwatersheds generate with ArcMap 10 for a larger watershed (WS 99).



Source: USDA, 2012
Ginger Pugh (November, 2012)

Military Curve Number Creation

Many commonly used hydrologic modeling programs incorporate the CN method for calculating runoff. Since there are no set CNs to represent military training disturbances, a four-tier intensity CN matrix was developed (undisturbed, light use, moderate use, and heavy use). Agricultural and natural land CNs were modified based on an extensive literature review on maneuver training damage (Althoff et al., 2007; Althoff and Thien, 2005; Anderson et al., 2005, 2006; Foster et al., 2006; Garten et al., 2003; Haugen et al., 2003; Kun et al., 2009; Perkins et al., 2007; USDS, 1986; Wang et al., 2009).

The CNs used for Undisturbed areas were based off of those defined by the USDA for Pastures, Rangeland or Range under good conditions where vegetative cover was greater than 75% (USDA, 1986). Undisturbed areas were defined as tallgrass prairie areas that had not experienced training for the last two to three years. This time of relief was chosen based off of research done by Althoff et al. (2007) on Fort Riley, which showed that after two years, given silty clay soils and three years, given silt loam soil, nematode abundance, which they found to be a good indicator of overall soil health, returned to pre-training condition. However, three years is probably too short of a time scale for a disturbed area to completely return to undisturbed conditions. For example, after native vegetation is removed, non-native species, often forbs, take their place which cause soils to have different infiltration capabilities (Foster et al., 2006). Additionally, the creation of a hardpan is common with heavy vehicles, which can persist for years after disturbance and compaction (Raper et al., 2005). However, the two to three year range was used in this study and should be verified with actual data.

Light Use training plots were defined as areas that had experienced minimal training over the last two to three years; minimal training was defined as being mostly foot traffic with vegetative cover maintained between 50-75%. Restriction of the light use class to foot traffic was based off of a study done by Garten et al. (2003), which showed a change in soil bulk density when foot traffic occurred versus undisturbed land which could potentially lead to increased runoff. The CNs used to represent light use were Pasture, Rangeland, or Range under fair conditions (Appendix A, Figure 3). Fair condition was chosen based on low levels of cover removal, which can lead to more runoff potential (Anderson et al., 2005).

Moderate Use training areas were defined as being used by machinery within the last two to three years, with vegetative cover reduced to 25-50%. Based on studies of military vehicle impacts on the soil (Althoff et al., 2005), this category would represent damage from a HMMWV, as it causes less disturbance than the LAVs and the M1A1, but can still cause sizeable disturbance. Moderate Use is modeled as the CN for Pasture, Rangeland, or Range under poor conditions. Poor condition was chosen in this case to represent a greater loss of cover.

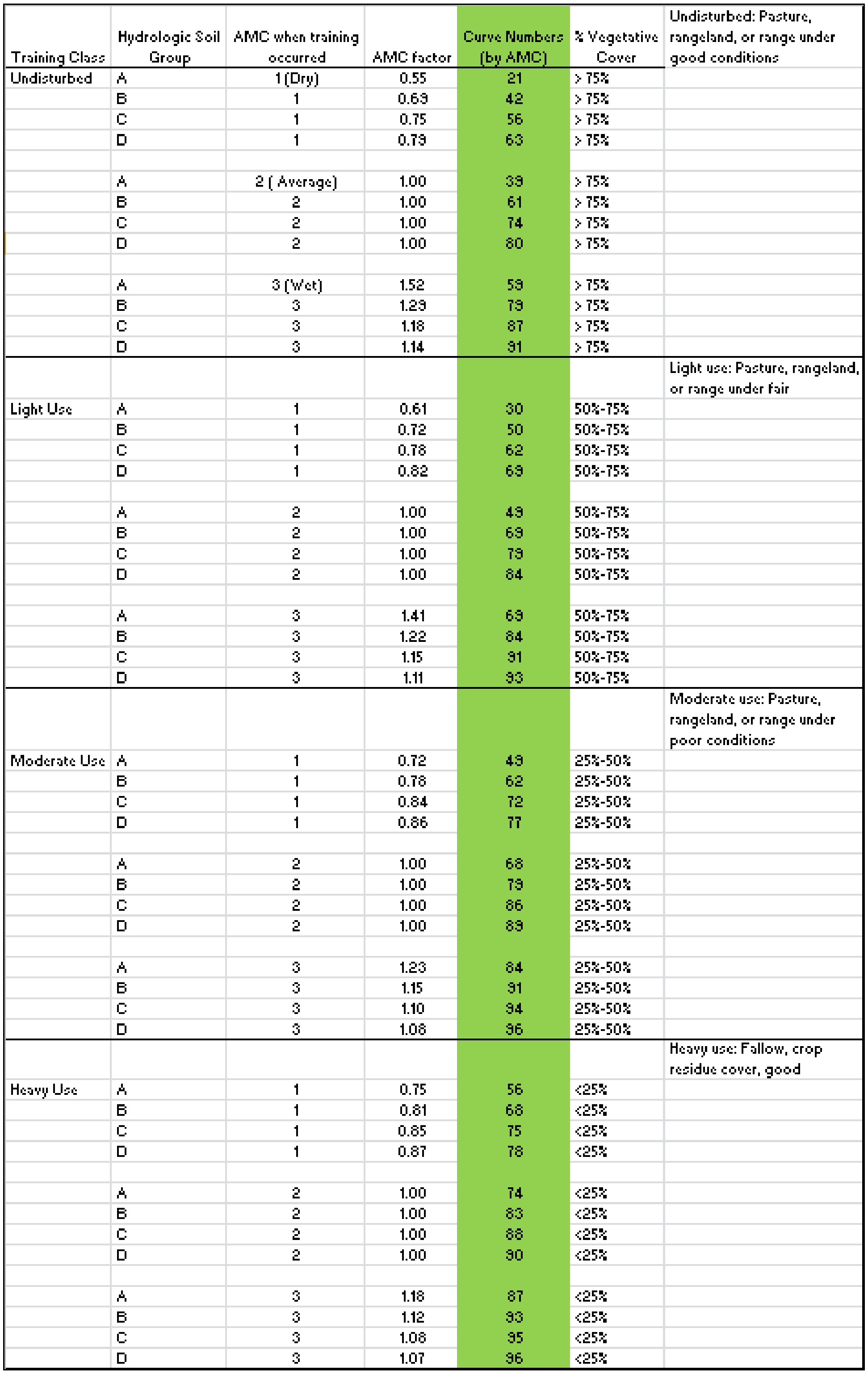
The most intensive training areas are defined as having Heavy use which results in less than 25% vegetative cover. This group includes vehicles such as the M1A1 Abrams and LAVs. Heavy use was modeled with a CN assumption of fallow, crop residue cover under good conditions based on the amount of mixing in the top horizons, and the large amounts of exposed soil that occur due to intense tank activity (Garten et al., 2003). This mixing and compaction is similar to what occurs during farming operations, though more compaction may be expected due to the lack of measures such as deep chiseling to remove hardpans. For this class, good condition was chosen because this is similar to cropland that has been harvested with conservation tillage practices, leaving stubble behind. Table 7 shows the general factors and their sources used to determine the values for the military CN classes.

Table 6. Factors and sources used in creating military CN classes.

Training Class	Impacts	References
Undisturbed	No training in the last two years Similar to pasture, rangeland or range under good conditions	Althoff et al., 2007 USDA, 1986
Light Use	Training within the last two to three years Foot training which increases bulk density Similar to pasture, rangeland or range under fair conditions Low levels of cover removal, fair condition	Althoff et al., 2007 Garten et al., 2003 USDA, 1986 Anderson et al., 2005
Moderate Use	Machinery training within the last two to three years Decreased cover from military vehicles Increased bulk density Similar to pasture, rangeland or range under poor conditions General vehicle type: HMMWV- less loss of cover than LAVs	Althoff et al., 2007 Anderson et al., 2005 Garten et al., 2003 USDA, 1986
Heavy Use	Machinery training within the last two to three years Decreased cover from military vehicles Increased bulk density Top soil mixing similar to agricultural practices Similar to fallow, crop residue, under good conditions General vehicle type: M1A1-greater vegetative cover loss	Althoff et al., 2005 Anderson et al., 2005 Garten et al., 2003 USDA, 1986

The amount of water in the soil before a rain event can also influence the effective curve number; the more moisture present, the higher the curve number. For each of the training classes, CNs were found for the AMC conditions based off of AMC adjustment factors for moving from average moisture conditions (AMC II) to dry conditions (AMC I) and wet conditions (AMC III) (Huffman et al., 2011). Original AMC adjustment factors were linearly interpolated by every tenth factor, producing small errors in the factor, but these errors are significantly small compared to the changes in the CN they produced. CNs for the different soil types (Hydrologic soil groups A, B, C, and D) were also found based off of the original CNs with the AMC corrections. Table 8 below displays the CNs found for each of the original training classes.

Table 7 Derived military CNs from research and application of similar agricultural practices

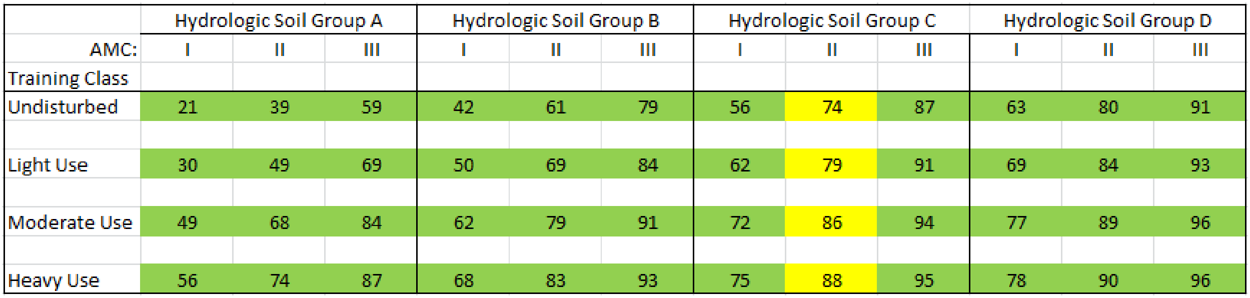


Training Class	Hydrologic Soil Group	AMC when training occurred	AMC factor	Curve Numbers (by AMC)	% Vegetative Cover	Undisturbed: Pasture, rangeland, or range under good conditions
Undisturbed	A	1 (Dry)	0.55	21	> 75%	
	B	1	0.69	42	> 75%	
	C	1	0.75	56	> 75%	
	D	1	0.79	63	> 75%	
	A	2 (Average)	1.00	39	> 75%	
	B	2	1.00	61	> 75%	
	C	2	1.00	74	> 75%	
	D	2	1.00	80	> 75%	
	A	3 (Wet)	1.52	59	> 75%	
	B	3	1.29	79	> 75%	
	C	3	1.18	87	> 75%	
	D	3	1.14	91	> 75%	
						Light use: Pasture, rangeland, or range under fair
Light Use	A	1	0.61	30	50%-75%	
	B	1	0.72	50	50%-75%	
	C	1	0.78	62	50%-75%	
	D	1	0.82	69	50%-75%	
	A	2	1.00	49	50%-75%	
	B	2	1.00	69	50%-75%	
	C	2	1.00	79	50%-75%	
	D	2	1.00	84	50%-75%	
	A	3	1.41	69	50%-75%	
	B	3	1.22	84	50%-75%	
	C	3	1.15	91	50%-75%	
	D	3	1.11	93	50%-75%	
						Moderate use: Pasture, rangeland, or range under poor conditions
Moderate Use	A	1	0.72	49	25%-50%	
	B	1	0.78	62	25%-50%	
	C	1	0.84	72	25%-50%	
	D	1	0.86	77	25%-50%	
	A	2	1.00	68	25%-50%	
	B	2	1.00	79	25%-50%	
	C	2	1.00	86	25%-50%	
	D	2	1.00	89	25%-50%	
	A	3	1.23	84	25%-50%	
	B	3	1.15	91	25%-50%	
	C	3	1.10	94	25%-50%	
	D	3	1.08	96	25%-50%	
						Heavy use: Fallow, crop residue cover, good
Heavy Use	A	1	0.75	56	<25%	
	B	1	0.81	68	<25%	
	C	1	0.85	75	<25%	
	D	1	0.87	78	<25%	
	A	2	1.00	74	<25%	
	B	2	1.00	83	<25%	
	C	2	1.00	88	<25%	
	D	2	1.00	90	<25%	
	A	3	1.18	87	<25%	
	B	3	1.12	93	<25%	
	C	3	1.08	95	<25%	
	D	3	1.07	96	<25%	

Since TR-55 specifies a minimum CN of 30, the CN value of 21 for Undisturbed areas with Hydrologic group A under AMC I conditions was considered to be 30. Because this was the only case of a CN below the TR-55 minimum, it was not considered to be a major problem, particularly in this study where the primary soils were not in the A hydrologic group. Research showed that land disturbance was greatly increased when training was done on land after a storm event (Althoff et al., 2005), especially under very wet conditions (AMC III conditions). However, disturbance was extremely variable given types of maneuvers performed and therefore this was not included in the analysis. For the purposes of this study, only CNs in the AMC II range were analyzed

CNs used to generate runoff values for the analysis are summarized in Table 9 below. The yellow column highlights the grouping used for this test, which were selected based on Fort Riley soils and average soil moisture conditions (CN 74-88). If the modeled site had more A or B soil types, there would have been a larger spread in the modeled CNs and likewise a larger change in potential runoff from undisturbed conditions to actual training conditions.

Table 8 Derived military CNs from research and application of similar agricultural practices used in analysis

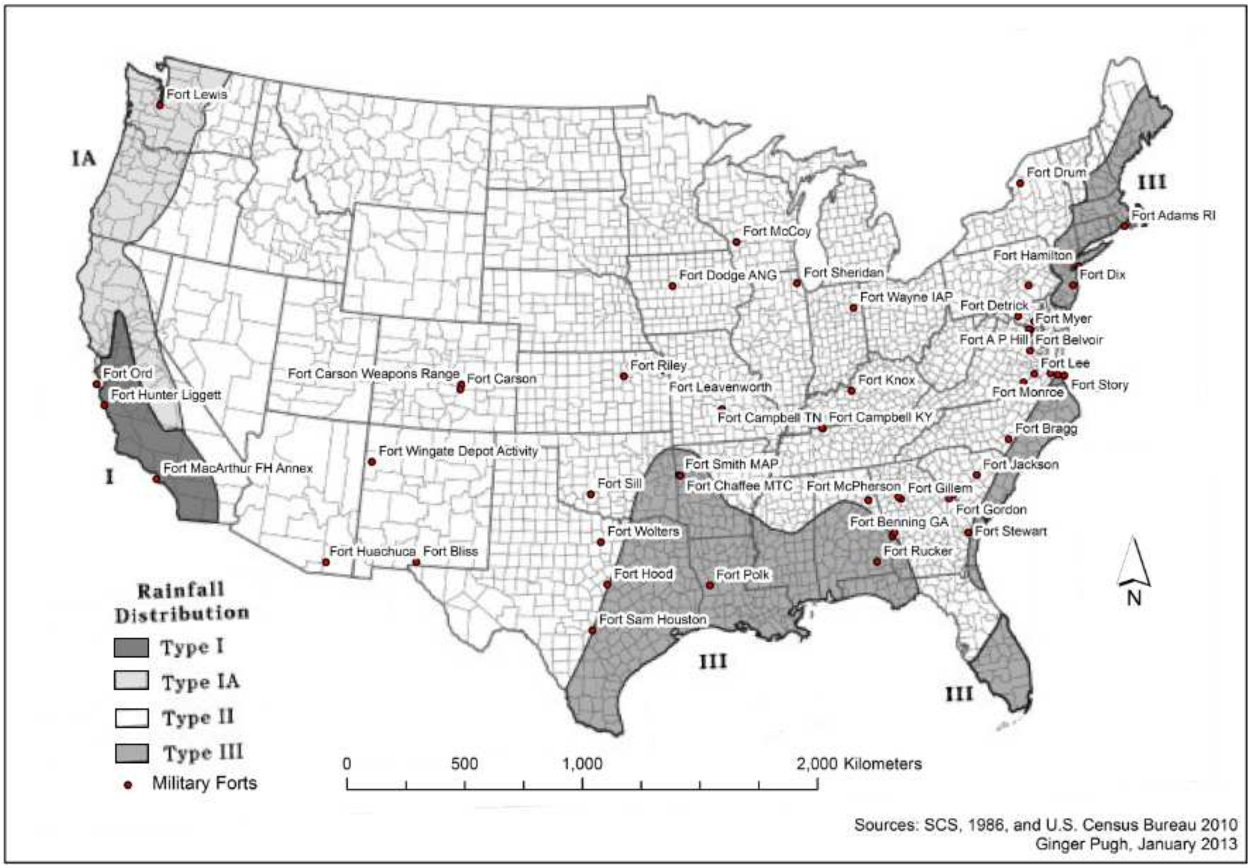


	Hydrologic Soil Group A			Hydrologic Soil Group B			Hydrologic Soil Group C			Hydrologic Soil Group D		
AMC:	I	II	III	I	II	III	I	II	III	I	II	III
Training Class												
Undisturbed	21	39	59	42	61	79	56	74	87	63	80	91
Light Use	30	49	69	50	69	84	62	79	91	69	84	93
Moderate Use	49	68	84	62	79	91	72	86	94	77	89	96
Heavy Use	56	74	87	68	83	93	75	88	95	78	90	96

Storm Distribution Types

The storm distribution used for this study was a type II storms, based on rainfall patters expected of Kansas (USDA, 1986). Type II storms describe rainfall events that start out slowly, then increases in intensity over the middle portion of the storm, and finally taper off in intensity near the end. Type II rainfall distributions are representative of the majority of the United States where many military training areas are located (Figure 17). A large number of forts are located in other zones, particularly in zone III. Zone II and III are relatively similar as compared to zones I and Ia (see Figure 6, SCS 24-hour rainfall distributions) the time of maximum rainfall intensity is over approximately the same interval of time. However, because type III storms have less dramatic increases in rainfall, they generate less runoff potential than the type II storms.

Figure 16. Contiguous U.S. Forts and their storm distribution types.



Sources: SCS, 1986, and U.S. Census Bureau 2010
Ginger Pugh, January 2013

Flow Types

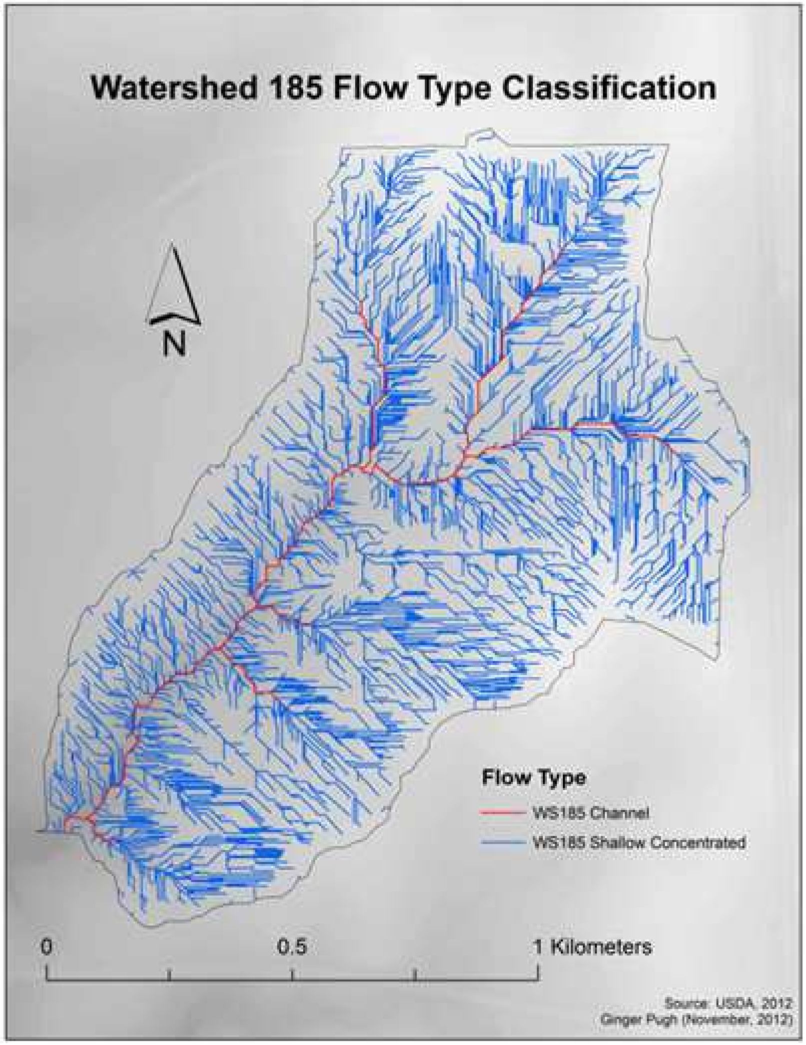
TR-55 considers three different flow types, sheet flow, shallow concentrated flow, and channel flow, when determining time of concentration. The different flow regimes were calculated by defining how much contributing area had to accumulate to reach each flow type. This was based on the concept that as flow accumulation increases, so does the concentration of flow (ESRI, 2008). The three meter DEM used in this analysis was filled to help reduce error and remove sinks.

Sheet flow length was based off of the McCuen-Spiess classification for sheet flow on rangeland of 23 meters (McCuen and Spiess, 1995). By experimenting with the three-meter DEM to match this 23 meter value, a flow accumulation value of 500 cells was set as the upper threshold for sheet flow. This produced the average flow length from the edge of each watershed to the start of the next flow type (shallow concentrated). To define the end at shallow concentrated flow, the DEM was examined to see where a visible stream network could be discerned (2000 cells accumulating). Based off of this observation, shallow concentrated flow was set between a flow accumulation value of 500 cells to 2000 cells. This left channel flow to be any flow accumulating over 2000 cells. These flow length definitions are summarized in Table 10 along with the actual areas they represent, provided that the area of each cell is 3-meters by 3-meters. If a different DEM resolution was used, different accumulation values would have been found. Figure 18 shows flow lengths for one watershed, others are available in Appendix B Figures 8 through 12.

Table 9. Flow accumulation definitions used in ArcMap to distinguish between the different flow types, calculated from a 3-meter DEM.

Flow Type	Flow Length Definition (for 3-meter DEM)	Accumulation Area (m^2)
Sheet	"flow accumulation ≤ 500", ~23 meters	≤ 4500
Shallow Concentrated	"500 < flow accumulation < 2000"	4500 < flow acc. < 18000
Channel	"flow accumulation ≥ 2000"	flow acc. ≥ 18000

Figure 17. Channel, shallow concentrated and sheet flow lengths for watershed 185.



Once the flow lengths were determined, average slopes for each of the three flow types were estimated for each watershed by averaging a series of slopes for sheet flow. Elevations on the edge of the watershed were compared to elevations at the beginning of sheet flow, and averaged over the distance between the two points. Shallow concentrated flow slopes were determined by taking the difference in elevation between the beginning shallow concentrated flow and the beginning of channel flow. Channel flow slope was determined for each subwatershed from the start of channel flow to the end of each subwatershed. Table 11 shows flow lengths and slopes calculated for sheet and shallow concentrated flow, while Table 12 shows these values for channel flow.

Table 10. Flow lengths and slopes for sheet and shallow concentrated flow calculated from 3-meter DEM.

Watershed	Sheet Flow (m)	Shallow Concentrated (m)	Sheet slope (m/m)	Shallow concentrated slope (m/m)
99	23.5	120	0.04	0.06
117	23.5	190	0.03	0.09
153	23.5	90	0.05	0.08
185	23.5	280	0.04	0.06
249	23.5	200	0.02	0.03

Table 11. Channel flow lengths and slopes by subwatershed calculated from 3-meter DEM.

Channel Flow										
Sub area	WS 99 Length (m)	WS 99 Slope (m/m)	WS 117 Length (m)	WS 117 Slope (m/m)	WS 153 Length (m)	WS 153 Slope (m/m)	WS 185 Length (m)	WS 185 slope (m/m)	WS 249 Length (m)	WS 249 Slope (m/m)
Sub1	507	0.03	1124	0.02	160	0.06	91	0.06	228	0.01
Sub2	497	0.03	298	0.03	134	0.06	503	0.01	49	0.02
Sub3	1145	0.02	696	0.02	56	0.02	184	0.05	70	0.02
Sub4			71	0.01			125	0.01	284	0.01
Sub5			319	0.01			130	0.03	396	0.01
Sub6							417	0.01	348	0.01
Sub7							348	0.03	312	0.01
Sub8							230	0.02	300	0.01
Sub9							510	0.02	476	0.01
Sub10							490	0.01		

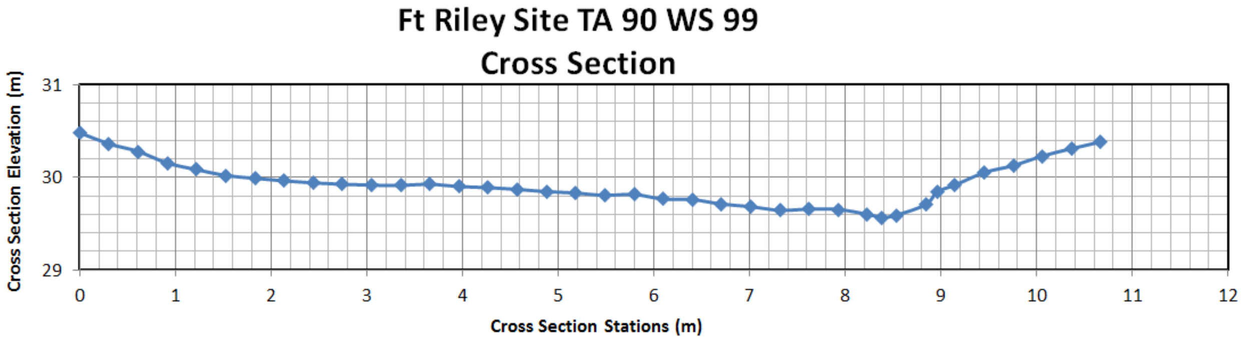
Additional Time of Concentration Details

A stream assessment was conducted for each of the five watersheds to determine the cross-sectional area, wetted perimeter, bed width and lining (Table 13). An example cross-section survey for WS 99 is shown below (Figure 19). Information for other watershed assessments presented in Appendix B (Figures 13 to 17).

Table 12. Cross-sectional area, wetted perimeter, bottom width, and average side slope data from on-site measurements.

Watershed	Cross-Sectional Area (m^2)	Wetted Perimeter (m)	Bottom Width (m)	Average Side Slope (H:1)
99	0.56	4.0	1.2	5
117	0.36	2.2	1.0	2
153	0.48	4.2	0.8	6
185	1.68	3.5	1.6	2
249	1.34	3.0	1.8	2

Figure 18. WS 99 stream cross section assessment used to determine time of concentration details.



Land Use and Soil

Land use data was determined by using a vegetation assessment of Fort Riley (Delisle et al., 2012) and on-site surveys. Together, these showed the primary landuse for the sample watersheds to be tallgrass prairie and rangeland. Soil data was obtained through SSURGO for the purpose of defining soil hydrologic groups, which is the primary soil information used by the TR-55 program. Runoff is directly associated with the hydrologic soil group as it increases from an A to a D soil. A shapefile was again joined with a database table to determine areas in each of the four hydrologic groups (A, B, C and D).

Storm Data

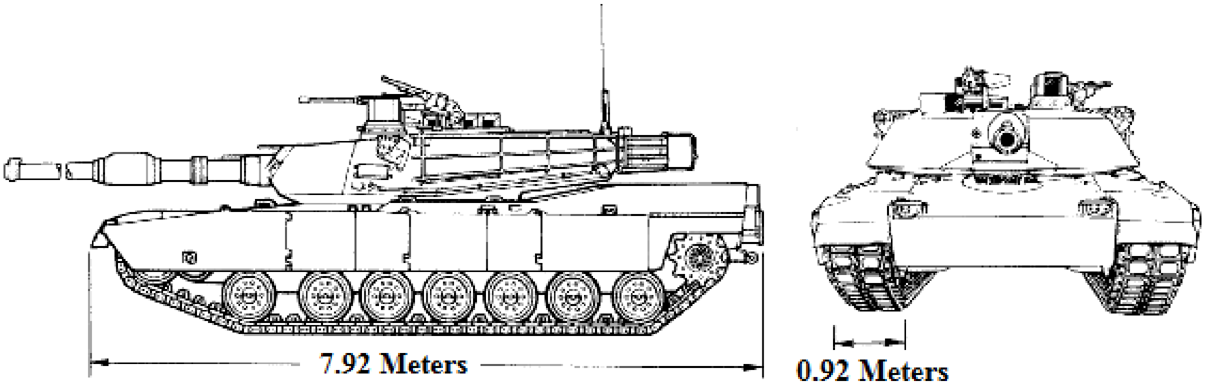
Storm data used for the sites was generated through the TR-55 program. Three different storm sizes were selected to represent a reasonable range of design storms (2-year, 10-year, and 25-year storms). Two-year storms were modeled based on how they are the most common storm for producing runoff. Ten-year storms were selected based on most minor infrastructure being designed to handle flow from these types. Twenty-five-year storms were selected based on these being the design storms for major flooding events.

Maneuver Impact Area

To quantify the amount of training required to attain each disturbance percentage, the concept of the Red-Amber-Green Maneuver Impact Mile (MIM), converted to kilometers for this study, was applied.

Based off of the standard MIM, the MIMs used for this study’s definition are calculated using the area of impact (square meters) of an M1A2 Abrams (Figure 20) and distance traveled, given the assumption of only one tank in operation and no repeat coverage of the same area. The total area that would have to be covered for each of the sample watersheds was calculated in increasing increments of 10% disturbance. The dimensions used for the footprint of the M1A2 are a hull length of 7.92 meters and each track width of 0.92 meters (The Armor Site, 2012).

Figure 19. M1A2 Abrams Battle Tank dimensions, modified from The Armor Site, 2012.



The amount of disturbance was quantified by assuming east-west and north-south passes, however, most training procedures involve non-uniform and semi-random driving patterns. This simplification was used to generalize the amount of coverage that would be required for different sized watersheds.

TR-55 Sensitivity to Curve Number

In order to get an initial idea of how much runoff results produced by TR-55 changed in response to CN a test with a sample watershed was ran. This test assumed natural prairie conditions with CN varying from 30 to 98 (the ranges that TR-55 can model). Table 1 Appendix B shows inputs for the sample run.

Inputs were assumed based on field estimates of an undisturbed watershed and from personal experience. Two comparisons were done, the first using the graphical discharge method to determine peak flow rates given different storm events; and the second, the tabular method to determine amount of runoff per storm event. All of the 24-hour storm events available to model in TR-55 were used (1-, 2-, 5-, 10, 25-, 50-, and 100-year storms).

Watershed Analysis

Originally I had hoped to be able to compare simulated runoff data to actual data collected by ISCO water samplers placed at each pour point and use that to confirm CN assessments and validate the sensitivity analysis. However, there were no significant rainfall events during the time of this study. Because of this, values were compared versus modeled undisturbed conditions to determine statistical significance.

Two different values generate by TR-55 were examined for statistical difference: runoff amount (mm) and runoff rate (m^3s^{-1}). Time of concentration was also considered for analysis since it varies by CN. However, TR-55 assumes a simplified version of the Manning's Kinematic equation in which effects of infiltration are considered negligible (USDA, 1986). As a result, changes in CN in TR-55 have no effect on time of concentration. Because of this the time of concentration analysis based on CN variations was unnecessary as no relationship existed.

Runoff Amount and Rate Analysis

Runoff was analyzed using a 3-way factorial. The three variables considered when setting up the statistical analysis were: watershed, training intensity, and disturbance percentage. This included running least squares means analyses for the three variables and using the 3-way interaction of the variables as the error term. The SAS code for this analysis is available in Appendix B Figure 18 (Cassandra Kaul, KSU-Department of Statistics, personal communication, 13 March, 2013). The five watersheds were blocked and degrees of freedom for each variable are listed in Table 14.

Table 13. SAS program factorial analysis degrees of freedom.

Variable	Degrees of Freedom
Watershed (WS)	5-1= 4
Training Intensity (TI)	3-1= 2
Disturbance Percentage (D%)	11-1= 10
TI*D%	20
WS*TI	8
WS*D%	40
WS*TI*D% (error term)	80

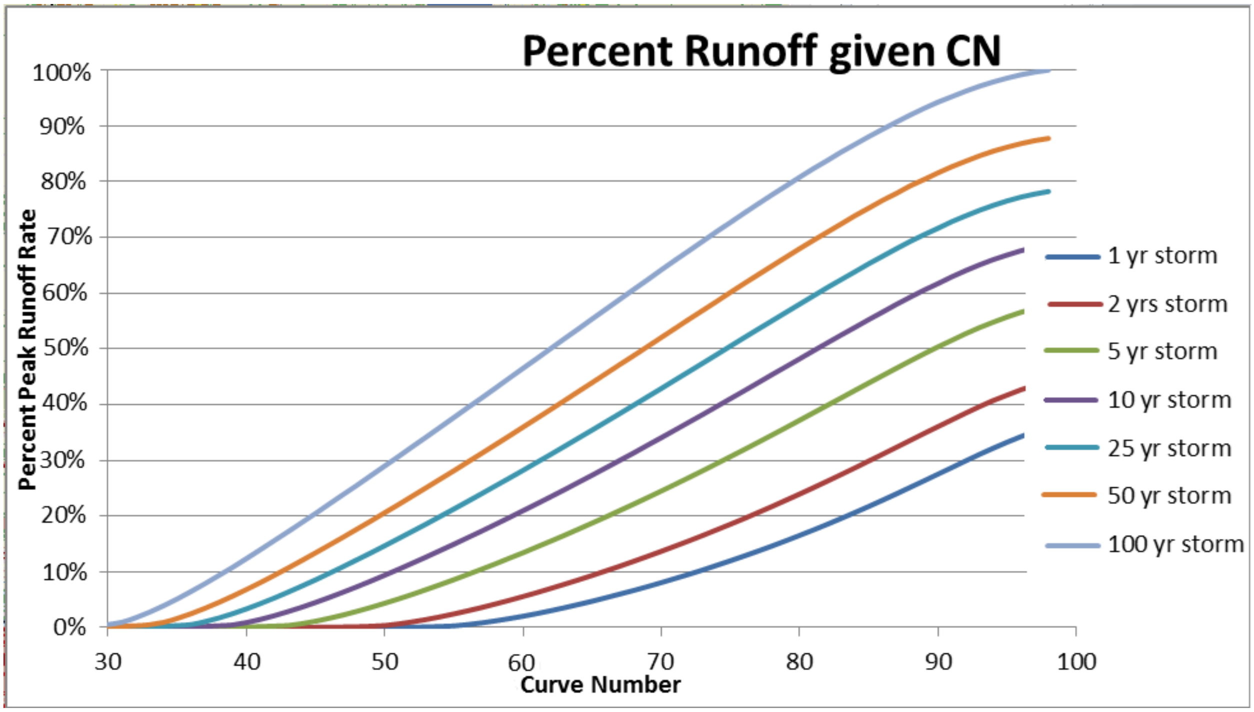
The analysis was broken up into three trials, one for each storm type (2, 10, and 25 years). Significant difference for each of the least square means tests was determined by comparing the absolute value of the t-values to p-values in the SAS program. If the absolute value of the t-value was greater than p-value, then that comparison was considered to be statistically significant, and the null hypothesis that the runoff is different given increases in disturbance percentage or training intensity was rejected. The p-values from the simple effects test are not constant because they consider individual error from the mean for each comparison (SAS, 2013).

Chapter 4 - Results and Discussion

TR-55 Sensitivity to CN analysis

Increases in CN and storm size increased the peak runoff rate (Figure 21) and amount (Figure 22). The peak runoff was scaled from the maximum value by taking each individual peak discharge value, dividing it by the respective storm event runoff value given a CN of 98, and multiplying by 100 to get a percent change. The minimum CN required for runoff changed for each storm return period. For example, runoff was not initiated until a CN of approximately 55 for the 1-year storm event while the 100 year storm generated runoff with a much lower CN of only 30.

Figure 20. Peak runoff rate trends given changes in CN from initial CN sensitivity analysis.



Runoff depth (TR-20 output tab) showed a similar trend with increases in runoff as the CN was increased (Figure 22). For the smaller storm return periods, runoff did not occur with the lower CNs, but increased with storm magnitude and and CN. This is due to smaller storm events not producing enough rainfall to fill the initial abstraction and storage values for the area, leaving no excess water to runoff. Table 15 shows the CN thresholds for each storm type where runoff began to occur.

Figure 21. Percent runoff amount given different CNs from initial CN sensitivity analysis.

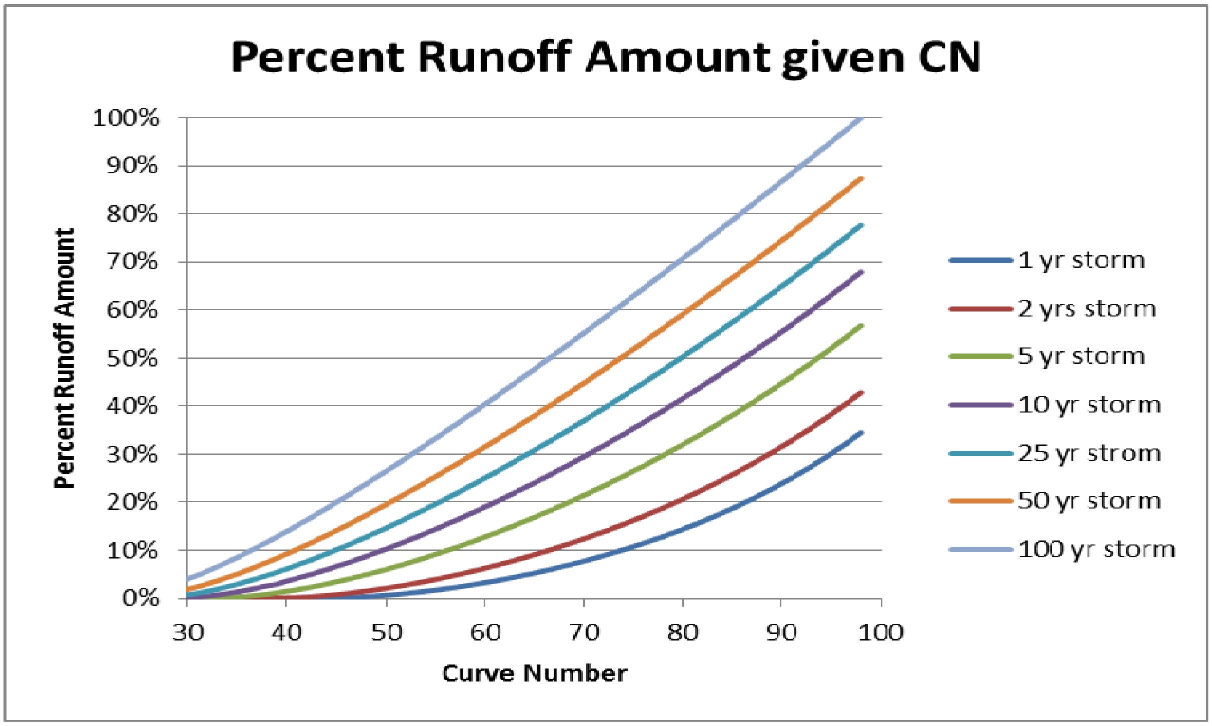


Table 14. Critical values for CN for runoff given various storm events from initial CN sensitivity analysis.

Storm Event	CN where Peak Runoff > 0	Range of Values for TR-55
1 year storm	43	43-98
2 year storm	39	39-98
5 year storm	33	33-98
10 year storm	all values	30-98
25 year storm	all values	30-98
50 year storm	all values	30-98
100 year storm	all values	30-98

Runoff Amount Statistical Analysis

Modeled runoff amount was analyzed in response to disturbance percentages, watersheds, and training intensities. Runoff amount ranged from a low of about 10 mm for a 2-year storm with no disturbance to over 100 mm for the 25-year storm with 100% disturbance. The statistical analysis showed some regions of disturbance percentage where significant difference did not occur between the training classes, generally less than 30% disturbance. Similarities in runoff amount between the training intensities were only found in low disturbance percentages, with rounding by TR-55 causing some discrepancies for 20% disturbance.

Original interpretation of runoff amount showed a general trend of runoff increasing with increased disturbance percentage. However, this pattern of increase varied for the different training intensities. Light use showed a relatively consistent increase in a stair-step fashion with every other change in disturbance percentage resulting in a one integer increase in CN. The stair-step increases were a result of minimal increases in the CN and how TR-55 rounds output (Table 16 and Figure 23).

Table 15. Military CNs by disturbance percentage for each of the three training intensities.

	Disturbance Percentage										
Training Intensity	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Light Use	74	75	75	76	76	77	77	78	78	79	79
Moderate Use	74	75	76	78	79	80	81	82	84	85	86
Heavy Use	74	75	77	78	80	81	82	84	85	87	88

For the moderate and heavy use training classes, there was a much greater increase in runoff as the percent of disturbed land was increased (Figures 24 and 25). This more rapid increase in runoff was a result of the wider ranges in CN. This similarity was reflected in the 10 and 25- year storms, just with increasing magnitudes of runoff amount (Appendix B, Figures 19 to 27).

Overall watersheds CNs were a weighted average of undisturbed and disturbed land for each training class. In the future, when a significant runoff event is measured with the ISCOs, these can be checked and adjusted to better match actual conditions. Conducting a sensitivity analysis with increments finer than 10% would not be likely to improve results because the model requires integer CNs and smaller changes would not have generate great enough differences.

Figure 22. Watershed comparison of runoff amount (mm) at different disturbance levels for a 2-year storm with light training use.

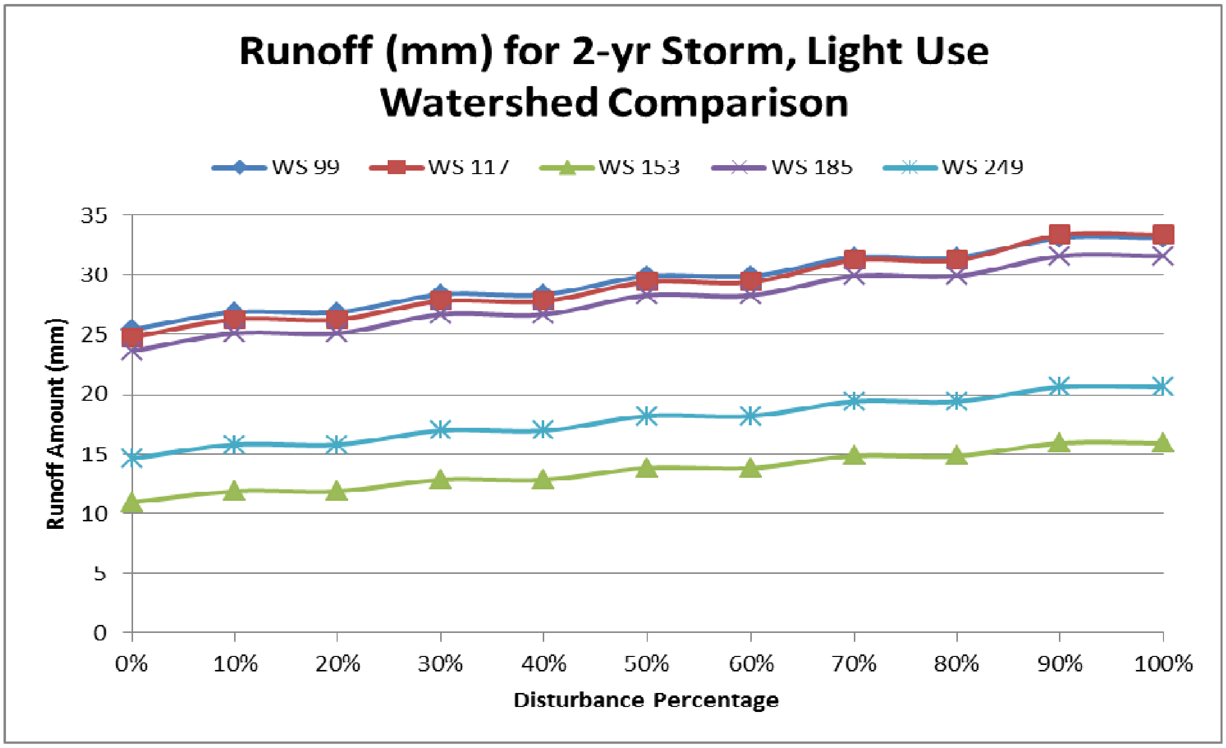


Figure 23. Watershed comparison of runoff amount (mm) at different disturbance levels for a 2-year storm with moderate training use.

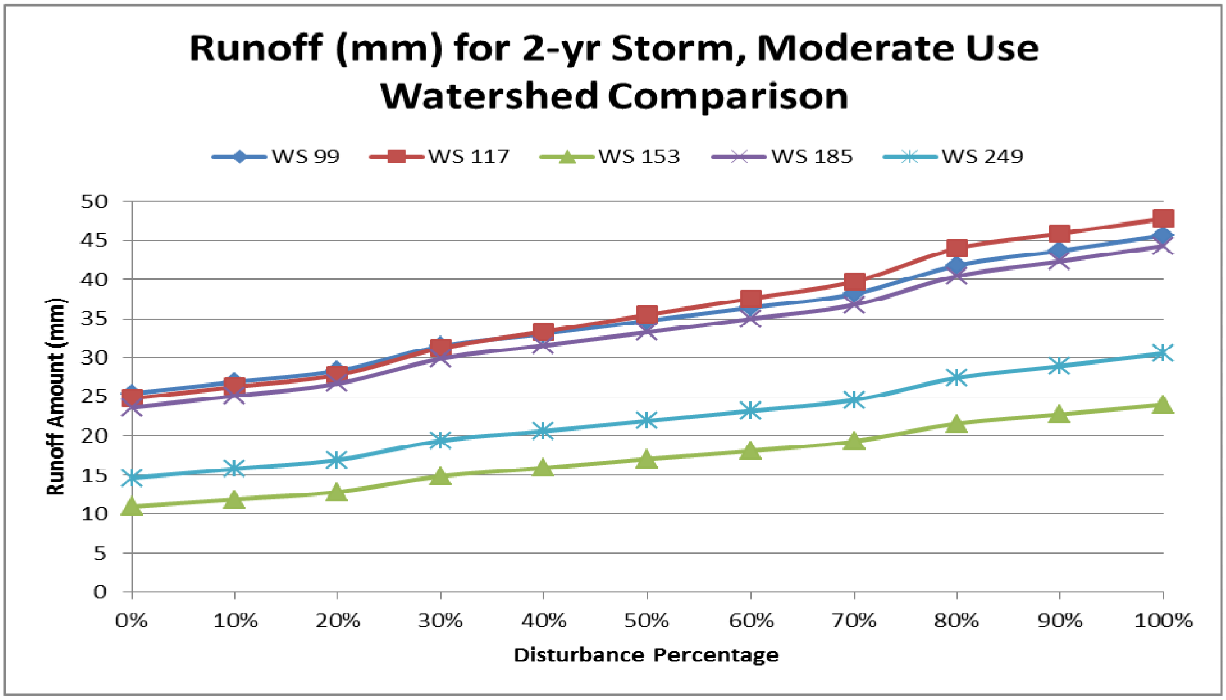
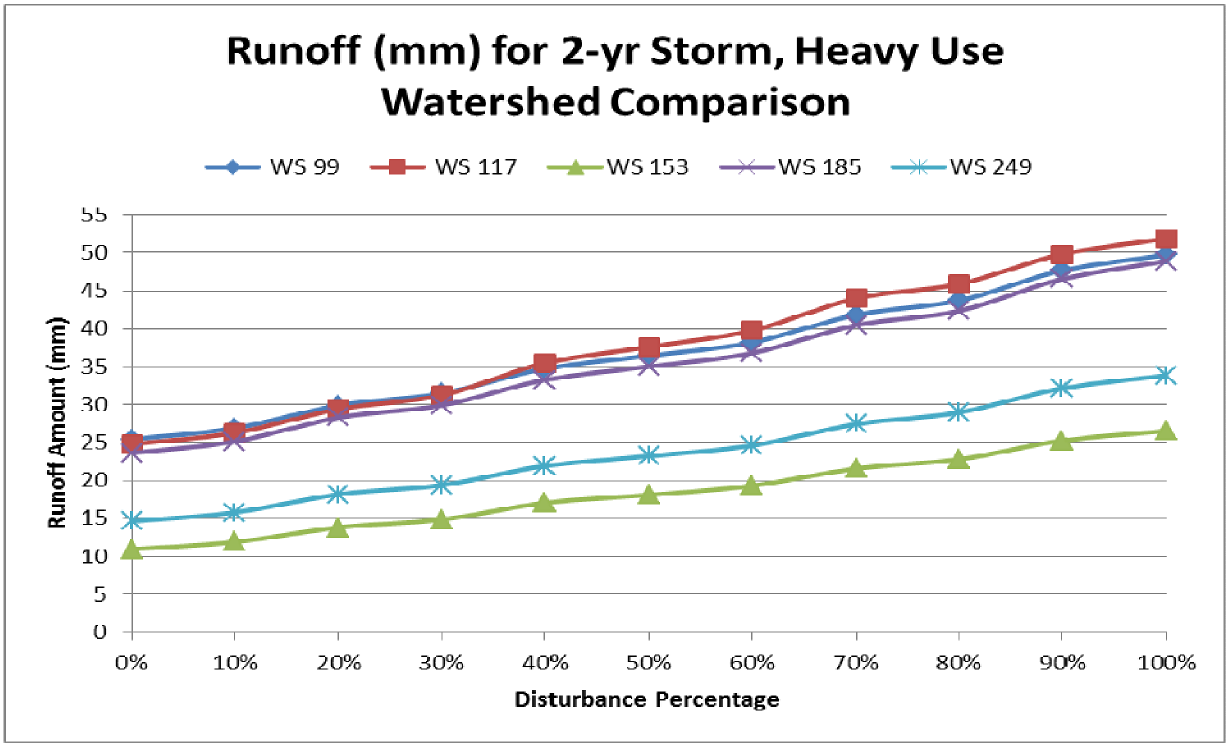


Figure 24. Watershed comparison of runoff amount (mm) at different disturbance levels for a 2-year storm with heavy training use.



Watersheds 99, 117 and 185 showed similar responses to the changes in disturbance percentage while watersheds 249 and 153 yielded much lower responses to the changes. This was most likely due to variability in time of concentration since each of the watersheds had differing stream lengths and slopes. For example, watersheds 249 and 153 both have shorter lengths of channels flow with watershed 249 being much squatter and spread out than some of the longer and narrower watersheds, such as 185. Because the runoff was calculated as a depth per unit area, the overall size of the watershed did not impact the reported runoff amounts. If more watersheds with more similar slopes and stream morphology were used in the analysis, more similar responses in runoff would have been seen as this would have reduced variability in the modeling inputs.

A least squares means simple effects comparison which averaged the runoff from the watersheds at the different disturbance percentages showed significant difference between each increase in disturbance percentage from undisturbed conditions (0% disturbed) for all three training intensity classes (Table 17). Training intensity and disturbance percentage simple effects comparisons by training intensity for all storm types are presented in Appendix B Tables 2, 3 and 4.

Table 16. Training intensity and disturbance percentage least squares means by training intensity for runoff amount values from a 2-year storm.

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By training intensity: 2-year storm							
Simple Effect Level[1]	**Disturbance Percentage[3]**	**Disturbance Percentage**	**Estimate[4]**	**Standard Error[5]**	**DF[6]**	**t-Value[7]**	**Pr > |t|[8]**
ti H[2]	10	0	1.3098	0.4360	80	3.00	0.0036
ti H	20	0	3.7338	0.4360	80	8.56	<.0001
ti H	30	0	5.4928	0.4360	80	12.60	<.0001
ti H	40	0	8.2730	0.4360	80	18.98	<.0001
ti H	50	0	9.8468	0.4360	80	22.59	<.0001
ti H	60	0	11.4888	0.4360	80	26.35	<.0001
ti H	70	0	14.4398	0.4360	80	33.12	<.0001
ti H	80	0	16.4752	0.4360	80	37.79	<.0001
ti H	90	0	19.6090	0.4360	80	44.98	<.0001
ti H	100	0	21.4680	0.4360	80	49.24	<.0001
ti L[2]	10	0	1.3098	0.4360	80	3.00	0.0036
ti L	20	0	1.3098	0.4360	80	3.00	0.0036
ti L	30	0	2.6494	0.4360	80	6.08	<.0001
ti L	40	0	2.6494	0.4360	80	6.08	<.0001
ti L	50	0	4.0400	0.4360	80	9.27	<.0001
ti L	60	0	4.0400	0.4360	80	9.27	<.0001
ti L	70	0	5.4928	0.4360	80	12.60	<.0001
ti L	80	0	5.4928	0.4360	80	12.60	<.0001
ti L	90	0	7.0180	0.4360	80	16.10	<.0001
ti L	100	0	7.0180	0.4360	80	16.10	<.0001
ti M[2]	10	0	1.3098	0.4360	80	3.00	0.0036
ti M	20	0	2.6494	0.4360	80	6.08	<.0001
ti M	30	0	5.4928	0.4360	80	12.60	<.0001

Simple Effect Comparisons of training intensity and disturbance percentage
Least Squares Means By training intensity: 2-year storm

Simple Effect Level[1]	Disturbance Percentage[3]	Disturbance Percentage	Estimate[4]	Standard Error[5]	DF[6]	t-Value[7]	Pr > |t|[8]
ti M	40	0	7.0180	0.4360	80	16.10	<.0001
ti M	50	0	8.6032	0.4360	80	19.73	<.0001
ti M	60	0	10.1872	0.4360	80	23.37	<.0001
ti M	70	0	11.8372	0.4360	80	27.15	<.0001
ti M	80	0	15.1676	0.4360	80	34.79	<.0001
ti M	90	0	16.8516	0.4360	80	38.65	<.0001
ti M	100	0	18.5798	0.4360	80	42.62	<.0001

1) Simple effect level was what the analysis was organized by, which was training intensity (ti)

2) Training intensities are shown as L= Light, M= Moderate, and H= Heavy

3) Disturbance percentage refers to the comparison between different disturbance percentage combinations

4) Estimate refers to the estimated value between the two disturbance percentages being compared (mm).

5) Standard error shows the amount of uncertainty overall, which is about 44%

6) DF refers to degrees of freedom for the entire analysis

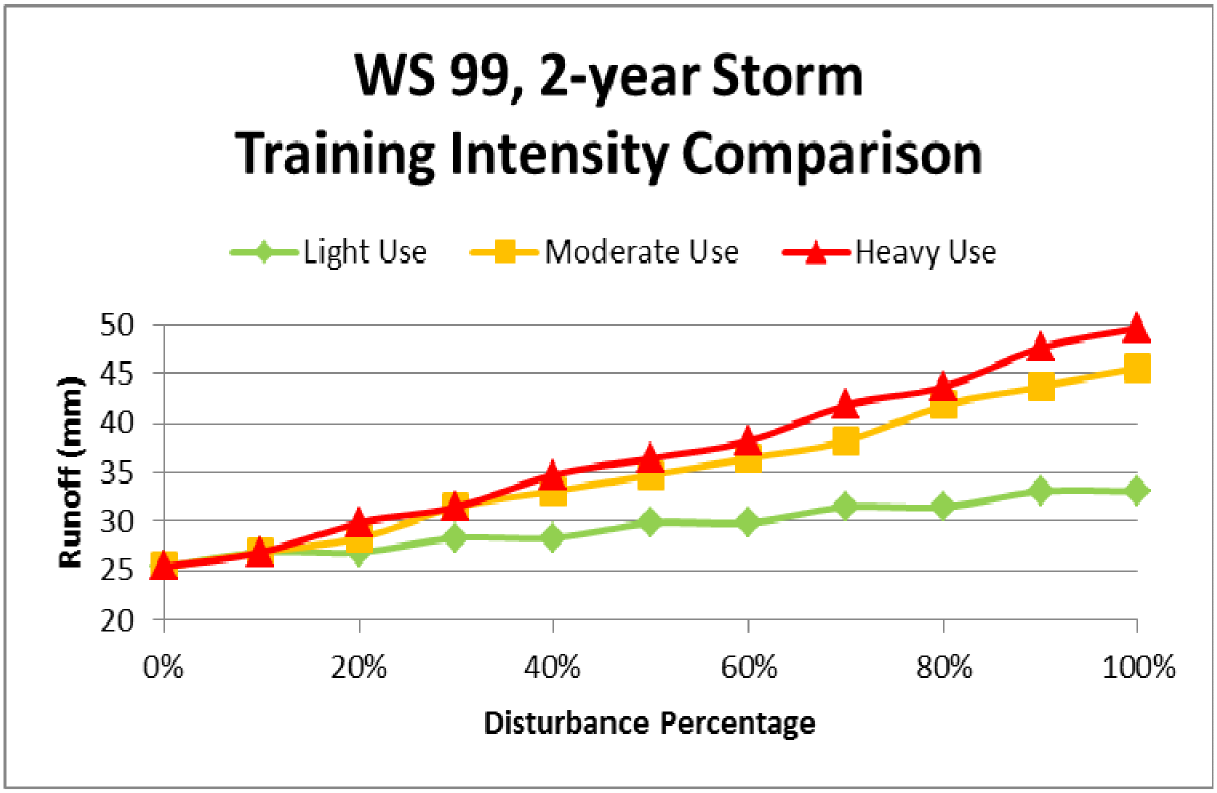
7) t-value is a test statistic to check the null hypothesis

8) pr > |t| is the p-value used to test the t-value against

The analysis of the disturbance percentage and training intensity by disturbance percentage showed moderate and heavy training classes to be fairly similar compared to the light use class, with no change occurring for 0% and 10%, with some similarities and 20% and 30% (Figure 26). Each of the storms followed similar paths with only the magnitude of runoff increasing as storm size increased (Appendix B, Figures 28 to 42). This similarity was due to the CNs determined for military use being very similar for moderate and heavy use training. As disturbance percentage increased, so did the difference between the different training intensities.

For example, watershed 99 showed that between 0% and 10% disturbance there was very little change in runoff between the training intensities. At 100% disturbance, the variance in runoff was nearly 15 mm from light to heavy use conditions.

Figure 25. Training Intensity Comparison, WS 99 2-year Storm.



The variation of runoff amounts was also analyzed by looking at the mean and standard deviation for all watersheds at each storm (Figures 27, 28, and 29). By looking at the percent change values associated with each percent rise, we can see that the smaller storm events had a greater change in percent runoff from undisturbed as disturbance increased than the larger storms did (Tables 18, 20, and 22). Light use changed nearly 25% for a 2- year storm from undisturbed to 100% disturbance, whereas moderate and heavy use increased by about 65% to 70% respectively. The 10 year storm showed an increase from light (15% increase) to moderate (38% increase) to heavy (44%) between 0-100% disturbance, and the 25 year also reflected this trend from light (12%), moderate (33%), to heavy (38%). From these values, it is evident that there is a decreasing trend in percent runoff change as storm size increases. This is because the smaller storms are more dramatically impacted by storage capacities of the soil, whereas the larger volumes associated with the larger storms quickly fill available storage and generate runoff. The data showed that as disturbance percentage increased the standard deviation, or variation from the mean, also increased (Tables 19, 21, and 23). For a 2-year storm with light training, the standard deviation ranged from 5.87 at 0% to 7.32 at 100%, moderate use ranged from 5.93 to 9.43, and heavy use ranged from 5.95 to 10.11. As the training intensity increased the range of standard deviations also increased. These trends can also be seen by the coefficient of variation (CV), a normalized dispersion measurement, which shows decreasing dispersion as disturbance intensity and training intensity increase. This means that as disturbance percentage and training intensity increase, runoff amount values became less variable. This was also the case with storm size, the more rainfall the closer the runoff amount values were to the average.

Figure 26. Training intensity trends by disturbance percentage and runoff amount, error bars represent one standard deviation from the mean, for a 2-year storm.

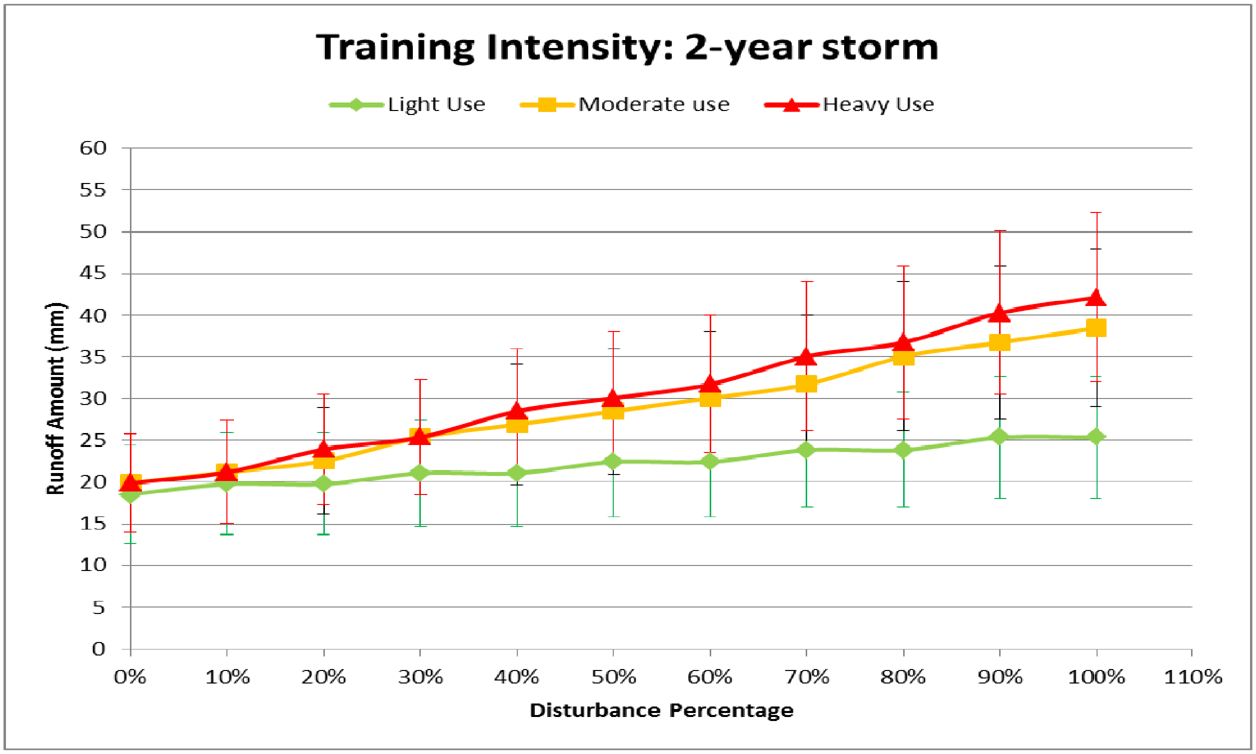


Table 17. Percent change and total percent change of runoff amount by disturbance percentage for a 2-year storm for light, moderate and heavy use training.

Percent change of runoff amount by disturbance percentage: 2-year storm										
	0% to 10%	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Light Use	**6.8%**	**0.0%**	**6.6%**	**0.0%**	**6.4%**	**0.0%**	**6.3%**	**0.0%**	**6.3%**	**0.0%**
Total change	6.8%	6.8%	13.4%	13.4%	19.7%	19.7%	26.0%	26.0%	32.3%	32.3%
Moderate Use	6.8%	6.6%	13.1%	6.3%	6.1%	5.7%	5.7%	10.7%	4.9%	4.8%
Total change	6.8%	13.4%	26.4%	32.7%	38.8%	44.5%	50.2%	60.9%	65.8%	70.5%
Heavy Use	6.8%	13.4%	6.3%	12.8%	5.7%	5.7%	10.7%	4.9%	9.8%	4.7%
Total change	6.8%	20.2%	26.5%	39.2%	44.9%	50.6%	61.3%	66.2%	76.0%	80.7%

Table 18. Average, standard deviation, and coefficient of variation data from a 2-year storm runoff amount data for light, moderate and heavy training uses from 0 to 100% disturbance.

	Disturbance Percentage										
Light Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	18.50	19.77	19.77	21.08	21.08	22.43	22.43	23.85	23.85	25.36	25.36
Standard Deviation	5.87	6.10	6.10	6.36	6.36	6.62	6.62	6.93	6.93	7.32	7.32
CV (%)	31.71	30.86	30.86	30.17	30.17	29.49	29.49	29.05	29.05	28.88	28.88
	Disturbance Percentage										
Moderate Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	19.89	21.20	22.54	25.38	26.90	28.49	30.07	31.72	35.05	36.74	38.47
Standard Deviation	5.93	6.15	6.39	6.91	7.24	7.54	7.90	8.21	8.89	9.15	9.43
CV (%)	29.84	29.04	28.36	27.22	26.92	26.47	26.27	25.87	25.35	24.91	24.52
	Disturbance Percentage										
Heavy use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	19.89	21.20	23.93	25.38	28.49	30.07	31.72	35.05	36.74	40.29	42.17
Standard Deviation	5.93	6.15	6.63	6.91	7.54	7.90	8.21	8.89	9.15	9.76	10.11
CV (%)	29.84	29.04	27.70	27.22	26.47	26.27	25.87	25.35	24.91	24.23	23.97

Figure 27. Training intensity trends by disturbance percentage and runoff amount, error bars represent one standard deviation from the mean, for a 10-year storm.

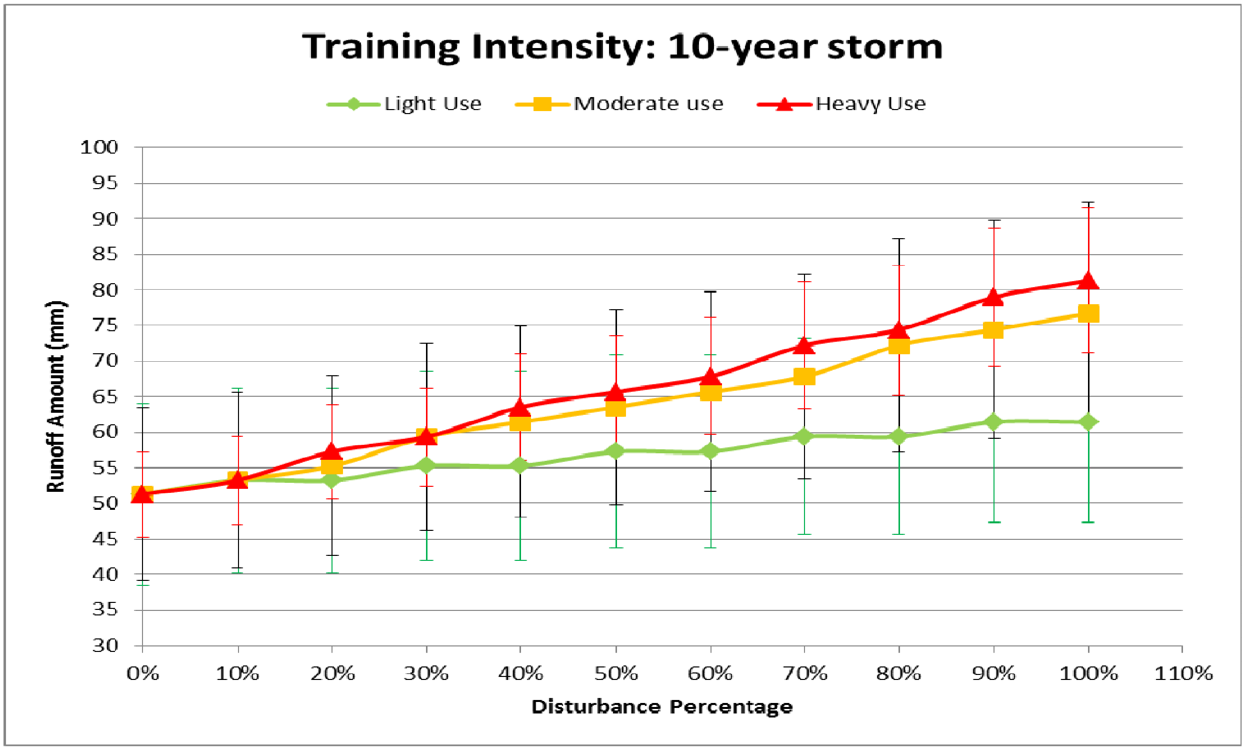


Table 19. Percent change and total percent change of runoff amount by disturbance percentage for a 10-year storm for light, moderate and heavy use training.

Percent change of runoff amount by disturbance percentage: 10-year storm										
	0% to 10%	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Light Use	3.9%	0.0%	3.8%	0.0%	3.7%	0.0%	3.7%	0.0%	3.5%	0.0%
Total change	3.9%	3.9%	7.7%	7.7%	11.4%	11.4%	15.1%	15.1%	18.6%	18.6%
Moderate Use	3.9%	3.8%	7.5%	3.5%	3.4%	3.4%	3.3%	6.5%	3.0%	3.0%
Total change	3.9%	7.7%	15.2%	18.8%	22.2%	25.6%	28.9%	35.4%	38.5%	41.5%
Heavy Use	3.9%	7.7%	3.7%	7.1%	3.4%	3.3%	6.5%	3.0%	6.1%	3.0%
Total change	3.9%	11.6%	15.2%	22.3%	25.7%	29.1%	35.6%	38.6%	44.7%	47.7%

Table 20. Average, standard deviation, and coefficient of variance data from a 10-year storm runoff amount data for light, moderate and heavy training uses from 0 to 100% disturbance.

	Disturbance Percentage										
Light	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	51.25	53.23	53.23	55.24	55.24	57.27	57.27	59.34	59.34	61.41	61.41
Standard Deviation	12.75	13.00	13.00	13.26	13.26	13.53	13.53	13.80	13.80	14.09	14.09
CV (%)	24.87	24.43	24.43	24.01	24.01	23.62	23.62	23.26	23.26	22.94	22.94
	Disturbance Percentage										
Moderate Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	51.25	53.23	55.24	59.34	61.41	63.50	65.66	67.82	72.20	74.39	76.65
Standard Deviation	12.14	12.39	12.64	13.16	13.44	13.77	14.06	14.39	14.99	15.35	15.63
CV (%)	23.69	23.28	22.53	22.19	21.68	21.42	21.22	20.76	20.63	20.18	19.96
	Disturbance Percentage										
Heavy use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	51.25	53.23	57.27	59.34	63.50	65.66	67.82	72.20	74.39	78.95	81.30
Standard Deviation	12.14	12.39	12.91	13.16	13.77	14.06	14.39	14.99	15.35	15.94	16.23
CV (%)	23.69	23.28	22.53	22.19	21.68	21.42	21.22	20.76	20.63	20.18	19.96

Figure 28. Training intensity trends by disturbance percentage and runoff amount, error bars represent one standard deviation from the mean, for a 25-year storm.

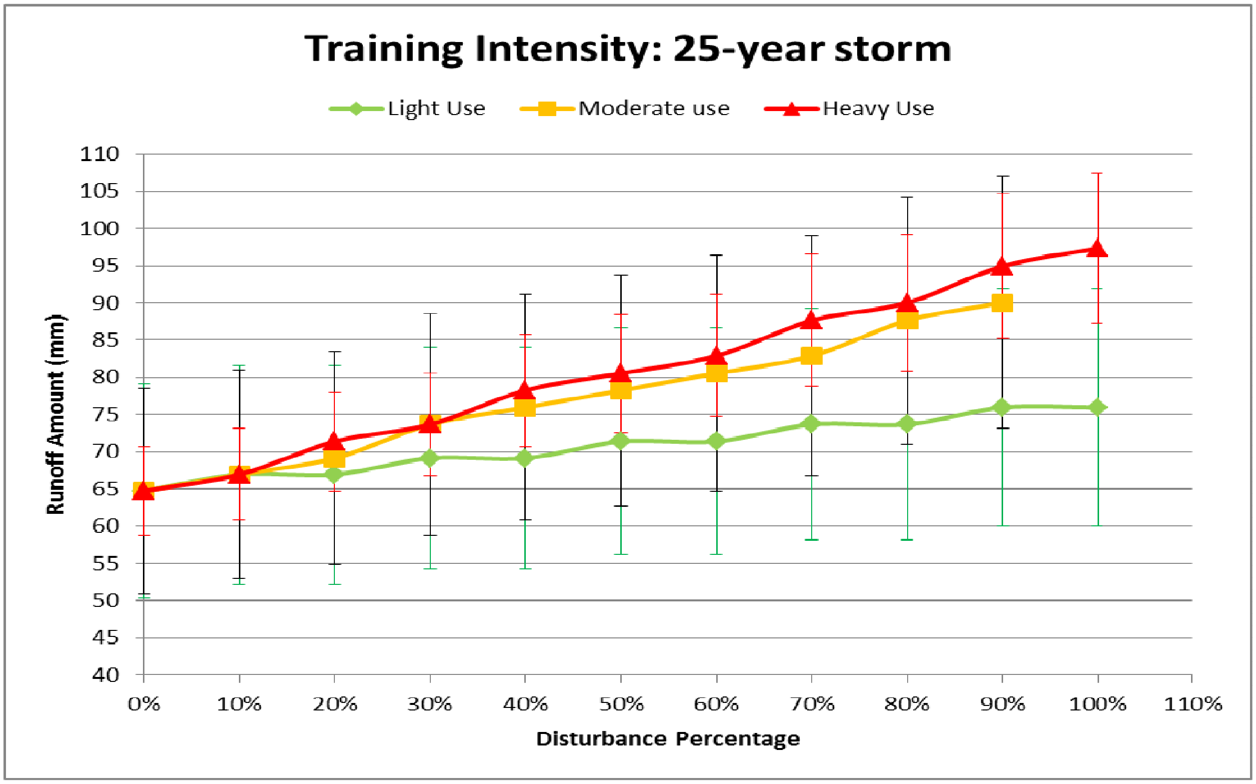


Table 21. Percent change and total percent change of runoff amount by disturbance percentage for a 25-year storm for light, moderate and heavy use training.

Percent change of runoff amount by disturbance percentage: 25-year storm										
	0% to 10%	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Light Use	3.5%	0.0%	3.3%	0.0%	3.3%	0.0%	3.2%	0.0%	3.1%	0.0%
Total change	3.5%	3.5%	6.8%	6.8%	10.0%	10.0%	13.3%	13.3%	16.4%	16.4%
Moderate Use	3.5%	3.3%	6.6%	3.1%	3.0%	2.9%	2.9%	5.7%	2.7%	2.7%
Total change	3.5%	6.8%	13.4%	16.5%	19.5%	22.4%	25.3%	31.1%	33.8%	36.5%
Heavy Use	3.5%	6.7%	3.2%	6.2%	2.9%	2.9%	5.7%	2.7%	5.4%	2.6%
Total change	3.5%	10.2%	13.4%	19.6%	22.5%	25.4%	31.2%	33.9%	39.3%	41.8%

Table 22. Average, standard deviation, and coefficient of variance data from a 25-year storm runoff amount data for light, moderate and heavy training uses from 0 to 100% disturbance.

	Disturbance Percentage										
Light Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	64.73	66.93	66.93	69.14	69.14	71.38	71.38	73.66	73.66	75.95	75.95
Standard Deviation	14.42	14.67	14.67	14.95	14.95	15.24	15.24	15.56	15.56	15.91	15.91
CV (%)	22.29	21.92	21.92	21.62	21.62	21.35	21.35	21.12	21.12	20.95	20.95
	Disturbance Percentage										
Moderate Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	64.73	66.93	69.14	73.66	75.95	78.24	80.53	82.88	87.63	90.03	92.49
Standard Deviation	13.76	13.99	14.26	14.85	15.18	15.50	15.82	16.08	16.61	16.95	17.26
CV (%)	21.25	20.91	20.62	20.16	19.99	19.81	19.64	19.41	18.95	18.83	18.67
	Disturbance Percentage										
Heavy use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	64.73	66.93	71.38	73.66	78.24	80.53	82.88	87.63	90.03	94.93	97.38
Standard Deviation	13.76	13.99	14.54	14.85	15.50	15.82	16.08	16.61	16.95	17.63	18.01
CV (%)	21.25	20.91	20.38	20.16	19.81	19.64	19.41	18.95	18.83	18.57	18.49

The statistical analysis showed training intensities to be similar for low range disturbance percentages (Table 24). These similarities occurred at 0%, 10%, and 30% for the training classes. That 20% disturbance did not show this difference was probably due to rounding by TR-55 (integer CNs) since the t-value and comparative p-value are relatively close compared to other insignificant comparisons. For these low percentages, the null hypothesis of significant difference was rejected.

Table 23. Training intensity and disturbance percentage least squares means simple effects comparison for runoff amount from a 2-year storm.

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By disturbance percentage: 2-year storm							
Simple Effect Level[1]	**Training Intensity[4]**	**Training Intensity**	**Estimate[5]**	**Standard Error[6]**	**DF[7]**	**t-Value[8]**	**Pr > |t|[9]**
dist[3] 0	H[2]	M[2]	-344E-17	0.4360	80	-0.00	1.0000
dist 0	L[2]	M	-269E-17	0.4360	80	-0.00	1.0000
dist 10	H	M	-888E-18	0.4360	80	-0.00	1.0000
dist 10	L	M	1.78E-15	0.4360	80	0.00	1.0000
dist 20	H	M	1.0844	0.4360	80	2.49	0.0150
dist 20	L	M	-1.3396	0.4360	80	-3.07	0.0029
dist 30	H	M	6.66E-15	0.4360	80	0.00	1.0000
dist 30	L	M	-2.8434	0.4360	80	-6.52	<.0001
dist 40	H	M	1.2550	0.4360	80	2.88	0.0051
dist 40	L	M	-4.3686	0.4360	80	-10.02	<.0001
dist 50	H	M	1.2436	0.4360	80	2.85	0.0055
dist 50	L	M	-4.5632	0.4360	80	-10.47	<.0001
dist 60	H	M	1.3016	0.4360	80	2.99	0.0038
dist 60	L	M	-6.1472	0.4360	80	-14.10	<.0001
dist 70	H	M	2.6026	0.4360	80	5.97	<.0001
dist 70	L	M	-6.3444	0.4360	80	-14.55	<.0001
dist 80	H	M	1.3076	0.4360	80	3.00	0.0036
dist 80	L	M	-9.6748	0.4360	80	-22.19	<.0001
dist 90	H	M	2.7574	0.4360	80	6.32	<.0001
dist 90	L	M	-9.8336	0.4360	80	-22.56	<.0001
dist 100	H	M	2.8882	0.4360	80	6.62	<.0001
dist 100	L	M	-11.5618	0.4360	80	-26.52	<.0001

<table>
<tr><th colspan="8">Simple Effect Comparisons of training intensity and disturbance percentage
Least Squares Means By disturbance percentage: 2-year storm</th></tr>
<tr><th>Simple Effect Level[1]</th><th>Training Intensity[4]</th><th>Training Intensity</th><th>Estimate[5]</th><th>Standard Error[6]</th><th>DF[7]</th><th>t-Value[8]</th><th>Pr > |t|[9]</th></tr>
<tr><td colspan="8">1) Simple effect level is what the analysis is organized by (disturbance percentage)</td></tr>
<tr><td colspan="8">2) training intensity class were referred to as L= Light, M= Moderate, and H= Heavy</td></tr>
<tr><td colspan="8">3) dist refers to disturbance percentage</td></tr>
<tr><td colspan="8">4) Training intensity refers to the training intensities being compared.</td></tr>
<tr><td colspan="8">5) Estimate refers to the estimated value between the two training intensities being compared (mm).</td></tr>
<tr><td colspan="8">6) Standard error shows the amount of uncertainty overall, which is about 44%</td></tr>
<tr><td colspan="8">7) DF refers to degrees of freedom for the entire analysis</td></tr>
<tr><td colspan="8">8) t-value is a test statistic to check the null hypothesis</td></tr>
<tr><td colspan="8">9) pr > |t| is the p-value used to test the t-value against</td></tr>
</table>

Runoff Rate Statistical Analysis

Runoff flow rate (m^3s^{-1}) was also analyzed using a 3-way factorial. Unlike runoff amount that was relatively consistent across the watersheds, there was more variance by watershed because runoff rate was dependent on the watershed area. Runoff rates ranged from less than 1 m^3s^{-1} for the 2-year storm on undisturbed ground, to over 30 m^3s^{-1} for the 25-year storm on heavily disturbed land.

The runoff rate analysis showed a wide spread of individual watershed response to land disturbance (Figure 30). Other storm and intensity combinations are available in Appendix B, Figures 46 through 54. Variability was primarily because of the dependency of runoff rate on area. Though the watersheds were relatively similar in size, there was still a large spread in areas particularly with the smallest watershed (WS 153) which was over one square kilometer smaller than the larger watersheds (Table 25). That the area does not completely determine the runoff rate potential was due to the additional dependency of rate on time of concentration details with the general trend showing the larger watersheds producing higher runoff rates that the smaller ones.

Figure 29. Watershed comparison of runoff Rate (m^3s^{-1}) for a 2-year storm under moderate training intensity.

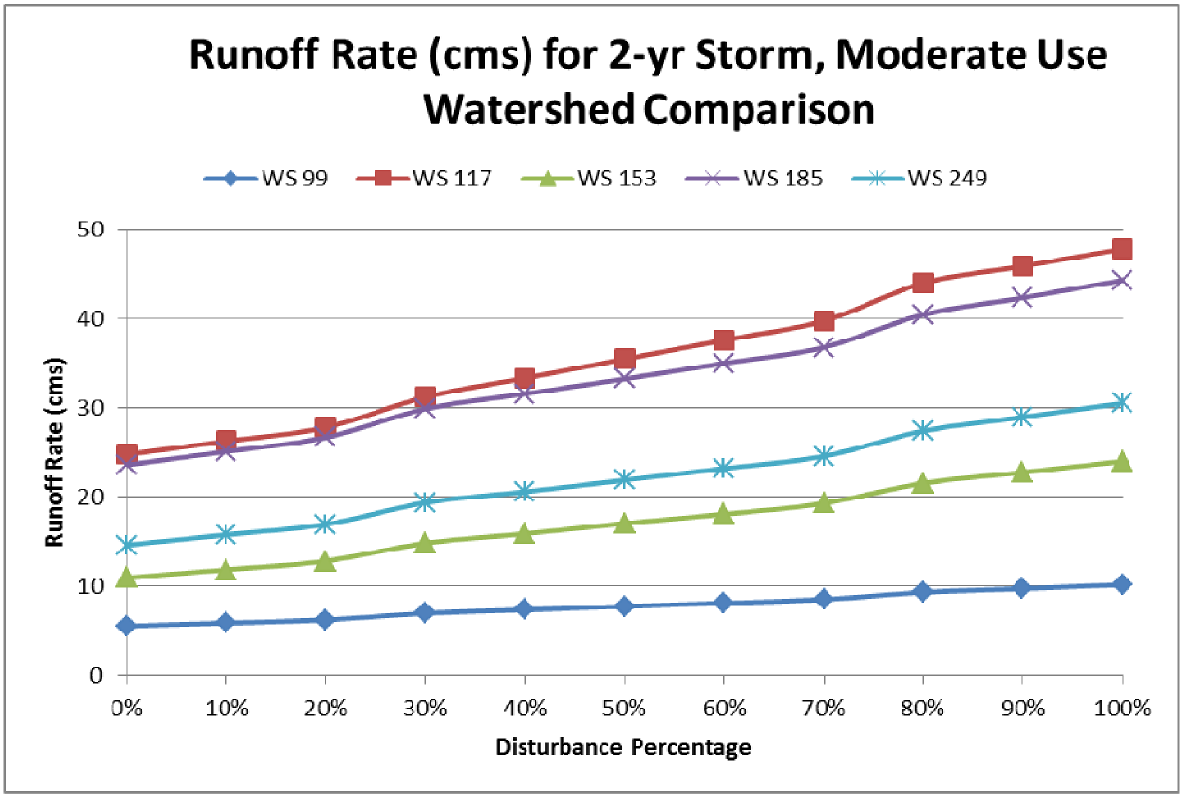


Table 24. Watershed areas by code used in analysis, general runoff rate potential as is relates to watershed area (color) and actual ranked potential (1-5).

Watershed	Total Area (km^2)	General Runoff Rate Potential from Figure 30
185	1.33	2
249	1.01	3
117	0.81	1 (most potential)
99	0.27	5 (least potential)
153	0.05	4

This influence of watershed size was particularly noticeable when examining results from the watershed and disturbance percentage simple effects comparison (Table 26). A complete version of the simple effects table is available in Appendix B, Table 7. The only case where runoff rate was not found to be significantly different occurred in watershed 153, the smallest watershed. Watershed 99, the second to smallest watershed, also showed a tendency to similarity when heavy and moderate conditions were compared for a 2-year storm; however, this did not show in the larger storm analyses. These oddities lead me to believe that maintaining very similar areas when analyzing runoff rates is very important. Even though these differences did not seem that significant before, they limit the types of data that can be properly analyzed making initial watershed selection the key to usable replications. This is true not only for area, but also for the factors influencing time of concentration details such as slope, channel lengths and surface material assumptions.

Table 25. Training intensity and disturbance percentage simple effects comparison by training intensity for peak runoff rate from a 2-year storm.

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By training intensity: 2-year storm							
Simple Effect Level[1]	**dist[3]**	**dist**	**Estimate[4]**	**Standard Error[5]**	**DF[6]**	**t-Value[7]**	**Pr > |t|[8]**
ti H	**10**	**0**	0.3880	0.3003	80	1.29	0.2001
ti H	**20**	**0**	1.1940	0.3003	80	3.98	0.0002
ti H	**30**	**0**	1.6120	0.3003	80	5.37	<.0001
ti H	**40**	**0**	2.4660	0.3003	80	8.21	<.0001
ti H	**50**	**0**	2.9020	0.3003	80	9.66	<.0001
ti H	**60**	**0**	3.3500	0.3003	80	11.15	<.0001
ti H	**70**	**0**	4.2500	0.3003	80	14.15	<.0001
ti H	**80**	**0**	4.7720	0.3003	80	15.89	<.0001

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By training intensity: 2-year storm

Simple Effect Level[1]	dist[3]	dist	Estimate[4]	Standard Error[5]	DF[6]	t-Value[7]	Pr > |t|[8]
ti H	**90**	**0**	5.6700	0.3003	80	18.88	<.0001
ti[2] H	**100**	**0**	6.1480	0.3003	80	20.47	<.0001
ti L	**10**	**0**	0.3880	0.3003	80	1.29	0.2001
ti L	**20**	**0**	0.3880	0.3003	80	1.29	0.2001
ti L	**30**	**0**	0.7860	0.3003	80	2.62	0.0106
ti L	**40**	**0**	0.7860	0.3003	80	2.62	0.0106
ti L	**50**	**0**	1.1940	0.3003	80	3.98	0.0002
ti L	**60**	**0**	1.1940	0.3003	80	3.98	0.0002
ti L	**70**	**0**	1.6120	0.3003	80	5.37	<.0001
ti L	**80**	**0**	1.6120	0.3003	80	5.37	<.0001
ti L	**90**	**0**	2.0380	0.3003	80	6.79	<.0001
ti L	**100**	**0**	2.0380	0.3003	80	6.79	<.0001
ti M	**10**	**0**	0.3880	0.3003	80	1.29	0.2001
ti M	**20**	**0**	0.7860	0.3003	80	2.62	0.0106
ti M	**30**	**0**	1.6120	0.3003	80	5.37	<.0001
ti M	**40**	**0**	2.0380	0.3003	80	6.79	<.0001
ti M	**50**	**0**	2.4660	0.3003	80	8.21	<.0001
ti M	**60**	**0**	2.9020	0.3003	80	9.66	<.0001
ti M	**70**	**0**	3.3500	0.3003	80	11.15	<.0001
ti M	**80**	**0**	4.2500	0.3003	80	14.15	<.0001
ti M	**90**	**0**	4.7720	0.3003	80	15.89	<.0001
ti M	**100**	**0**	5.1900	0.3003	80	17.28	<.0001

1) Simple effect level is what the analysis is organized by (training intensity)

2) ti refers to the training intensity class where L= Light, M= Moderate, and H= Heavy

3) Dist refers to the disturbance percentages which are being compared.

4) Estimate refers to the estimated value between the two disturbance percentages being compared (m^3s^{-1}).

<table>
<tr><th colspan="8">Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By training intensity: 2-year storm</th></tr>
<tr><th>Simple Effect Level[1]</th><th>dist[3]</th><th>dist</th><th>Estimate[4]</th><th>Standard Error[5]</th><th>DF[6]</th><th>t-Value[7]</th><th>Pr > |t|[8]</th></tr>
<tr><td colspan="8">5) Standard error shows the amount of uncertainty overall, which is about 44%
6) DF refers to degrees of freedom for the entire analysis
7) t-value is a test statistic to check the null hypothesis
8) pr > |t| is the p-value used to test the t-value against</td></tr>
</table>

Runoff rate increased as disturbance percentage and training intensity increased, with the light, moderate, and heavy use classes spreading apart as disturbance percentage increases (Figure 31). All other watershed and storm event combinations are available in Appendix B Figures 55 to 69. At lower disturbance percentages, each of the storm events showed training intensities to be very similar (Table 27). At both 0% and 10% disturbance, there was no significant change in runoff between light, moderate and heavy training use classes. Another point of similarity occurred at 30% disturbance between moderate and heavy uses. This mimics responses shown by the runoff amount statistical analysis.

Figure 30. Training Intensity Comparison of Runoff Rate (m^3s^{-1}) for WS 99, 2-year Storm.

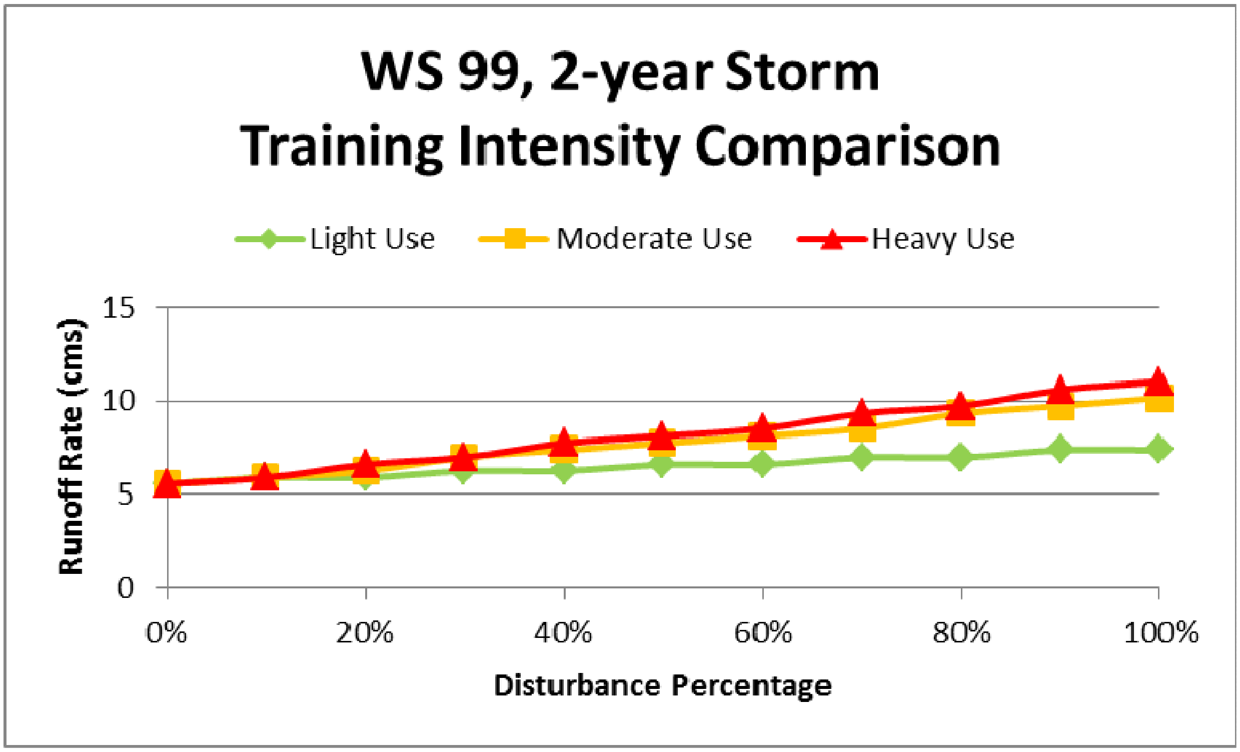


Table 26. Percent changes between training intensity classes given disturbance percent changes for a 2-year storm.

	Percent Disturbance										
TI Changes	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Light to Moderate	0.0%	0.0%	6.1%	11.9%	18.0%	17.3%	23.2%	22.4%	33.9%	33.3%	38.4%
Light to Heavy	0.0%	0.0%	12.3%	11.9%	24.2%	23.2%	29.3%	33.9%	40.7%	44.3%	50.1%
Moderate to Heavy	0.0%	0.0%	5.9%	0.0%	5.2%	5.1%	4.9%	9.5%	5.0%	8.2%	8.4%

To look at runoff rate trends, values for each watershed were averaged by disturbance percentage and error bars added to represent a one standard deviation spread from the mean (Figures 32, 33, and 34). Changes in runoff rate and total change in runoff rate can be seen in Tables 28, 30, and 32. The smaller storm events again showed greater potential for runoff rate change than the larger storm events. Total percent runoff change also increased as training intensity increased. Statistics on the data showed increase of the standard deviation with disturbance percentage and training intensity, and an increase as storm sized increased as well (Tables 29, 31, and 33). The coefficient of variation however had a much smaller spread with the runoff rate data than the runoff amount data, changing by only a fraction of a percentage whereas the runoff amount data varied by multiple percentages. As disturbance was increased the coefficient of variance slightly decrease (57.78% to 57.62% for a 2-year storm with light use), this trend remained the same but decreased in magnitude as training intensity was increased. Storm size only slightly impacted the coefficient of variance, on the magnitude of 0.1% change. From this it can be seen that runoff rate also decreases in variability as more disturbance is done, at higher levels, and with larger rainfall events.

Figure 31. Training intensity error in runoff rate by disturbance percentage for a 2-year storm.

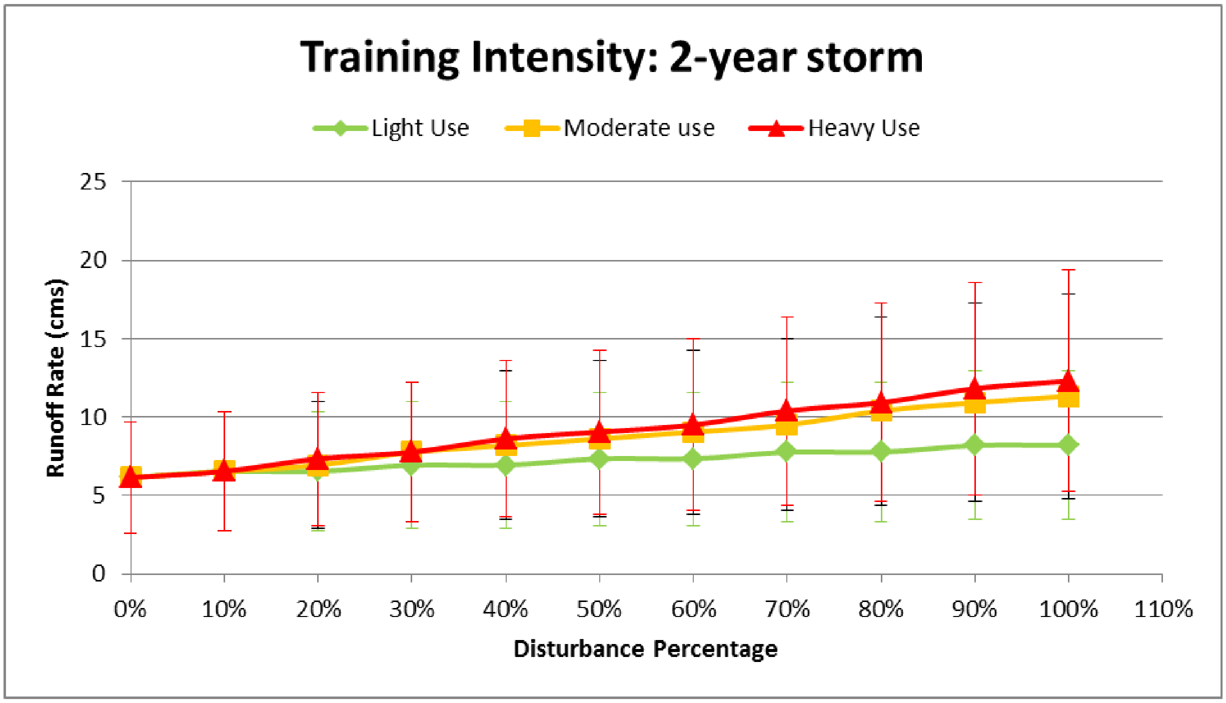


Table 27. Runoff rate percent changes by disturbance percentage, individual steps and running total: 2-year storm.

Percent change of runoff rate by disturbance percentage: 2-year storm										
	0% to 10%	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Light Use	**6.6%**	**0.0%**	**6.3%**	**0.0%**	**6.2%**	**0.0%**	**6.1%**	**0.0%**	**6.0%**	**0.0%**
Total change	6.6%	6.6%	12.9%	12.9%	19.1%	19.1%	25.1%	25.1%	31.2%	31.2%
Moderate Use	6.6%	6.3%	12.6%	6.0%	5.9%	5.6%	5.5%	10.5%	4.8%	4.7%
Total change	6.6%	12.9%	25.5%	31.5%	37.4%	43.0%	48.5%	59.0%	63.8%	68.5%
Heavy Use	6.6%	12.9%	6.1%	12.3%	5.6%	5.5%	10.5%	4.8%	9.7%	4.7%
Total change	6.6%	19.5%	25.5%	37.8%	43.4%	48.8%	59.3%	64.1%	73.8%	78.5%

Table 28. Average, standard deviation, and coefficient of variance data from a 2-year storm runoff rate data for light, moderate and heavy training uses from 0 to 100% disturbance.

	Disturbance Percentage										
Light Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	6.16	6.55	6.55	6.95	6.95	7.35	7.35	7.77	7.77	8.20	8.20
Standard Deviation	3.56	3.79	3.79	4.01	4.01	4.25	4.25	4.48	4.48	4.72	4.72
CV %	57.78	57.85	57.85	57.72	57.72	57.74	57.74	57.71	57.71	57.62	57.62
	Disturbance Percentage										
Moderate Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	6.16	6.55	6.95	7.77	8.20	8.63	9.06	9.51	10.41	10.93	11.35
Standard Deviation	3.56	3.79	4.01	4.48	4.72	4.97	5.22	5.48	5.99	6.34	6.52
CV %	57.78	57.85	57.72	57.71	57.62	57.67	57.61	57.60	57.53	57.96	57.42
	Disturbance Percentage										
Heavy use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	6.16	6.55	7.35	7.77	8.63	9.06	9.51	10.41	10.93	11.83	12.31
Standard Deviation	3.56	3.79	4.25	4.48	4.97	5.22	5.48	5.99	6.34	6.79	7.06
CV %	57.78	57.85	57.74	57.71	57.67	57.61	57.60	57.53	57.96	57.37	57.35

Figure 32. Training intensity error in runoff rate by disturbance percentage for a 10-year storm.

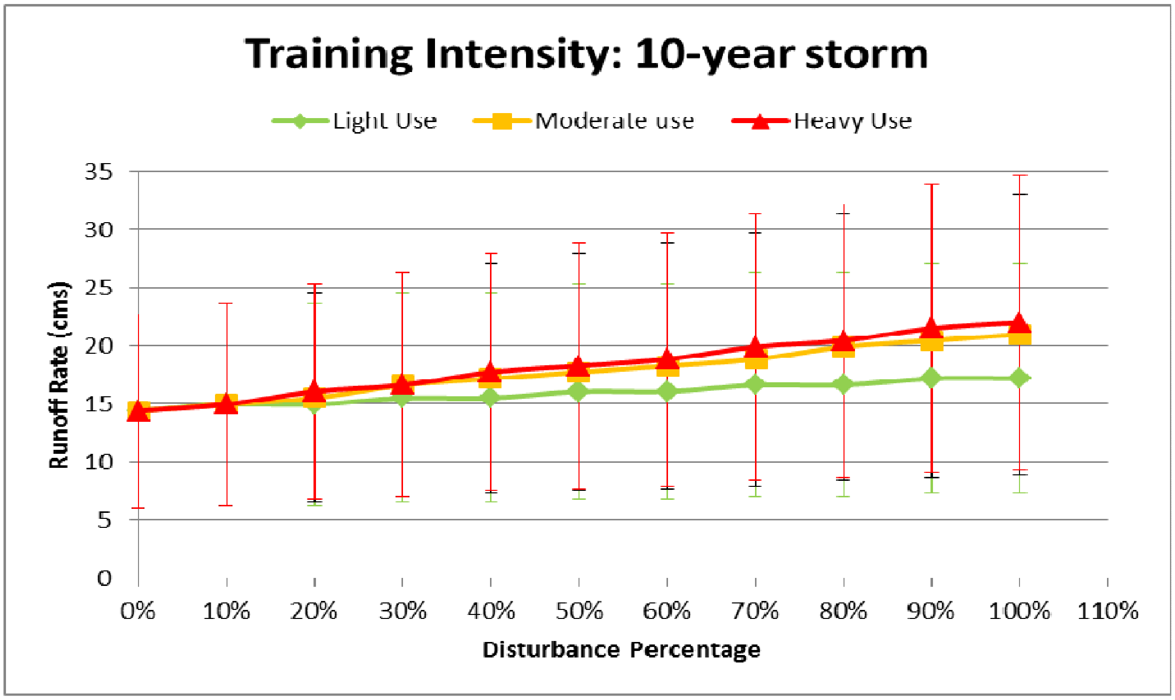


Table 29. Runoff rate percent changes by disturbance percentage, individual steps and running total: 10-year storm.

Percent change of runoff rate by disturbance percentage: 10-year storm										
	0% to 10%	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Light Use	6.8%	6.5%	8.5%	6.4%	5.9%	4.0%	7.6%	5.5%	7.0%	3.5%
Total change	6.8%	13.3%	21.8%	28.2%	34.1%	38.2%	45.7%	51.2%	58.2%	61.8%
Moderate Use	6.6%	6.4%	8.4%	6.3%	5.9%	3.9%	7.5%	5.5%	7.0%	3.5%
Total change	6.6%	13.0%	21.4%	27.8%	33.6%	37.6%	45.1%	50.5%	57.5%	61.0%
Heavy Use	6.6%	8.2%	8.9%	7.9%	5.8%	4.8%	7.8%	6.6%	7.2%	4.2%
Total change	6.6%	14.8%	23.7%	31.6%	37.4%	42.2%	50.0%	56.7%	63.8%	68.0%

Table 30. Average, standard deviation, and coefficient of variance data from a 10-year storm runoff rate data for light, moderate and heavy training uses from 0 to 100% disturbance.

	Disturbance Percentages										
Light Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	14.45	14.99	14.99	15.54	15.54	16.10	16.10	16.66	16.66	17.21	17.21
Standard Deviation	8.34	8.65	8.65	8.96	8.96	9.28	9.28	9.60	9.60	9.92	9.92
CV%	57.75	57.70	57.70	57.67	57.67	57.65	57.65	57.65	57.65	57.65	57.65
	Disturbance Percentages										
Moderate Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	14.45	14.99	15.54	16.66	17.21	17.76	18.31	18.87	19.95	20.49	21.02
Standard Deviation	8.34	8.65	8.96	9.60	9.92	10.23	10.55	10.87	11.48	11.79	12.09
CV%	57.75	57.70	57.67	57.65	57.65	57.63	57.61	57.61	57.54	57.53	57.50
	Disturbance Percentages										
Heavy use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	14.45	14.99	16.10	16.66	17.76	18.31	18.87	19.95	20.49	21.54	22.03
Standard Deviation	8.34	8.65	9.28	9.60	10.23	10.55	10.87	11.48	11.79	12.38	12.67
CV%	57.75	57.70	57.65	57.65	57.63	57.61	57.61	57.54	57.53	57.49	57.50

Figure 33. Training intensity error in runoff rate by disturbance percentage for a 25-year storm.

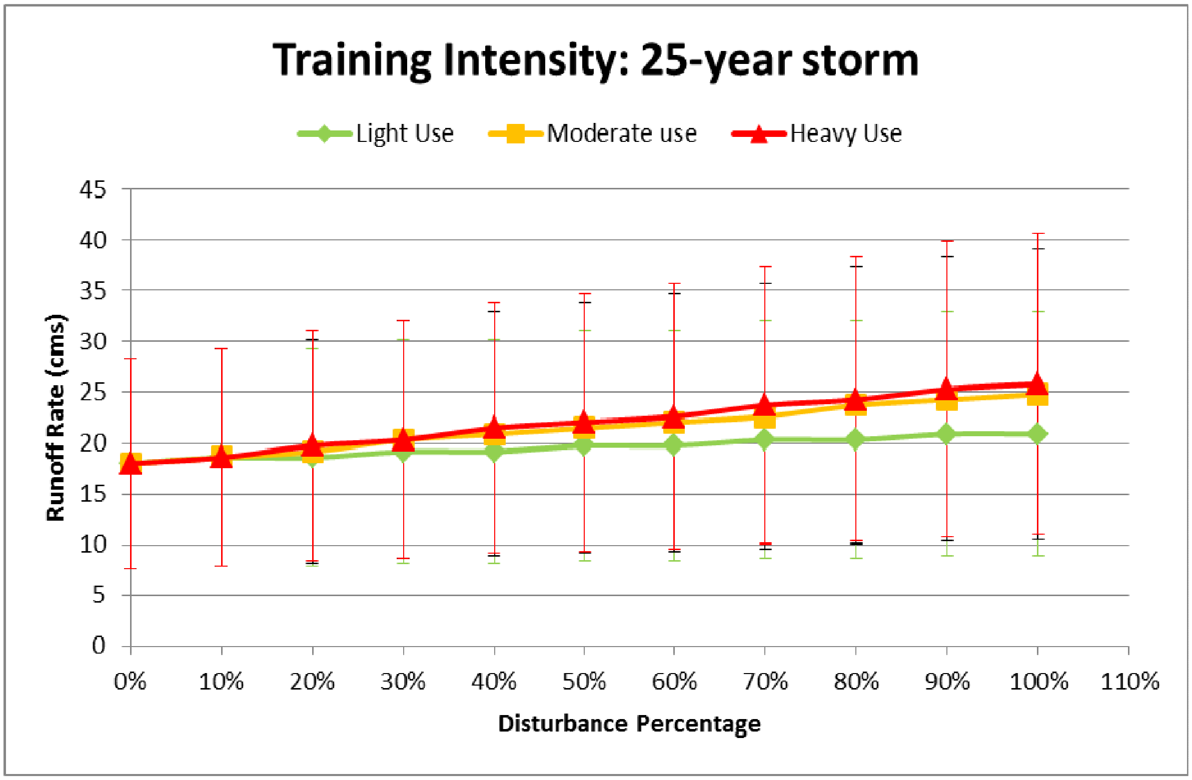


Table 31. Runoff rate percent changes by disturbance percentage, individual steps and running total: 25-year storm.

Percent change of runoff rate by disturbance percentage: 25-year storm										
	0% to 10%	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Light Use	6.7%	7.1%	8.6%	6.9%	5.9%	4.3%	7.6%	5.9%	7.0%	3.8%
Total change	6.7%	13.7%	22.3%	29.2%	35.1%	39.4%	47.0%	52.9%	60.0%	63.7%
Moderate Use	6.7%	7.1%	8.6%	6.9%	5.9%	4.3%	7.6%	5.9%	7.0%	3.8%
Total change	6.7%	13.7%	22.3%	29.2%	35.1%	39.4%	47.0%	52.9%	60.0%	63.7%
Heavy Use	6.6%	7.2%	8.6%	7.0%	5.9%	4.3%	7.7%	6.0%	7.1%	3.8%
Total change	6.6%	13.8%	22.4%	29.5%	35.3%	39.6%	47.3%	53.3%	60.3%	64.1%

Table 32. Average, standard deviation, and coefficient of variance data from a 25-year storm runoff rate data for light, moderate and heavy training uses from 0 to 100% disturbance.

	Disturbance Percentages										
Light Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	17.99	18.57	18.57	19.16	19.16	19.74	19.74	20.34	20.34	20.90	20.90
Standard Deviation	10.39	10.72	10.72	11.06	11.06	11.40	11.40	11.73	11.73	12.05	12.05
CV%	57.74	57.74	57.74	57.72	57.72	57.72	57.72	57.68	57.68	57.68	57.68
	Disturbance Percentages										
Moderate Use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	17.99	18.57	19.16	20.34	20.90	21.50	22.06	22.62	23.74	24.29	24.82
Standard Deviation	10.39	10.72	11.06	11.73	12.05	12.39	12.72	13.04	13.67	13.99	14.28
CV%	57.74	57.74	57.72	57.68	57.68	57.66	57.65	57.64	57.59	57.59	57.55
	Disturbance Percentages										
Heavy use	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average	17.99	18.57	19.74	20.34	21.50	22.06	22.62	23.74	24.29	25.32	25.83
Standard Deviation	10.39	10.72	11.40	11.73	12.39	12.72	13.04	13.67	13.99	14.57	14.87
CV%	57.74	57.74	57.72	57.68	57.66	57.65	57.64	57.59	57.59	57.56	57.56

A simple effects comparison of disturbance percentage and training intensity showed similar runoff rate responses at low disturbance percentages for all three storm events (Tables 34, 35, and 36), just as the runoff amount analysis did. At zero percent disturbance, the comparisons between light, moderate and heavy training showed no significant difference in runoff rate potential. This also occurred again at 30% from moderate to heavy uses, skipping the 20% disturbance level again presumably due to rounding assumptions made by TR-55.

Table 33. Simple effects comparison of training intensity and disturbance percentage LSMs by disturbance percentage for peak runoff rate from a 2-year storm.

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By disturbance percentage: 2 yr storm							
Simple Effect Level[1]	**ti[3]**	**ti**	**Estimate[4]**	**Standard Error[5]**	**DF[6]**	**t-Value[7]**	**Pr > |t|[8]**
dist[2] 0	**H**	**M**	-317E-17	0.4360	80	-0.00	1.0000
dist 0	**L**	**M**	-173E-18	0.4360	80	-0.00	1.0000
dist 10	**H**	**M**	6.6E-15	0.4360	80	0.00	1.0000
dist 10	**L**	**M**	1.05E-14	0.4360	80	0.00	1.0000
dist 20	**H**	**M**	1.0844	0.4360	80	2.49	0.0150
dist 20	**L**	**M**	-1.3396	0.4360	80	-3.07	0.0029
dist 30	**H**	**M**	8.82E-15	0.4360	80	0.00	1.0000
dist 30	**L**	**M**	-2.8434	0.4360	80	-6.52	<.0001
dist 40	**H**	**M**	1.2550	0.4360	80	2.88	0.0051
dist 40	**L**	**M**	-4.3686	0.4360	80	-10.02	<.0001
dist 50	**H**	**M**	1.2436	0.4360	80	2.85	0.0055
dist 50	**L**	**M**	-4.5632	0.4360	80	-10.47	<.0001
dist 60	**H**	**M**	1.3016	0.4360	80	2.99	0.0038
dist 60	**L**	**M**	-6.1472	0.4360	80	-14.10	<.0001
dist 70	**H**	**M**	2.6026	0.4360	80	5.97	<.0001
dist 70	**L**	**M**	-6.3444	0.4360	80	-14.55	<.0001
dist 80	**H**	**M**	1.3076	0.4360	80	3.00	0.0036
dist 80	**L**	**M**	-9.6748	0.4360	80	-22.19	<.0001
dist 90	**H**	**M**	2.7574	0.4360	80	6.32	<.0001
dist 90	**L**	**M**	-9.8336	0.4360	80	-22.56	<.0001
dist 100	**H**	**M**	2.8882	0.4360	80	6.62	<.0001
dist 100	**L**	**M**	-11.5618	0.4360	80	-26.52	<.0001
1) Simple effect level is what the analysis is organized by (disturbance percentage)							

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By disturbance percentage: 2 yr storm

Simple Effect Level[1]	ti[3]	ti	Estimate[4]	Standard Error[5]	DF[6]	t-Value[7]	Pr > |t|[8]

2) dist refers to disturbance percentage

3) ti refers to the training intensity class where L= Light, M= Moderate, and H= Heavy

4) Estimate refers to the estimated value between the two training intensities being compared (m^3s^{-1}).

5) Standard error shows the amount of uncertainty overall, which is about 44%

6) DF refers to degrees of freedom for the entire analysis

7) t-value is a test statistic to check the null hypothesis

8) pr > |t| is the p-value used to test the t-value against

Table 34. Simple effects comparison of training intensity and disturbance percentage LSMs by disturbance percentage for peak runoff rate from a 10-year storm.

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By disturbance percentage: 10 year storm

Simple Effect Level[1]	ti[3]	ti	Estimate[4]	Standard Error[5]	DF[6]	t-Value[7]	Pr > |t|[8]
dist[2] 0	**H**	**M**	1.01E-15	0.3545	80	0.00	1.0000
dist 0	**L**	**M**	6.85E-16	0.3545	80	0.00	1.0000
dist 10	**H**	**M**	5.89E-15	0.3545	80	0.00	1.0000
dist 10	**L**	**M**	9.12E-15	0.3545	80	0.00	1.0000
dist 20	**H**	**M**	0.5580	0.3545	80	1.57	0.1194
dist 20	**L**	**M**	-0.5480	0.3545	80	-1.55	0.1261
dist 30	**H**	**M**	4.56E-15	0.3545	80	0.00	1.0000
dist 30	**L**	**M**	-1.1140	0.3545	80	-3.14	0.0023
dist 40	**H**	**M**	0.5500	0.3545	80	1.55	0.1247
dist 40	**L**	**M**	-1.6680	0.3545	80	-4.71	<.0001
dist 50	**H**	**M**	0.5480	0.3545	80	1.55	0.1261
dist 50	**L**	**M**	-1.6600	0.3545	80	-4.68	<.0001
dist 60	**H**	**M**	0.5640	0.3545	80	1.59	0.1155

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By disturbance percentage: 10 year storm							
Simple Effect Level[1]	**ti[3]**	**ti**	**Estimate[4]**	**Standard Error[5]**	**DF[6]**	**t-Value[7]**	**Pr > |t|[8]**
dist 60	**L**	**M**	-2.2080	0.3545	80	-6.23	<.0001
dist 70	**H**	**M**	1.0760	0.3545	80	3.04	0.0032
dist 70	**L**	**M**	-2.2160	0.3545	80	-6.25	<.0001
dist 80	**H**	**M**	0.5380	0.3545	80	1.52	0.1330
dist 80	**L**	**M**	-3.2920	0.3545	80	-9.29	<.0001
dist 90	**H**	**M**	1.0500	0.3545	80	2.96	0.0040
dist 90	**L**	**M**	-3.2760	0.3545	80	-9.24	<.0001
dist 100	**H**	**M**	1.0160	0.3545	80	2.87	0.0053
dist 100	**L**	**M**	-3.8080	0.3545	80	-10.74	<.0001

1) Simple effect level is what the analysis is organized by (disturbance percentage)

2) dist refers to disturbance percentage

3) ti refers to the training intensity class where L= Light, M= Moderate, and H= Heavy

4) Estimate refers to the estimated value between the two training intensities being compared (m^3s^{-1}).

5) Standard error shows the amount of uncertainty overall, which is about 44%

6) DF refers to degrees of freedom for the entire analysis

7) t-value is a test statistic to check the null hypothesis

8) pr > |t| is the p-value used to test the t-value against

Table 35. Simple effects comparison of training intensity and disturbance percentage LSMs by disturbance percentage for peak runoff rate from a 25-year storm.

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By disturbance percentage : 25 year storm							
Simple Effect Level[1]	**ti[3]**	**ti**	**Estimate[4]**	**Standard Error[5]**	**DF[6]**	**t-Value[7]**	**Pr > |t|[8]**
dist[2] 0	**H**	**M**	-108E-17	0.3636	80	-0.00	1.0000
dist 0	**L**	**M**	-277E-17	0.3636	80	-0.00	1.0000
dist 10	**H**	**M**	-508E-17	0.3636	80	-0.00	1.0000

Simple Effect Comparisons of training intensity and disturbance percentage Least Squares Means By disturbance percentage : 25 year storm

Simple Effect Level[1]	ti[3]	ti	Estimate[4]	Standard Error[5]	DF[6]	t-Value[7]	Pr > |t|[8]
dist 10	**L**	**M**	-544E-17	0.3636	80	-0.00	1.0000
dist 20	**H**	**M**	0.5860	0.3636	80	1.61	0.1110
dist 20	**L**	**M**	-0.5880	0.3636	80	-1.62	0.1098
dist 30	**H**	**M**	6.03E-15	0.3636	80	0.00	1.0000
dist 30	**L**	**M**	-1.1800	0.3636	80	-3.24	0.0017
dist 40	**H**	**M**	0.5960	0.3636	80	1.64	0.1051
dist 40	**L**	**M**	-1.7420	0.3636	80	-4.79	<.0001
dist 50	**H**	**M**	0.5640	0.3636	80	1.55	0.1249
dist 50	**L**	**M**	-1.7520	0.3636	80	-4.82	<.0001
dist 60	**H**	**M**	0.5600	0.3636	80	1.54	0.1275
dist 60	**L**	**M**	-2.3160	0.3636	80	-6.37	<.0001
dist 70	**H**	**M**	1.1200	0.3636	80	3.08	0.0028
dist 70	**L**	**M**	-2.2820	0.3636	80	-6.28	<.0001
dist 80	**H**	**M**	0.5500	0.3636	80	1.51	0.1344
dist 80	**L**	**M**	-3.4020	0.3636	80	-9.36	<.0001
dist 90	**H**	**M**	1.0300	0.3636	80	2.83	0.0058
dist 90	**L**	**M**	-3.3900	0.3636	80	-9.32	<.0001
dist 100	**H**	**M**	1.0160	0.3636	80	2.79	0.0065
dist 100	**L**	**M**	-3.9160	0.3636	80	-10.77	<.0001

1) Simple effect level is what the analysis is organized by (disturbance percentage)

2) dist refers to disturbance percentage

3) ti refers to the training intensity class where L= Light, M= Moderate, and H= Heavy

4) Estimate refers to the estimated value between the two training intensities being compared (m^3s^{-1}).

5) Standard error shows the amount of uncertainty overall, which is about 44%

6) DF refers to degrees of freedom for the entire analysis

7) t-value is a test statistic to check the null hypothesis

8) pr > |t| is the p-value used to test the t-value against

Significant Runoff Thresholds

The main objective of this study was to determine how much military training could be done on a watershed before significant changes in runoff, which cause gully formation, would occur. This happened from the very first disturbance increase of 10% and continued for every 10% increase after that. Because of this, the main thresholds that had been hoped to make (green, amber, and red) were not feasible. From this we can see that even at very small disturbance levels, there is a significant change in runoff potential when using the CN method. Meaning, even if only a little training is done, there will still be enough impact to the landscape to cause gully formation.

To get an idea of how much training yielded different disturbance percentages, the MIM was examined in terms of passes for each watershed based on the standard dimensions of an M1A2 Abrams tank, but on a square kilometers scale (Figures 38 and 39, and Tables 37 and 38). Rangeland disturbance is usually around 30% for active training. For smaller watersheds, less passes are required to cause significant disturbance across the watershed, as oppose to larger watersheds where even severe disturbance can be averaged out over the larger area. Additionally, smaller watersheds are more likely to be quickly effected if training is concentrated on them, whereas with the larger watersheds the number of passes to reach the threshold may not even be feasible. If the large watersheds were to be broken down into smaller watersheds, and concentrated training done in these areas, a quicker rise in disturbance percentage would be seen. In other words, the more spread out the training, the less apt it is to cause major changes in disturbance percentage. Realistically speaking, disturbance percentages for the larger watersheds should never reach 100%, or even above 30% to 50%, with less disturbance in wood/shrubland and forested areas.

Figure 34. Average number of east to west passes by an M1A2 abrams to achieve a typical 30% disturbance percentage assumed for rangeland.

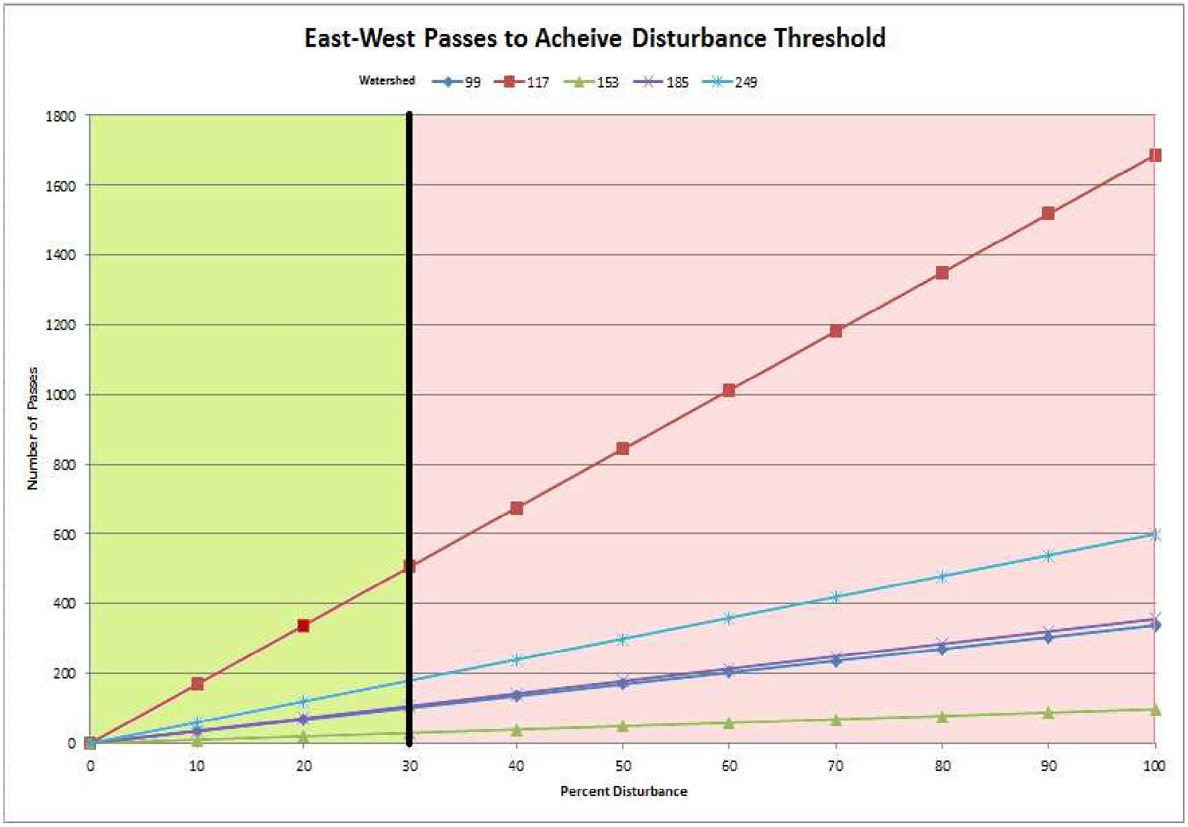


Table 36. Average number of east to west passes by an M1A2 abrams to a typical 30% disturbance percentage assumed for rangeland.

	East-West passes										
WS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
99	0	34	68	101	135	169	203	237	270	304	338
117	0	169	337	506	675	844	1012	1181	1350	1519	1687
153	0	10	20	29	39	49	59	68	78	88	98
185	0	36	71	107	143	178	214	249	285	321	356
249	0	60	120	180	240	300	360	420	480	540	599

Figure 35. Average number of north to south passes by an M1A2 abrams to achieve a typical 30% disturbance percentage assumed for rangeland, the green area depicts low erosion threat and the red area high erosion threat.

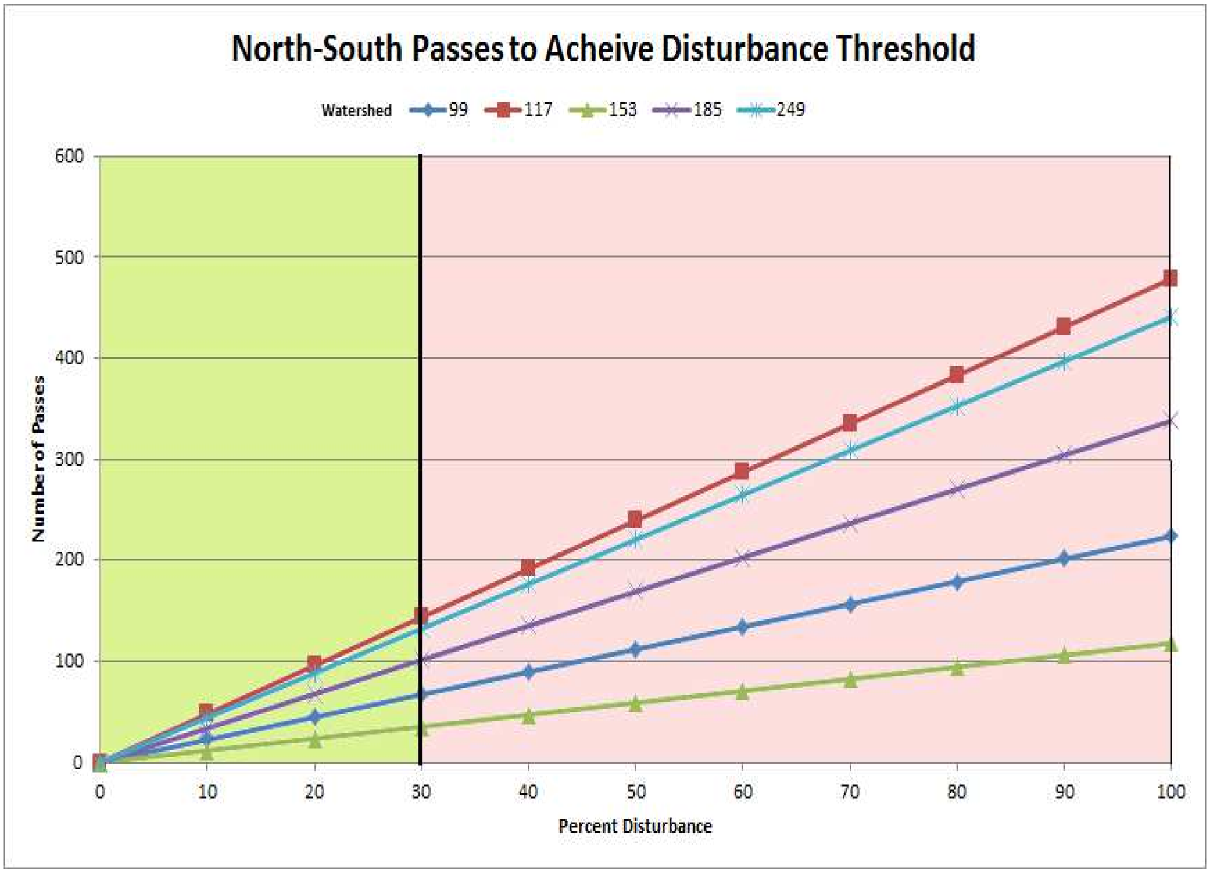


Table 37. Average number of east to west passes by an M1A2 abrams to achieve a typical 30% disturbance percentage assumed for rangeland.

	North-South passes										
WS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
99	0	22	45	67	90	112	134	157	179	201	224
117	0	48	96	144	192	239	287	335	383	431	479
153	0	12	24	35	47	59	71	83	94	106	118
185	0	34	68	101	135	169	203	237	270	304	338
249	0	44	88	132	176	221	265	309	353	397	441

Chapter 5 - Summary and Conclusions

Land disturbance created by military training significantly influences runoff and likewise erosion potential. This is due to decreased vegetative cover, decreased soil structure, loss of biota, and other land alterations caused by intensive training maneuvers. These alterations lead to decreased infiltration rates and water storage capacities within the soils which directly increase runoff. This can prove particularly problematic when considering gully formation, which can jeopardize the safety of soldiers training in damaged areas and decreases the overall health of the landscape and any waterways draining from those areas. This study showed that even very small increases in disturbance percentage lead to significant increases in runoff. At the first 10% increase in disturbance percentage for each training intensity and storm type, there was significant change to the runoff amount and rate. This first 10% increase in light use training for a 2-year storm showed a 6.8% increase in runoff amount and a 6.6% increase in runoff rate, this percent change only grew as disturbance percentage and training intensity were increased. Whenever training is done on Fort Riley, increased runoff can be expected downstream. This is compounded by the soil types on the fort being so susceptible to compaction. Most of the soils on Fort Riley are in hydrologic groups C and D, if more A and B type soils were present, less compaction could be expected, which would reduce increases in runoff potential.

This study used the NRCS program winTR-55 to model runoff data from military training lands on Fort Riley. No significant rain events occurred during the study period for model calibration and validation. Research objectives were to determine if the CN Method was sensitive enough to capture the differences in runoff potential for typical training operations and at what disturbance percentages and training intensities this change in runoff became statistically significant. CNs in TR-55 are used on an integer level, and so were not sensitive enough to accurately describe composite areas as they transitioned from undisturbed to disturbed conditions. CNs were derived from research studies and the similarities between certain training procedures and agricultural practices.

Five watersheds were selected for use as replications across the fort based on accessibility, size, and perceived training usage. Watershed selection played a key role in the analysis since flow rate is highly dependent on area. Because the five watersheds differed in area, slope, and stream length, they were not exact replications. This resulted in more varied responses for runoff rate than runoff amount due to the dependency of runoff rate on the relatively wide range of watershed areas considered.

Training types were broken into four categories: undisturbed, light use, moderate use and heavy use. Both runoff amount and peak runoff rate showed that with lower disturbance percentages, less than 30%, training intensities were not significantly different. Thus within the normal amounts of area disturbed for rangeland under military use (~33%) (Milchunas et al., 1999), the training intensities can be considered the same.

Disturbance percentages for each watershed were considered to increase from undisturbed conditions by increments of 10% of the total watershed area up to 100% disturbance. Each of the five watersheds was modeled in TR-55 and results in terms of runoff amount (mm) and peak runoff rate (m^3s^{-1}) were analyzed in terms of runoff response to training intensity and disturbance percentage with values from the watersheds used as replications. Both runoff amount (mm) and runoff rate showed significant change at every 10% increase in disturbance percentage.

Given that there were no rain events to calibrate and validate the proposed CNs, actual runoff could not be used to back calculate a CN from the sites and relate it to perceived training and disturbance percentages. In the future, given sizable rain events, this may be possible and more precise ranges of CNs created for the different training intensities. This could be done by relating the runoff amount (mm) back to the storage value (S), and then using that value to calculate the CN.

In the future, programs such as RiverMorph could also be used to link stream data to GIS to help automate the modeling process and to determine what storm size would be required for each watershed to create erosion in that channel (RiverMorph, 2012).

Runoff is the precursor to erosion, by monitoring abnormalities in runoff problematic areas for erosion can be pinpointed on a watershed scale. Once these areas are known, measures such as reduced training, restorative maintenance, or other best management practices can be implemented. Since we now know that any training on the fort will increased runoff amounts and peak runoff rates, preventative measures such a problem area mapping, more distributed training across the land, and other preventative measures will ultimately help to prevent gully formation in these problem areas. Reducing risks to soldiers and the environment is of paramount importance, and by being good stewards of the land we have, we can ensure a safe and productive future for the fort.

Bibliography

Althoff, D., P. Althoff, N. Lambrecht, P. Gipson, J. Pontius, and P. Woodford. 2007. Soil Properties and Perceived Disturbance of Grasslands Subjected to Mechanized Military Training: Evaluation of an Index. Land Degradation & Development 18: 269-288 (2007) 10.1002/ldr.773, John Wiley & Sons, Ltd. Online: http://dx.doi.org/10.1002/ldr.773.

Althoff, P., and S. Thien. 2005. "Impact of M1A1 Main Battle Tank Disturbance on Soil Quality, Invertebrates, and Vegetation Characteristics." Journal of Terramechanics 42.3-4 (2005): 159-76. Print

Anderson, A., A. Palazzo, P. Ayers, J. Fehmi, S. Shoop, and P. Sullivan. 2005. Assessing the Impacts of Military Vehicle Traffic on Natural Areas. Introduction to the Special Issue and Review of the Relevant Military Vehicle Impact Literature. Journal of Terramechanics 42.3-4 (2005): 143-58. Print.

Anderson, A., G Wang, S. Fang, G. Gertner, B. Guneralp, and D. Jones. 2005. Assessing and Predicting Changes in Vegetation Cover Associated with Military Land Use Activities using Field Monitoring Data at Fort Hood, Texas. *Journal of Terramechanics* 42.3-4 (2005): 207-29. Print.

Bhat S., K. Hatfield, J. Jacobs, and W. Graham. 2007. Relationships between military land use and storm-based indices on hydrologic variability. *Ecological Indicators 7* (2007) 553-564.

Boice, P. 1996. Managing Endangered Species on Military Lands. September 1996. Endangered Species Update. Available at: http://www.umich.edu/~esupdate /library/96.07-08/boice.html. Accessed 27 March 2012.

Carey, B. 2006. Gully Erosion. Natural Resources and Water, Facts: Land Series. Queensland Government, March 2006.

Collins, D., G. Tucker, N. Gasparini, and R. Bras. 2000. Application of a Landscape Evolution Model to Gully Management and Reclamation on Military Lands: Fort Carson, CO Case Study. Annual Report Submitted to the Army Research Office, March, 2000.

Defossez, P., and G. Richard. 2002. Models of soil compaction due to traffic and their evaluation. Soil and Tillage Research, 67 (2002) 41-64.

Delisle, J., C. Freeman, and D. Peterson. 2012. Vegetation Survey and Mapping of the Fort Riley Military Reservation, Kansas. Open-file Report No. 174. Kansas Biological Survey. Lawrence, KS. 78 pp.

Dept. of Ecology, Washington. 2012. Managing Vegetation on Coastal Slopes- Causes of Erosion. Available online at: http://www.ecy.wa.gov/programs/sea/pubs/93-31/chap1.html Accessed 21 May 2012.

Dix, S. 2011. "Environmental Concerns at Fort Riley Topic at MRC." The 1st Infantry Division Post August 8th, 2011. Available online at: http://www.fortrileypost.com/newsdetail.asp?article_id=5942. Accessed 27 March 2012.

DoA. 2011. Spill Prevention, Control, and Countermeasures Plan (SPCCP) and Installation Spill Contingency Plan (ISCP). Version 1. September, 2011.

DoD. 2006. U.S. Military Lands are Habitat for Hundreds of Species at Risk, Study Finds. Available at: http://www.natureserve.org/aboutUs/PressReleases/nr040824.pdf. Accessed 29 February 2012.

DoD. 2011. Natural Resources Conservation Program. DoD Reference No. 4715.03. Department of Defense, Instruction.

Dorsey, J. 2009. Curve Number Design Methodology. ODNR-DSWC. Available at: http://www.starkswcd.org/articles/CN_Design_Method.pdf Accessed: 20 April, 2013.

Dredging Specialists. Dredging 101-Hydraulic Dredging Costs. Mattoon, Illinois. Available online at: http://www.dredgingspecialists.com/Dredging101.htm Accessed 21 May 2012.

EPA. 1972. Clean Water Act. United States Environmental Protection Agency, Laws and Regulations. Available at: http://www.epa.gov/lawsregs/laws/cwa.html. Accessed 29 February 2012.

EPA. 1987. Clean Water Act Section 319. United States Environmental Protection Agency, Laws and Regulations. Available at: http://www.epa.gov/owow_keep/NPS/cwact.html. Accessed 29 February 2012.

US Army Corps of Engineers. 1999. Sensitivity Analysis of the Army Training and Testing Area Carrying Capacity (ATTACC) Model to User-specified Starting Parameters. US Army Corps of Engineers, Construction Engineering Research Laboratory. CERL Technical Report 99/64, July 1999.

ESRI. 2008. ArcGIS 9.2 Desktop Help, Flow Accumulation. Available online at: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=flow_accumulation. Accessed 14 January 2013.

Fang, S., G. Gertner, and A. Anderson. 2005. The Effect of Model Structure and Data in Modeling Land Conditions in Disturbed Complex Ecosystems. *Journal of environmental management* 85.1 (2007): 69-77. Print.

Flanagan, D., and J. Frankenberger. 2002. Water Erosion Prediction Project (WEPP) Window Interface Tutorial. USDA Agricultural Research Service & Purdue University. National Soil Erosion Research Laboratory. Accessed 2 April 2013. Available online at: http://www.ars.usda.gov/SP2UserFiles/ad_hoc/36021500WEPP/tutorial.pdf

FL Dept. of Environmental Protection. Blue-green Algae, Frequently asked questions. Available online at: http://www.dep.state.fl.us/water/bgalgae/faq.htm. Accessed 9 July 2012.

Foster, G. 1986. Understanding ephemeral gully erosion. Committee on conservation needs and opportunities. Soil Conservation Service: An Assessment of the National Resources Inventory, Volume 2.

Foster, J., P. Ayers, A. Lomardi-Przybylowicz, and K. Simmons. 2006. Initial Effects of Light Armored Vehicle use on Grassland Vegetation at Fort Lewis, Washington. *Journal of Environmental Management* 81.4 (2006): 315-22. Print.

Freeman, C. and J. Delisle. 2004. Vegetation of the Fort Riley Military Reservation. Kansas Biological Survey. Lawrence, KS.

Garten, C., T. Ashwood, V. Dale. 2003. Effect of military training on indicators of soil quality at Fort Benning, Georgia. Ecological Indicators 3 (2003) 171-179. Elsevier Ltd.

Gassman, P., M. Reyes, C. Green, and J. Arnold. 2006. The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. SWAT Invited Review Series. Accessed 2 April 2013. Available online at: http://www.card.iastate.edu/ environment/items/asabe_swat.pdf

Handley, K. 2011. Gully Erosion Assessment and Prediction on Non-Agricultural Lands using Logistic Regression. Kansas State University, Department of Biological and Agricultural Engineering.

Haugen, L., P. Ayers, and A. Anderson. 2003. Vehicle Movement Patterns and Vegetative Impacts during Military Training Exercises. *Journal of Terramechanics* 40.2 (2003): 83-95. Print.

INRMP. 2010. Fort Riley Integrated Natural Resources Management Plan. Fort Riley, Kansas. 4.4.1 Grassland Management, April 13th, 2010.

Johnson, S., G. Wang, H. Howard, and A. Anderson. 2010. Identification of Superfluous Roads in Terms of Sustainable Military Land Carrying Capacity and Environment. *Journal of Terramechanics* 48.2 (2011): 97-104. Print.

Jones, D., D. Kowalski, and R. Shaw. 1996. Calculating Revised Universal Soil Loss Equation (RUSLE) Estimates on Department of Defense Lands: A Review of RUSLE Factors and U.S. Army Land Condition-Trend Analysis (LCTA) Data Gaps. Center for ecological management of military lands. Department of Forest Science, Colorado state university.

Accessed 2 April 2013. Available online at: http://www.cemml.colostate.edu /assets/pdf/ tps-96-8.pdf

KDHE. 2010. Kansas Nonpoint Source Pollution Management Plan 2010 Update. Kansas Department of Health and Environment, Division of Environment, Bureau of Water. Available at: http://www.kdheks.gov/nps/resources/KSNPSMgmtPlan_04-29-2011_final.pdf. Accessed 29 February 2012.

KSU. 2011. Weather Data Library, Riley County. K-State Research and Extension. Available online at: http://www.ksre.ksu.edu/wdl/precip%20files/rl_p.asp. Accessed 27 April 2012.

Kun, L., P. Ayers, H. Howard, and A. Anderson, Influence of turning radius on wheeled military vehicle induced rut formation. *Journal of Terramechanics* Volume 46, Issue 2, April 2009, Pages 49-55, ISSN 0022-4898, 10.1016/j.jterra.2009.02.004.

KWO. 2007. Kansas-Lower Republican Basin. Available online at: http://www.kwo.org/Kansas_Water_Plan/KWP_Docs/VolumeIII/KLR/KLR_Atlas/map_kr_KWP_basemap_120607_tr.pdf. Accessed 22 May 2012.

LMNO Engineering. 1999. Hydrologic calculation for storm runoff discharge and curve numbers for watersheds. LMNO Engineering, Research, and Software, Ltd. Athens, Ohio. Available at: http://www.lmnoeng.com/Hydrology/hydrology.htm. Accessed 20 April, 2013.

McCuen, R., and J. Spiess. 1995. Assessment of kinematic wave time of concentration. Journal of Hydraulic Engineering, 121, 256-266.

Mendoza, G., A. Anderson, and G. Gertner. 2002. Integrating Multi-criteria Analysis and GIS for Land Condition Assessment: Part II- Allocation of Military Training Areas. *Journal of Geographic Information and Decision Analysis* Volume 6, No.1, Pages 17-30.

Milchunas, D., K. Schulz, and R. Shaw. 1999. Plant and Environmental Interactions. *Journal of Environmental Quality* 28:1533-1547.

Milner, B. 2009. A comparison of Tuttle Creek Reservoir and Milford Lake. Available online at: http://academic.emporia.edu/aberjame/student/milner2/Imagewebpage.htm. Accessed 22 May 2012.

Mishra, S., and V. Singh. (2003). Water Science and Technology Library: Soil Conservation Service CN (SCS-CN) Methodology. Netherlands: Kluwer Academic Publishers.

Misha, S., and V. Singh. 2004. Validity and Extension of the SCS-CN Method for Computing Infiltration Rate and Rainfall-Excess Rates. *Hydrologic Processes* 18, 3323-3345.

Nimmo, J. 2004. Porosity and Pore Size Distribution. U.S. Geological Survey. Encyclopedia of Soils in the Environment: London, Elsevier, v. 3, p. 295-303. Available online at: http://wwwr camnl.wr.usgs.gov/uzf/abs_pubs/papers/nimmo.04.encyc.por.ese.pdf. Accessed 9 May 2012.

NRCS. 2004. National Engineering Handbook, Part 630 Hydrology. United States Department of Agriculture, Natural Resource Conservation Service. Chapter 10, Estimation of Direct Runoff from Storm Rainfall.

NRCS. 2007. National Engineering Handbook, Part 630 Hydrology. United States Department of Agriculture, Natural Resource Conservation Service. Chapter 7, Hydrologic Soil Groups.

Ongley, E. 1996. Control of water pollution from agriculture- FAO irrigation and drainage paper 55. Natural Resources Management and Environment Department. GEMS/Water Collaborating Centre, Canada Centre for Inland Waters, Burlington, Canada.

Oxford, A. and E. Oxford. 2010. Chemistry in Soil-Plant Relationships. Alaska Agriculture in the Classroom, Agriculture in the classroom consortium and USDA. Available on line at: www.alaskafb.org/~akaitc/alaskaAITC/pdf/9_12/chemistry_ soil.pdf. Accessed 18 May 2012.

Perkins, D., N. Haws, J. Jawitz, B. Das, and P. Rao. 2007. Soil hydraulic properties as ecological indicators in forested watersheds impacted by mechanized military training, Ecological Indicators, Volume 7, Issue 3, July 2007, Pages 589-597, ISSN 1470-160X, 10.1016/j.ecolind.2006.07.003.

Raper, R., E. Schwab, S. Dabney. 2005. Measurement and variation of site-specific hardpans for silty upland soils in the Southeastern United States. Soil & Tillage Research 84 (2005) 7-17.

RiverMorph. 2012. RiverMorph Stream Restoration Software. Available at: http://www.rivermorph.com/index.php?p=1_2_Information. Accessed: 20 April 2013.

SAS. 2013. Base SAS® 9.3. Help and Documentation, Cary, NC: SAS Institute Inc. 2011.

SSURGO. 2012. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database for Fort Riley, Kansas. Available online at http://soildatamart.nrcs.usda.gov. Accessed 1 May, 2012.

Stitcher, P. 2010. “Like Hollow Point Bullets from the Sky- Combating Rain Splash Erosion”, *Restoring Utopia*. Available online at: http://restoringutopia.blogspot.com /2010/07/like-hollow-point-bullets-from-sky.html Accessed 21 May 2011.

Stone R. and D. Hilborn. 2000. Universal Soil Loss Equation. Factsheet. Ontario Minitstry of Agriculture, Food and Rural Affairs. Order no. 00-001, May 2001.

Swank, W. 1968. The influence of rainfall interception on streamflow. Water Resource Inst. Rep. 4. Clemson University, S.C. pp 101-112.

Torri, D. and B. Lorenzo. 2003. Equation for high-rate gully erosion. Elsevier Science, Catena 50 (2003) 449-467.

The Armor Site. 2012. M1A1/2 Abrams: The M1 Abrams MBT. Available Online at: http://www.fprado.com/armorsite/abrams.htm. Accessed 28 October 2012.

U.S. Army. 2011. Environmental assessment, New Fort Riley Elementary School, U.S. Army Garrison Fort Riley, Kansas.

U.S. Census. 2008. Kansas Data Access and Support Center. Census Military Boundaries. Available online at: http://www.kansasgis.org/catalog/index.cfm. Accessed 1 May, 2012.

U.S. Climate Data. 2012. Climate – Manhattan – Kansas. Available online at: http://www. usclimatedata.com/climate.php?location=USKS0358, Accessed 7 August 2012.

U.S. EPA. 2010. 2010 Waterbody Report for Milford Lake. Available online at: http://iaspub.epa.gov/tmdl_waters10/attains_waterbody.control?p_list_id=KS-KR-17-LM019001&p_cycle=2010&p_state=KS&p_report_type=T. Accessed 22 May 2012.

USDA SCS. 1975. Soil Survey of Riley County and Part of Geary County, Kansas. United States Department of Agriculture Soil Conservation Service in Cooperation with Kansas Agricultural Experiment Station.

USDA. 1986. Urban Hydrology for Small Watersheds. United States Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division. Technical Release 55, June 1986.

USDA. 1997. Changes in Erosion, 1982- 1997. National Resources Inventory, 1997.

USDA. 2001. Rangeland Soil Quality- Water Erosion. Soil Quality Information Sheet. Rangeland Sheet 9, May 2001. USDA, Natural Resources Conservation Service.

USDA. 2013. WinTR-55 Watershed Hydrology. United States Department of Agriculture, Natural Resources Conservation Service. Available at: http://www.nrcs.usda.gov /wps/portal/nrcs/detailfull/national/water/?&cid=stelprdb1042901. Accessed 20 April 2013.

USGS. 2009. Small Watershed Hydrology, WinTR-55 User Guide. United States Department of Agriculture, Natural Resources Conservation Service, Conservation of Engineering Division.

USGS. 2012. The National Map Viewer. Available online at: http://viewer.nationalmap.gov/viewer/. Accessed 1 October, 2012.

Virginia Dept. of Conservation and Recreation. 2012. Stormwater Management, Chapter 4, Hydrologic Methods. Available at: http://www.dcr.virginia.gov/stormwater_management/documents/Chapter_4.pdf. Accessed: 1 December, 2012.

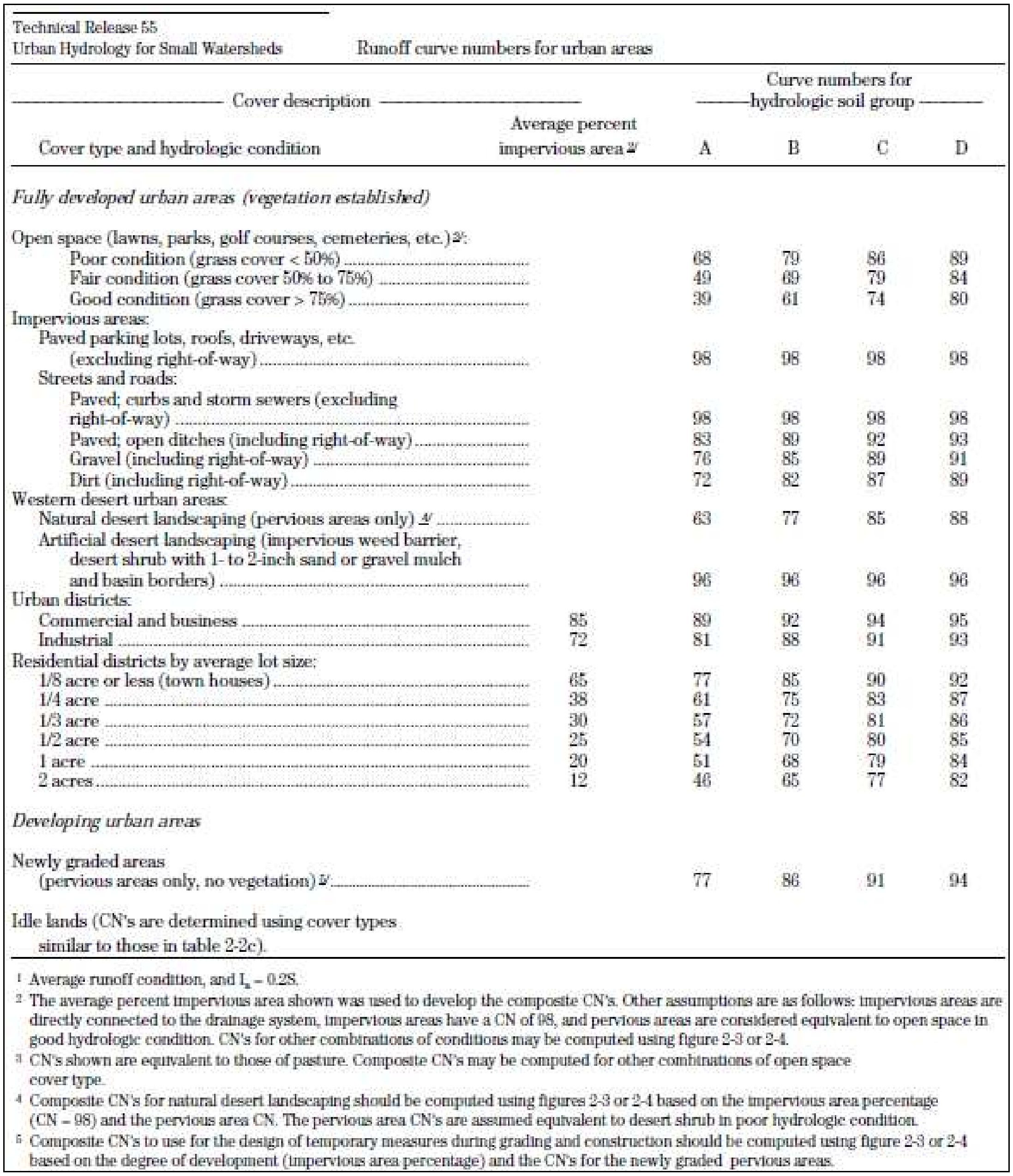
Wang G., G. Gertner, A. Anderson, and H. Howard. 2009. Simulating Spatial Pattern and Dynamics of Military Training Impacts for Allocation of Land Repair Using Images.

Environmental Management (2009) 44:810-823 DOI 10.1007/s00267-009-9363-z. Springer Science and Business Media, LLC 2009. Published online: 26 August 2009.

Ward, A., and S. Trimble. Environmental Hydrology, Second Edition. CRC Press LLC, 2004.

Appendix A - Research Data

Figure A. 1. NRCS CNs.



Technical Release 55
Urban Hydrology for Small Watersheds

Runoff curve numbers for urban areas

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1] Average runoff condition, and $I_a = 0.2S$.

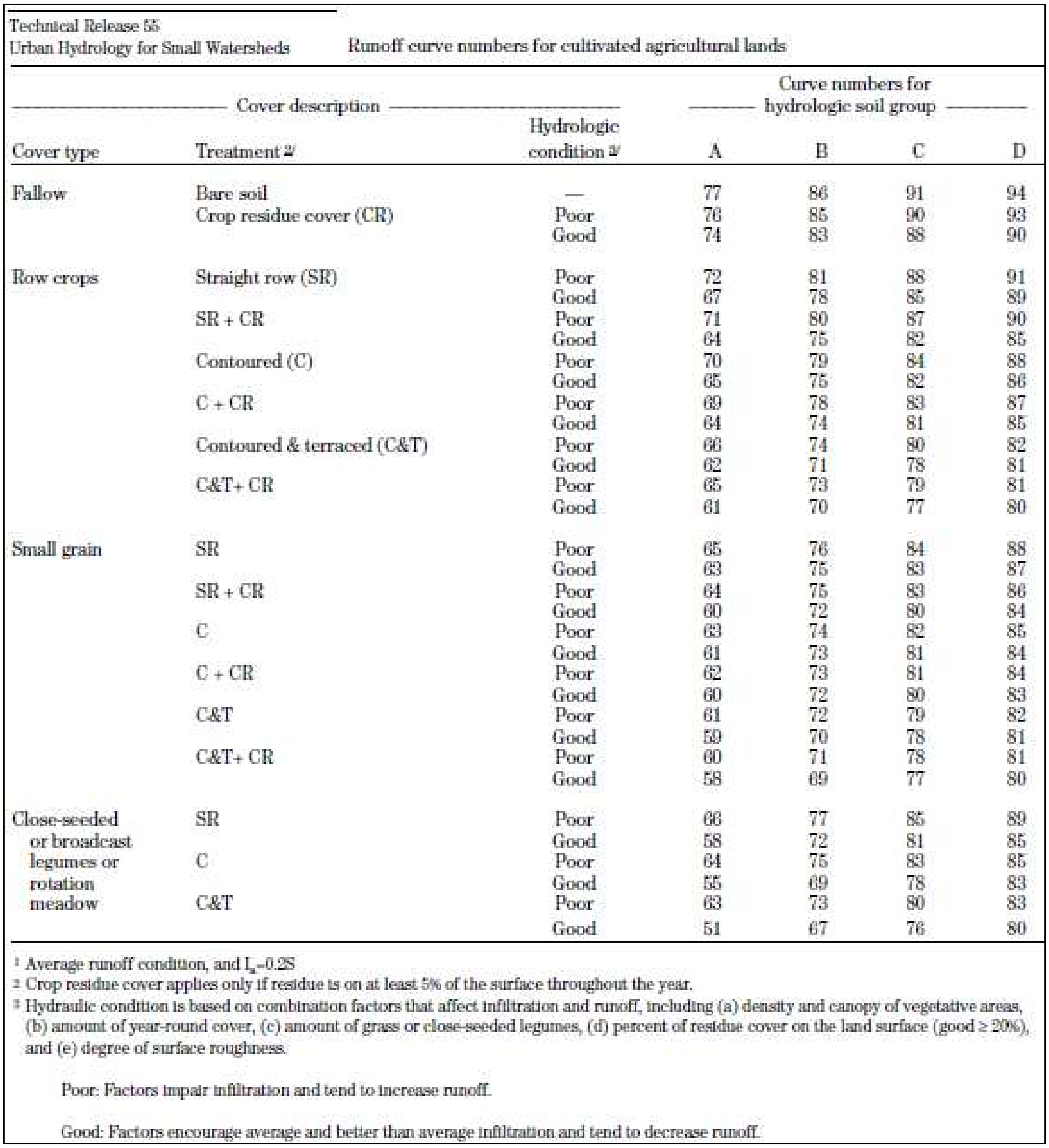
[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Figure A. 2. NRCS CNs.



Technical Release 55
Urban Hydrology for Small Watersheds

Runoff curve numbers for cultivated agricultural lands

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition, and I_a=0.2S

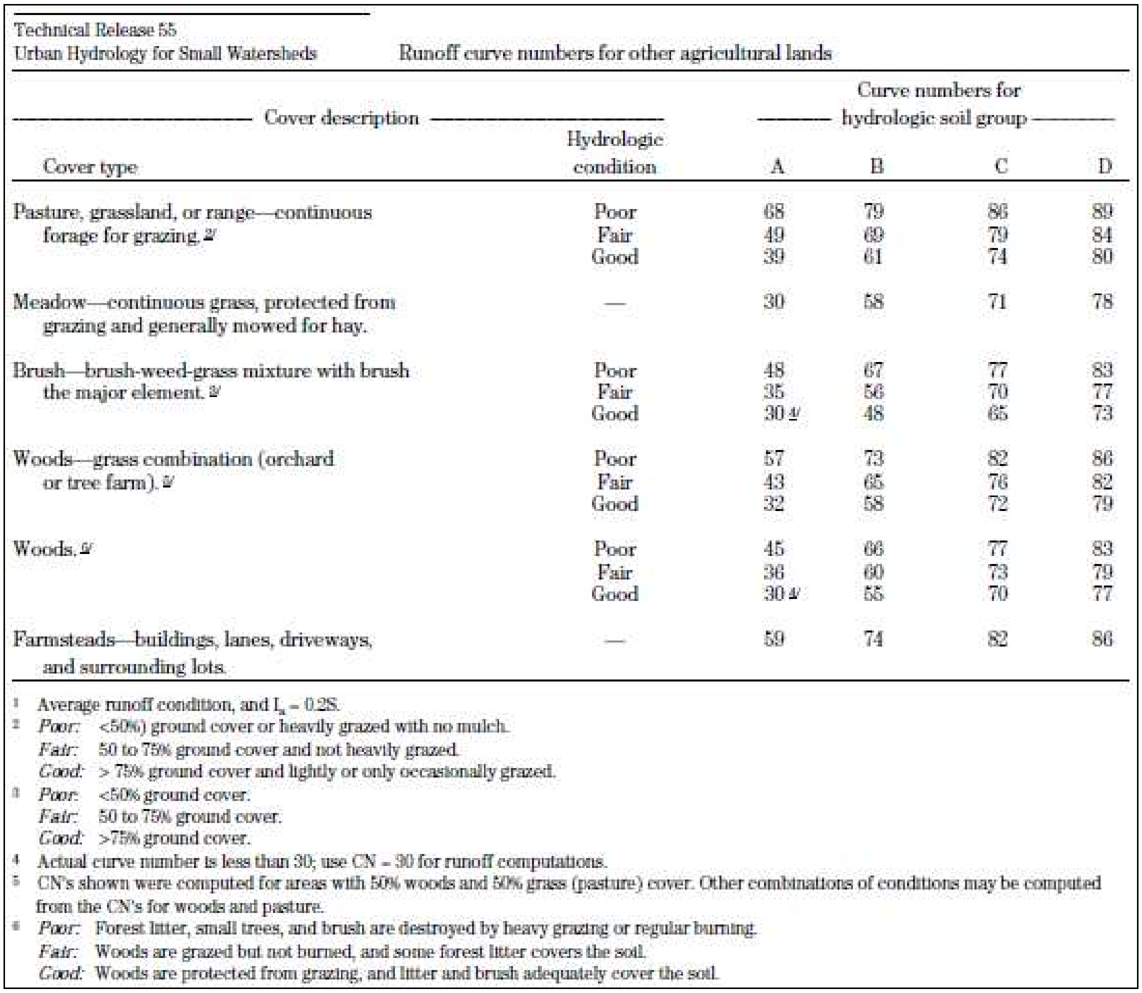
[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

[3] Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Figure A. 3. NRCS CNs.



Technical Release 55
Urban Hydrology for Small Watersheds

Runoff curve numbers for other agricultural lands

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1] Average runoff condition, and $I_a = 0.2S$.

[2] *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

[3] *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4] Actual curve number is less than 30; use CN = 30 for runoff computations.

[5] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6] *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Appendix B - Experimental Data

Figure B. 1. Watershed delineation through ArcMap 10 Model Builder.

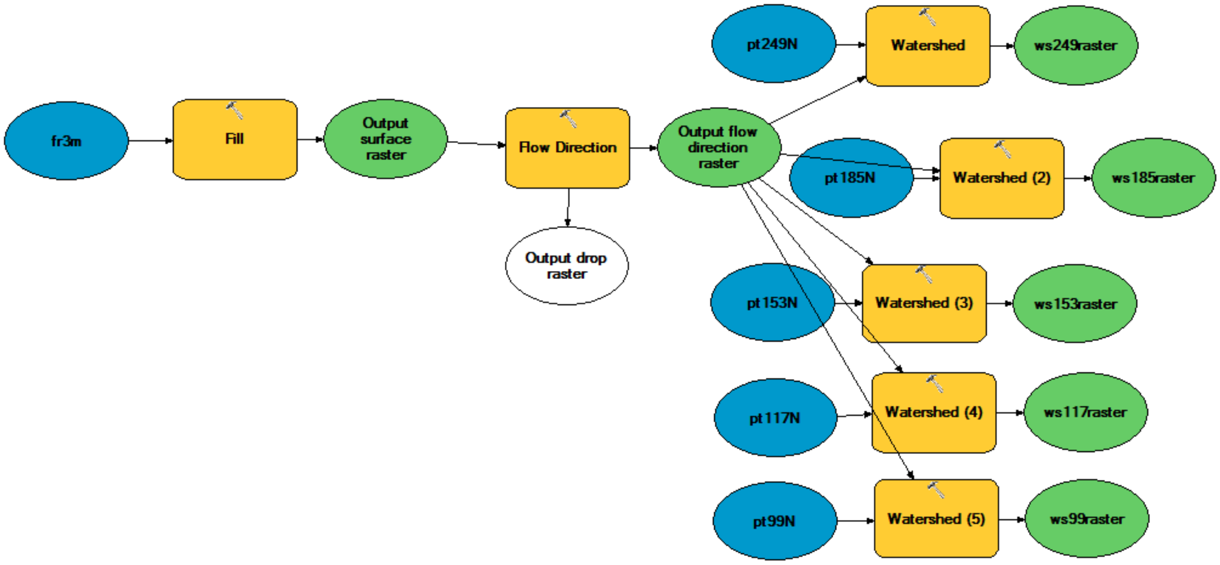


Figure B. 2. Stream delineation for sample watershed in ArcMap 10 ModelBuilder.

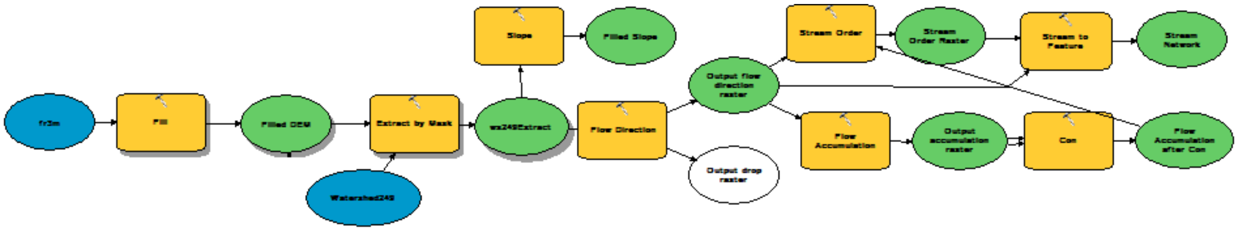
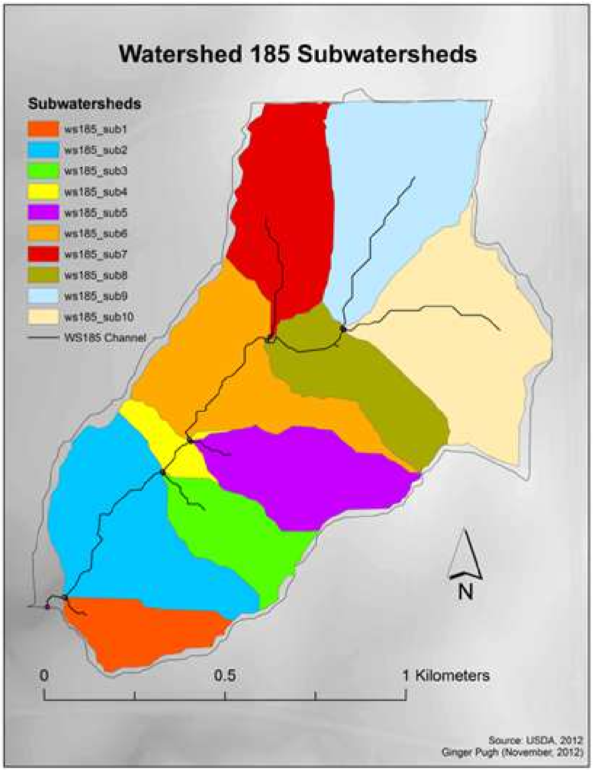
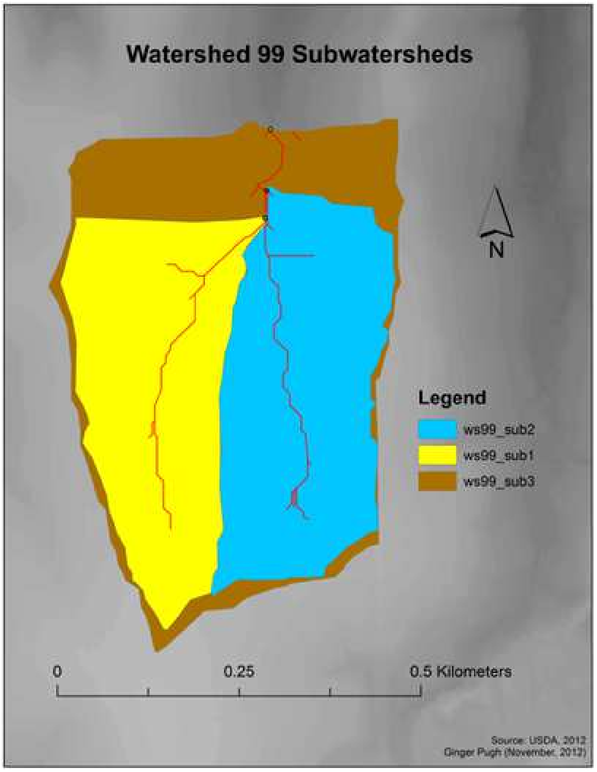


Figure B. 3. WS 185 subwatersheds delineated from a 3-meter DEM.



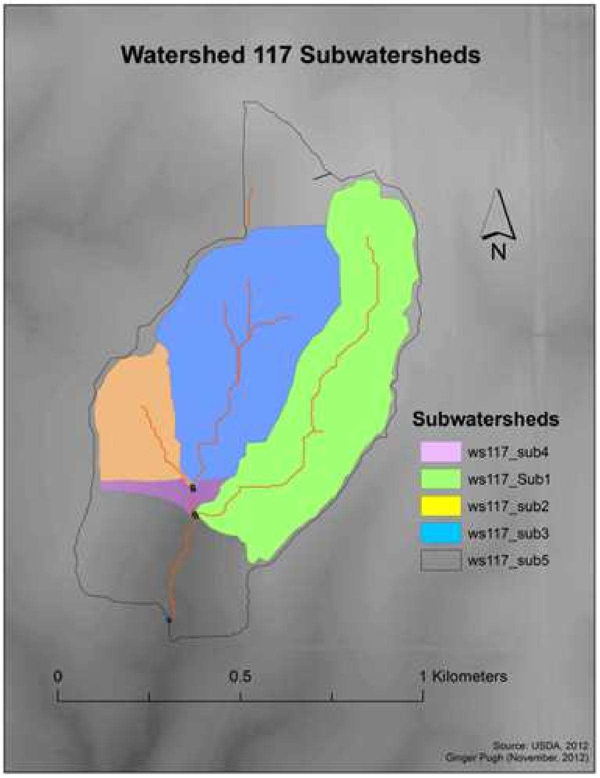
Source: USDA, 2012
Ginger Pugh (November, 2012)

Figure B. 4. WS 99 subwatersheds delineated from a 3-meter DEM.



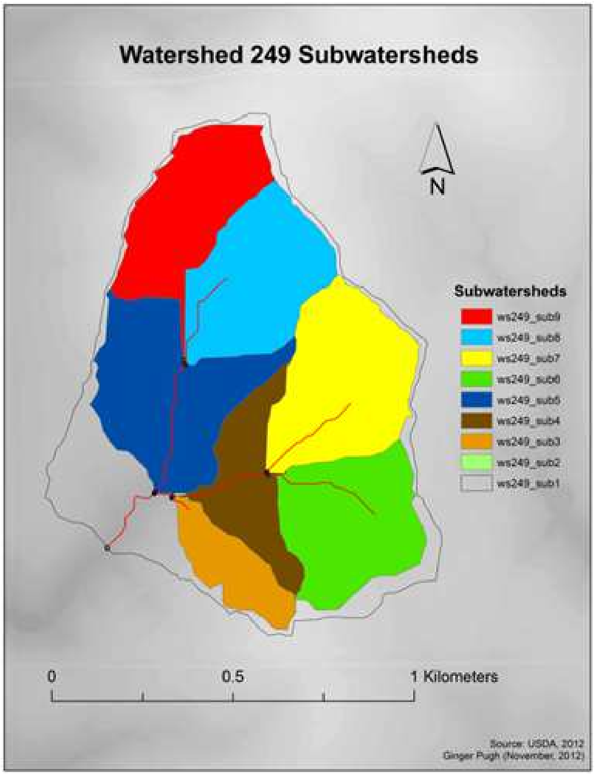
Source: USDA, 2012
Ginger Pugh (November, 2012)

Figure B. 5. WS 117 Subwatersheds delineated from a 3-meter DEM.



Source: USDA, 2012
Ginger Pugh (November, 2012)

Figure B. 6. WS 249 subwatersheds delineated from a 3-meter DEM.



Source: USDA, 2012
Ginger Pugh (November, 2012)

Figure B. 7. WS 153 subwatersheds delineated from a 3-meter DEM.

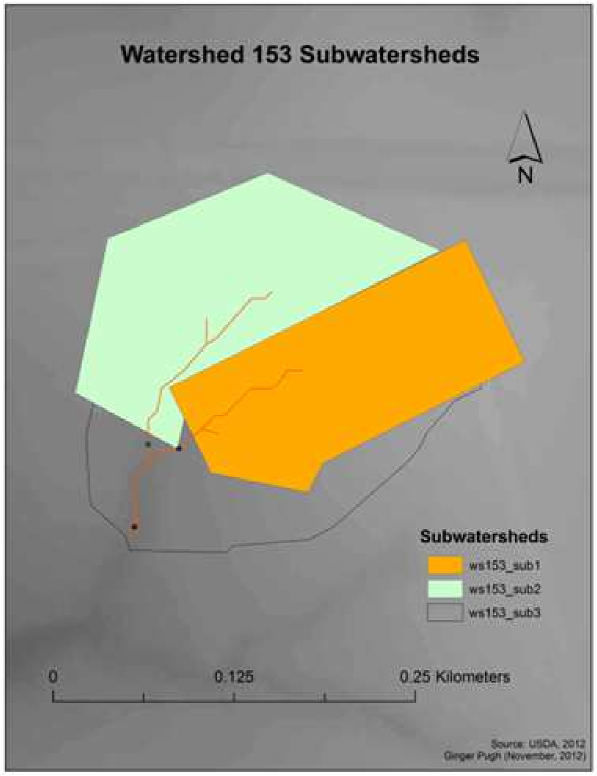


Figure B. 8. WS 185 flow classes derived from a 3-meter DEM.

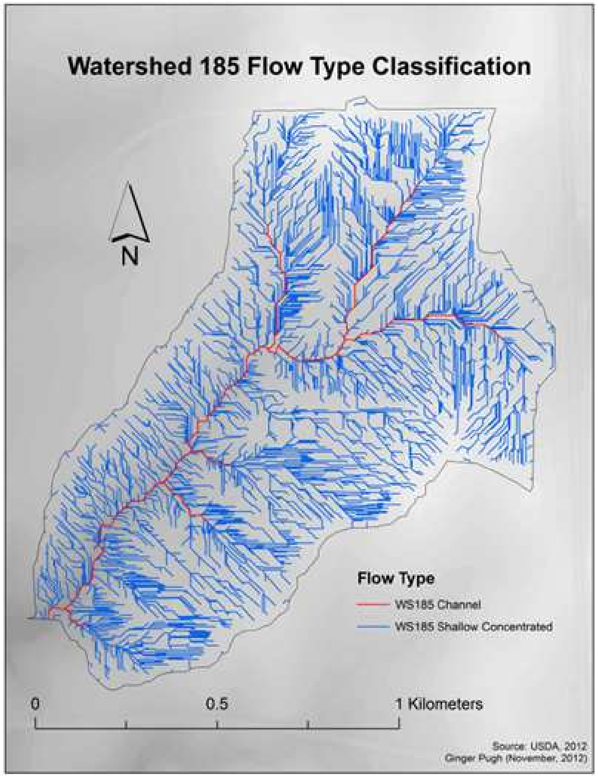


Figure B. 9. WS 99 flow classes derived from a 3-meter DEM.

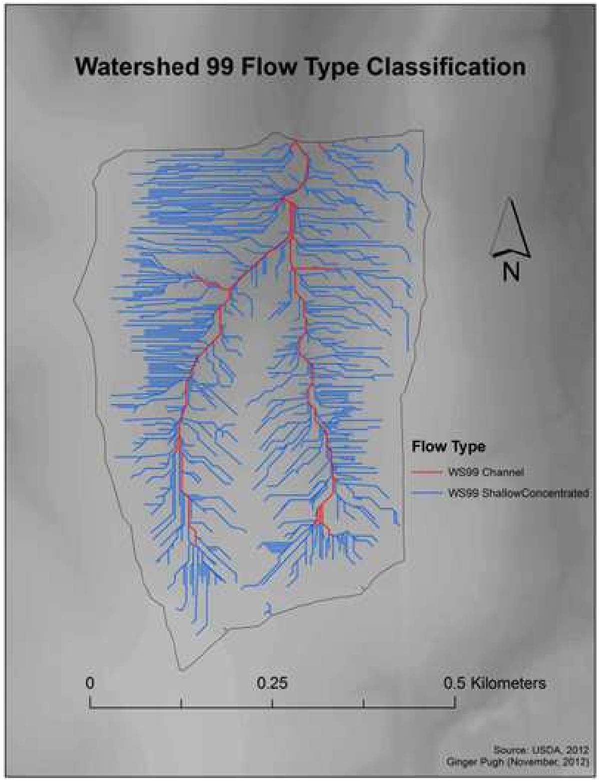


Figure B. 10. WS 117 flow classes derived from a 3-meter DEM.

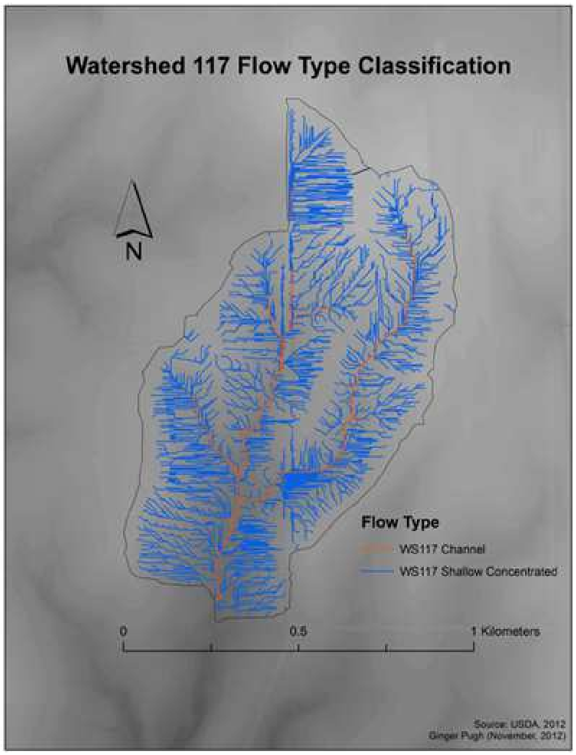


Figure B. 11. WS 153 flow classes derived from a 3-meter DEM.

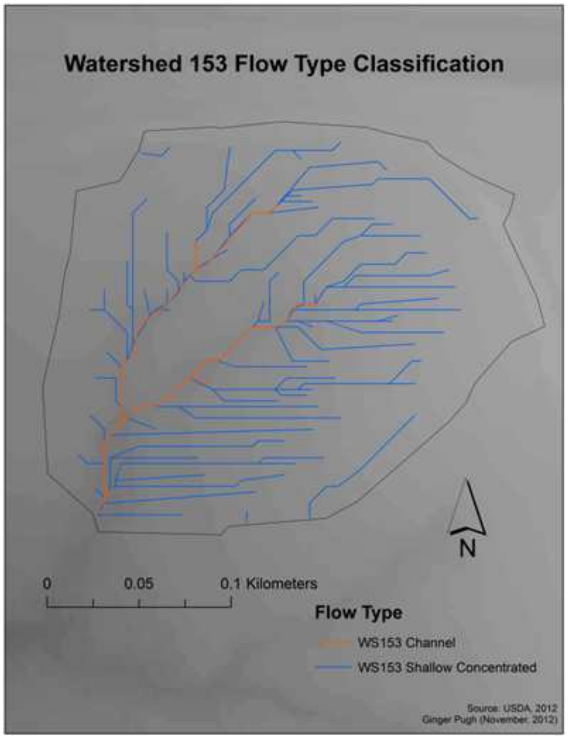


Figure B. 12. WS 249 flow classes derived from a 3-meter DEM.

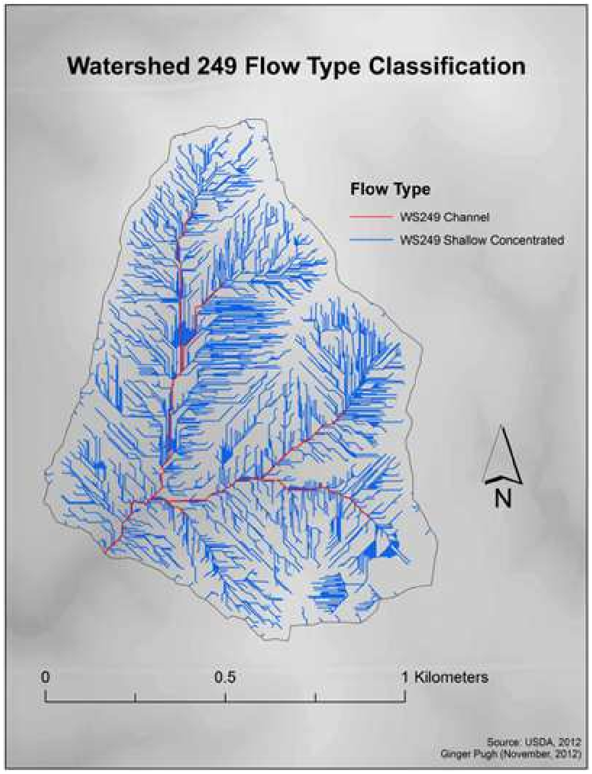


Figure B. 13. WS 99 cross section from on-site stream analysis.

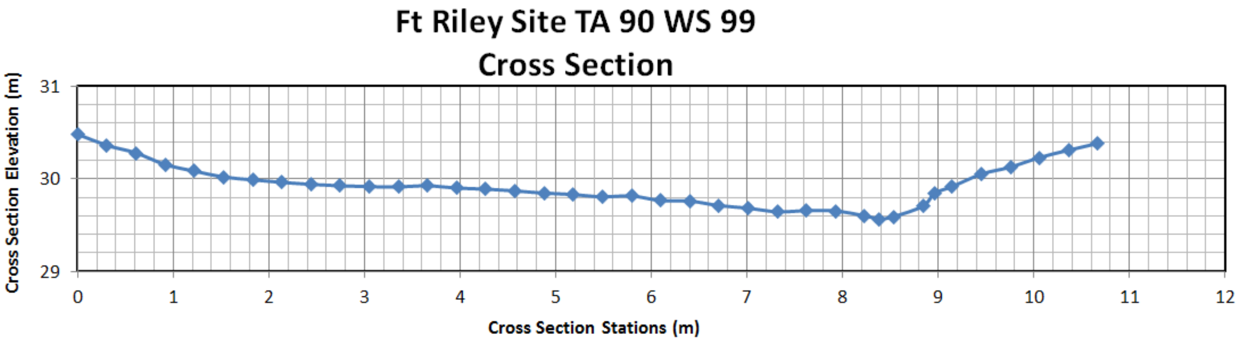


Figure B. 14. WS 117 cross section from on-site stream analysis.

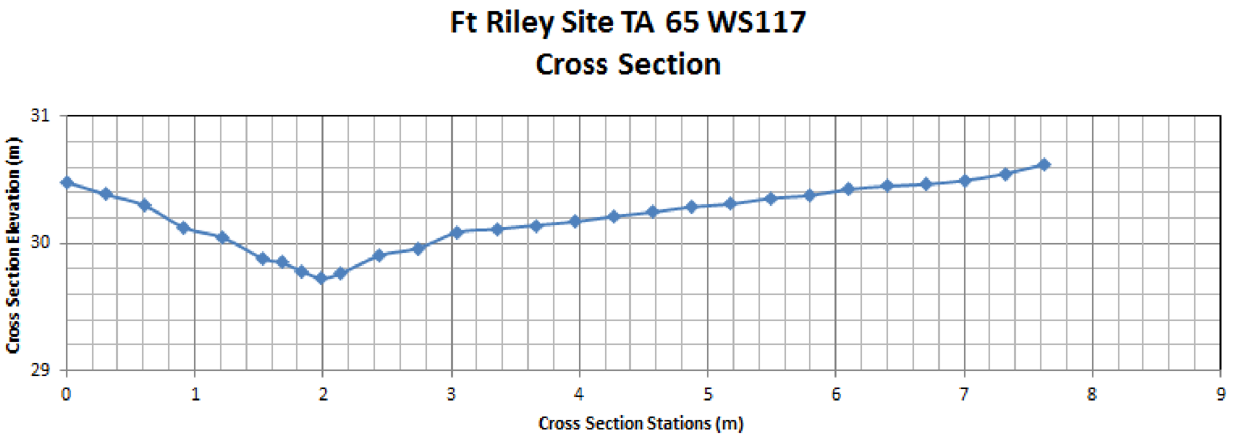


Figure B. 15. WS 153 cross section from on-site stream analysis.

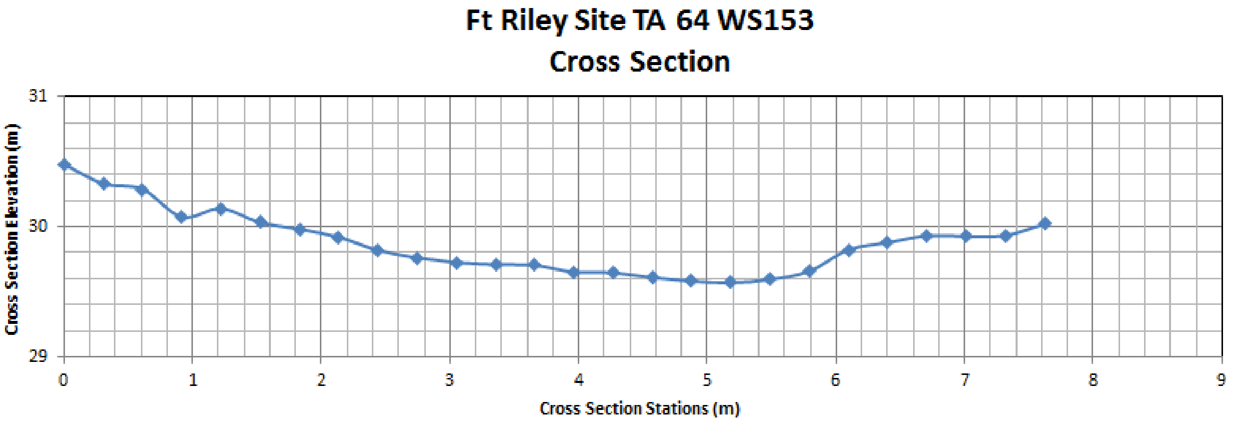


Figure B. 16. WS 185 cross section from on-site stream analysis.

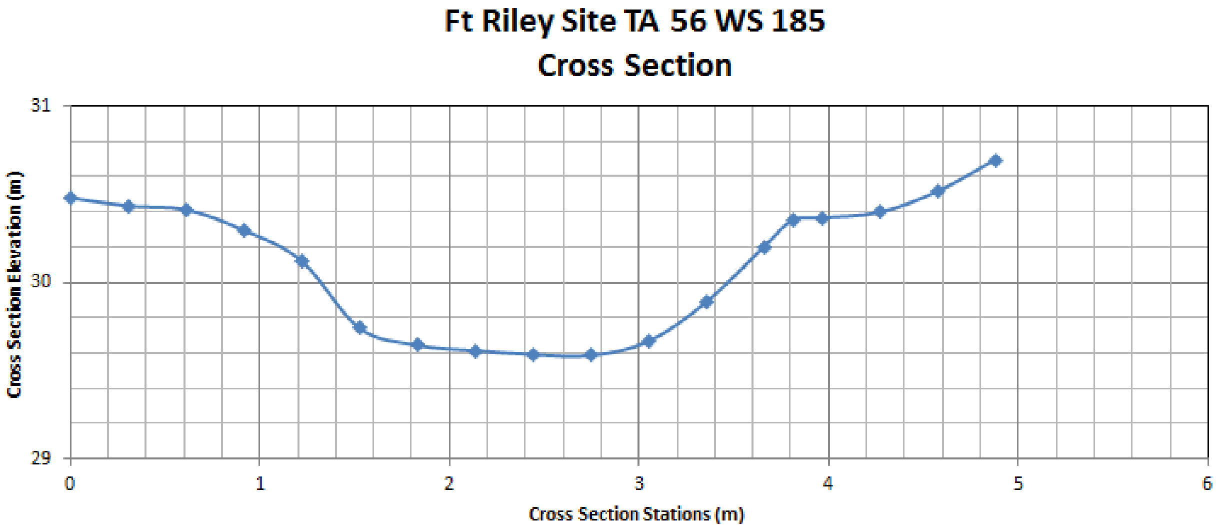


Figure B. 17. WS 249 cross section from on-site stream analysis.

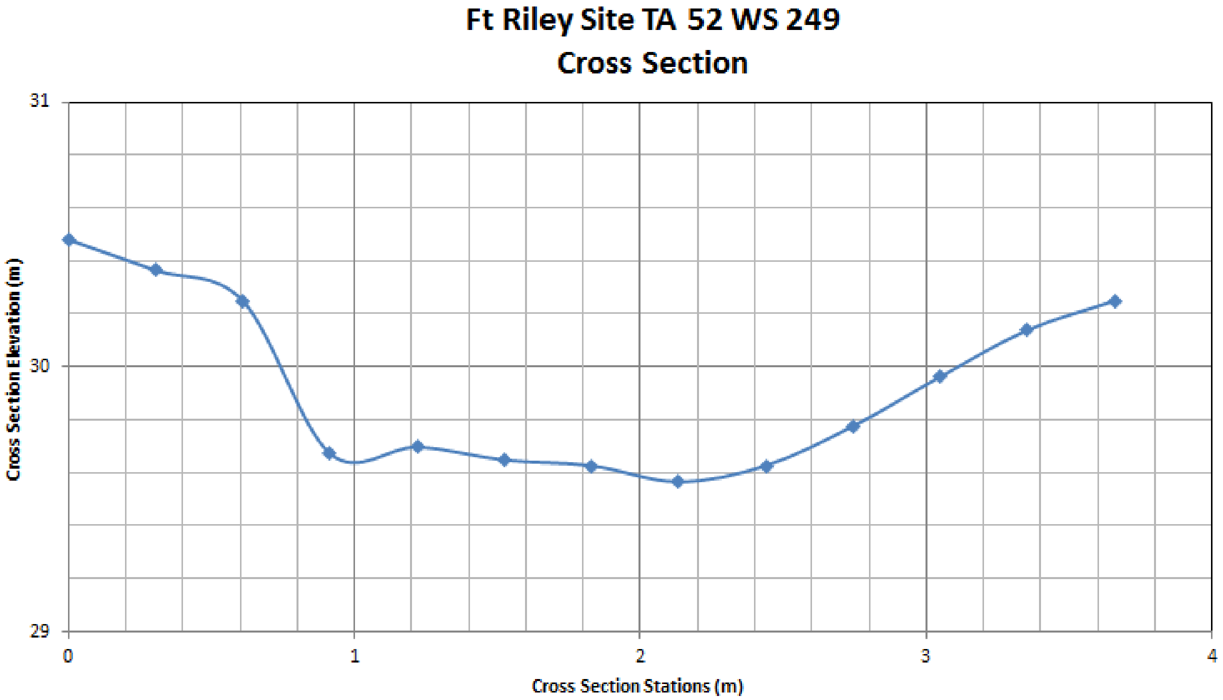


Table B. 1. TR-55 inputs for initial CN response analysis.

WinTR-55: Inputs	
User	Pugh
Project	Fort Riley
Subtitle	Trial 1
State	Kansas
County	Riley
Sub-areas expressed in	Acres
Dimensionless Unit Hydrograph	Standard
Storm Data Source	Riley County, KS (NRCS)
Rainfall Distribution Identifier	Type II
Land Use Details	
Area	247 acres
Curve Number	Variable from 30-98
Time of Concentration Details	
Sub-area Name	Undisturbed
Sheet flow Length	77 feet
Sheet flow slope	0.01
Sheet flow Surface (Manning's n)	Range, Natural (0.13)
Sheet flow Time of concentration	0.154 hours
Shallow concentrated Length	30 feet
Shallow concentrated Slope	0.01
Shallow concentrated Surface (Manning's n)	Unpaved
Shallow concentrated TOC	0.005
Channel length	50 feet
Channel Velocity	5 ft/s
Channel TOC	.003 hr
Total length	157 feet
Total velocity	.2692 ft/s
Total TOC	0.162 hours
Reach Data	
Reach Name	Reach 1
Receiving Reach	Outlet
Reach Length (ft)	50
Manning n	0.09
Friction slope (ft/ft)	0.01
Bottom Width (ft)	2
Average Side Slopes	2: 1
Storm Data Source	
NRCS Storm Data	Riley County, KS
Rainfall Distribution Type	Type II

Figure B. 18. SAS code for runoff analyses by Cassandra Kaul, KSU Dept. of Statistics.

SAS code for running statistical analysis

```
data ginger;
     input ws$ ti$ dist runoff @@;
datalines;
INSERT DATA HERE
;
title 'Analysis for 2 year storm';

proc glimmix data=ginger;
     class ws ti dist;
     model runoff = ws ti dist ti*dist ws*ti ws*dist;
     output out=new resid=r;

     lsmeans ws ti dist ti*dist ws*ti ws*dist/cl;

     lsmeans ws/pdiff adjust=tukey;
     lsmeans dist/pdiff=control('0') adjust=tukey;
     lsmeans ti/pdiff=control('M') adjust=tukey;

     lsmeans ti*dist/slice=ti slicediff=(ti dist)
slicedifftype=control('M' '0');
     lsmeans ws*dist/slice=ws slicediff=ws;
     lsmeans ws*ti/slice=ws slicediff=(ws ti) slicedifftype =
control('WS_99' 'M');
     ods output LSmeans=new2;
run;

ods graphics on;
ods select MeanPlot;
```

```
proc glimmix data=ginger;
     class ws ti dist;
     model runoff = ws ti dist ti*dist ws*ti ws*dist;
     lsmeans ti*dist/diff=control('M' '0') plot=mean(sliceby=ti
join);
     lsmeans ws*dist/diff=control ('WS_99' '0')
plot=mean(sliceby=ws join);
     lsmeans ws*ti/diff=control('WS_99' 'M')
plot=mean(sliceby=ws join);
run;

ods graphics off;
proc univariate normal plot data=new;
     var r;
run;
```

Table B. 2. Disturbance percentage and training intensity square means simple effects comparison of runoff amount by training intensity: 2-year storm.

Simple Effect Comparisons of ti*dist Least Squares Means By ti							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ti H	**10**	**0**	0.3880	0.3003	80	1.29	0.2001
ti H	**20**	**0**	1.1940	0.3003	80	3.98	0.0002
ti H	**30**	**0**	1.6120	0.3003	80	5.37	<.0001
ti H	**40**	**0**	2.4660	0.3003	80	8.21	<.0001
ti H	**50**	**0**	2.9020	0.3003	80	9.66	<.0001
ti H	**60**	**0**	3.3500	0.3003	80	11.15	<.0001
ti H	**70**	**0**	4.2500	0.3003	80	14.15	<.0001
ti H	**80**	**0**	4.7720	0.3003	80	15.89	<.0001
ti H	**90**	**0**	5.6700	0.3003	80	18.88	<.0001
ti H	**100**	**0**	6.1480	0.3003	80	20.47	<.0001

Simple Effect Comparisons of ti*dist Least Squares Means By ti							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ti L	**10**	**0**	0.3880	0.3003	80	1.29	0.2001
ti L	**20**	**0**	0.3880	0.3003	80	1.29	0.2001
ti L	**30**	**0**	0.7860	0.3003	80	2.62	0.0106
ti L	**40**	**0**	0.7860	0.3003	80	2.62	0.0106
ti L	**50**	**0**	1.1940	0.3003	80	3.98	0.0002
ti L	**60**	**0**	1.1940	0.3003	80	3.98	0.0002
ti L	**70**	**0**	1.6120	0.3003	80	5.37	<.0001
ti L	**80**	**0**	1.6120	0.3003	80	5.37	<.0001
ti L	**90**	**0**	2.0380	0.3003	80	6.79	<.0001
ti L	**100**	**0**	2.0380	0.3003	80	6.79	<.0001
ti M	**10**	**0**	0.3880	0.3003	80	1.29	0.2001
ti M	**20**	**0**	0.7860	0.3003	80	2.62	0.0106
ti M	**30**	**0**	1.6120	0.3003	80	5.37	<.0001
ti M	**40**	**0**	2.0380	0.3003	80	6.79	<.0001
ti M	**50**	**0**	2.4660	0.3003	80	8.21	<.0001
ti M	**60**	**0**	2.9020	0.3003	80	9.66	<.0001
ti M	**70**	**0**	3.3500	0.3003	80	11.15	<.0001
ti M	**80**	**0**	4.2500	0.3003	80	14.15	<.0001
ti M	**90**	**0**	4.7720	0.3003	80	15.89	<.0001
ti M	**100**	**0**	5.1900	0.3003	80	17.28	<.0001

Table B. 3. Disturbance percentage and watershed least square means simple effects comparison of runoff amount by watershed: 10-year storm.

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_117	0	10	-2.1320	0.4869	80	-4.38	<.0001
ws WS_117	0	20	-4.3123	0.4869	80	-8.86	<.0001
ws WS_117	0	30	-7.2567	0.4869	80	-14.90	<.0001
ws WS_117	0	40	-9.5627	0.4869	80	-19.64	<.0001
ws WS_117	0	50	-11.8743	0.4869	80	-24.39	<.0001
ws WS_117	0	60	-13.4507	0.4869	80	-27.62	<.0001
ws WS_117	0	70	-16.5737	0.4869	80	-34.04	<.0001
ws WS_117	0	80	-18.9767	0.4869	80	-38.97	<.0001
ws WS_117	0	90	-22.2080	0.4869	80	-45.61	<.0001
ws WS_117	0	100	-23.8973	0.4869	80	-49.08	<.0001
ws WS_117	10	20	-2.1803	0.4869	80	-4.48	<.0001
ws WS_117	10	30	-5.1247	0.4869	80	-10.52	<.0001
ws WS_117	10	40	-7.4307	0.4869	80	-15.26	<.0001
ws WS_117	10	50	-9.7423	0.4869	80	-20.01	<.0001
ws WS_117	10	60	-11.3187	0.4869	80	-23.25	<.0001
ws WS_117	10	70	-14.4417	0.4869	80	-29.66	<.0001
ws WS_117	10	80	-16.8447	0.4869	80	-34.59	<.0001
ws WS_117	10	90	-20.0760	0.4869	80	-41.23	<.0001
ws WS_117	10	100	-21.7653	0.4869	80	-44.70	<.0001
ws WS_117	20	30	-2.9443	0.4869	80	-6.05	<.0001
ws WS_117	20	40	-5.2503	0.4869	80	-10.78	<.0001
ws WS_117	20	50	-7.5620	0.4869	80	-15.53	<.0001
ws WS_117	20	60	-9.1383	0.4869	80	-18.77	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_117	20	70	-12.2613	0.4869	80	-25.18	<.0001
ws WS_117	20	80	-14.6643	0.4869	80	-30.12	<.0001
ws WS_117	20	90	-17.8957	0.4869	80	-36.75	<.0001
ws WS_117	20	100	-19.5850	0.4869	80	-40.22	<.0001
ws WS_117	30	40	-2.3060	0.4869	80	-4.74	<.0001
ws WS_117	30	50	-4.6177	0.4869	80	-9.48	<.0001
ws WS_117	30	60	-6.1940	0.4869	80	-12.72	<.0001
ws WS_117	30	70	-9.3170	0.4869	80	-19.13	<.0001
ws WS_117	30	80	-11.7200	0.4869	80	-24.07	<.0001
ws WS_117	30	90	-14.9513	0.4869	80	-30.71	<.0001
ws WS_117	30	100	-16.6407	0.4869	80	-34.18	<.0001
ws WS_117	40	50	-2.3117	0.4869	80	-4.75	<.0001
ws WS_117	40	60	-3.8880	0.4869	80	-7.98	<.0001
ws WS_117	40	70	-7.0110	0.4869	80	-14.40	<.0001
ws WS_117	40	80	-9.4140	0.4869	80	-19.33	<.0001
ws WS_117	40	90	-12.6453	0.4869	80	-25.97	<.0001
ws WS_117	40	100	-14.3347	0.4869	80	-29.44	<.0001
ws WS_117	50	60	-1.5763	0.4869	80	-3.24	0.0018
ws WS_117	50	70	-4.6993	0.4869	80	-9.65	<.0001
ws WS_117	50	80	-7.1023	0.4869	80	-14.59	<.0001
ws WS_117	50	90	-10.3337	0.4869	80	-21.22	<.0001
ws WS_117	50	100	-12.0230	0.4869	80	-24.69	<.0001
ws WS_117	60	70	-3.1230	0.4869	80	-6.41	<.0001
ws WS_117	60	80	-5.5260	0.4869	80	-11.35	<.0001
ws WS_117	60	90	-8.7573	0.4869	80	-17.99	<.0001
ws WS_117	60	100	-10.4467	0.4869	80	-21.45	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_117	70	80	-2.4030	0.4869	80	-4.94	<.0001
ws WS_117	70	90	-5.6343	0.4869	80	-11.57	<.0001
ws WS_117	70	100	-7.3237	0.4869	80	-15.04	<.0001
ws WS_117	80	90	-3.2313	0.4869	80	-6.64	<.0001
ws WS_117	80	100	-4.9207	0.4869	80	-10.11	<.0001
ws WS_117	90	100	-1.6893	0.4869	80	-3.47	0.0008
ws WS_153	0	10	-1.4390	0.4869	80	-2.96	0.0041
ws WS_153	0	20	-2.8970	0.4869	80	-5.95	<.0001
ws WS_153	0	30	-4.8543	0.4869	80	-9.97	<.0001
ws WS_153	0	40	-6.3163	0.4869	80	-12.97	<.0001
ws WS_153	0	50	-7.8017	0.4869	80	-16.02	<.0001
ws WS_153	0	60	-8.8273	0.4869	80	-18.13	<.0001
ws WS_153	0	70	-10.8717	0.4869	80	-22.33	<.0001
ws WS_153	0	80	-12.4217	0.4869	80	-25.51	<.0001
ws WS_153	0	90	-14.5640	0.4869	80	-29.91	<.0001
ws WS_153	0	100	-15.7640	0.4869	80	-32.37	<.0001
ws WS_153	10	20	-1.4580	0.4869	80	-2.99	0.0037
ws WS_153	10	30	-3.4153	0.4869	80	-7.01	<.0001
ws WS_153	10	40	-4.8773	0.4869	80	-10.02	<.0001
ws WS_153	10	50	-6.3627	0.4869	80	-13.07	<.0001
ws WS_153	10	60	-7.3883	0.4869	80	-15.17	<.0001
ws WS_153	10	70	-9.4327	0.4869	80	-19.37	<.0001
ws WS_153	10	80	-10.9827	0.4869	80	-22.56	<.0001
ws WS_153	10	90	-13.1250	0.4869	80	-26.96	<.0001
ws WS_153	10	100	-14.3250	0.4869	80	-29.42	<.0001
ws WS_153	20	30	-1.9573	0.4869	80	-4.02	0.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_153	20	40	-3.4193	0.4869	80	-7.02	<.0001
ws WS_153	20	50	-4.9047	0.4869	80	-10.07	<.0001
ws WS_153	20	60	-5.9303	0.4869	80	-12.18	<.0001
ws WS_153	20	70	-7.9747	0.4869	80	-16.38	<.0001
ws WS_153	20	80	-9.5247	0.4869	80	-19.56	<.0001
ws WS_153	20	90	-11.6670	0.4869	80	-23.96	<.0001
ws WS_153	20	100	-12.8670	0.4869	80	-26.43	<.0001
ws WS_153	30	40	-1.4620	0.4869	80	-3.00	0.0036
ws WS_153	30	50	-2.9473	0.4869	80	-6.05	<.0001
ws WS_153	30	60	-3.9730	0.4869	80	-8.16	<.0001
ws WS_153	30	70	-6.0173	0.4869	80	-12.36	<.0001
ws WS_153	30	80	-7.5673	0.4869	80	-15.54	<.0001
ws WS_153	30	90	-9.7097	0.4869	80	-19.94	<.0001
ws WS_153	30	100	-10.9097	0.4869	80	-22.41	<.0001
ws WS_153	40	50	-1.4853	0.4869	80	-3.05	0.0031
ws WS_153	40	60	-2.5110	0.4869	80	-5.16	<.0001
ws WS_153	40	70	-4.5553	0.4869	80	-9.36	<.0001
ws WS_153	40	80	-6.1053	0.4869	80	-12.54	<.0001
ws WS_153	40	90	-8.2477	0.4869	80	-16.94	<.0001
ws WS_153	40	100	-9.4477	0.4869	80	-19.40	<.0001
ws WS_153	50	60	-1.0257	0.4869	80	-2.11	0.0383
ws WS_153	50	70	-3.0700	0.4869	80	-6.30	<.0001
ws WS_153	50	80	-4.6200	0.4869	80	-9.49	<.0001
ws WS_153	50	90	-6.7623	0.4869	80	-13.89	<.0001
ws WS_153	50	100	-7.9623	0.4869	80	-16.35	<.0001
ws WS_153	60	70	-2.0443	0.4869	80	-4.20	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_153	60	80	-3.5943	0.4869	80	-7.38	<.0001
ws WS_153	60	90	-5.7367	0.4869	80	-11.78	<.0001
ws WS_153	60	100	-6.9367	0.4869	80	-14.25	<.0001
ws WS_153	70	80	-1.5500	0.4869	80	-3.18	0.0021
ws WS_153	70	90	-3.6923	0.4869	80	-7.58	<.0001
ws WS_153	70	100	-4.8923	0.4869	80	-10.05	<.0001
ws WS_153	80	90	-2.1423	0.4869	80	-4.40	<.0001
ws WS_153	80	100	-3.3423	0.4869	80	-6.86	<.0001
ws WS_153	90	100	-1.2000	0.4869	80	-2.46	0.0159
ws WS_185	0	10	-2.1400	0.4869	80	-4.39	<.0001
ws WS_185	0	20	-4.3073	0.4869	80	-8.85	<.0001
ws WS_185	0	30	-7.2403	0.4869	80	-14.87	<.0001
ws WS_185	0	40	-9.4877	0.4869	80	-19.49	<.0001
ws WS_185	0	50	-11.7647	0.4869	80	-24.16	<.0001
ws WS_185	0	60	-13.3733	0.4869	80	-27.47	<.0001
ws WS_185	0	70	-16.5213	0.4869	80	-33.93	<.0001
ws WS_185	0	80	-18.9170	0.4869	80	-38.85	<.0001
ws WS_185	0	90	-22.0923	0.4869	80	-45.37	<.0001
ws WS_185	0	100	-23.7447	0.4869	80	-48.77	<.0001
ws WS_185	10	20	-2.1673	0.4869	80	-4.45	<.0001
ws WS_185	10	30	-5.1003	0.4869	80	-10.47	<.0001
ws WS_185	10	40	-7.3477	0.4869	80	-15.09	<.0001
ws WS_185	10	50	-9.6247	0.4869	80	-19.77	<.0001
ws WS_185	10	60	-11.2333	0.4869	80	-23.07	<.0001
ws WS_185	10	70	-14.3813	0.4869	80	-29.54	<.0001
ws WS_185	10	80	-16.7770	0.4869	80	-34.46	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_185	10	90	-19.9523	0.4869	80	-40.98	<.0001
ws WS_185	10	100	-21.6047	0.4869	80	-44.37	<.0001
ws WS_185	20	30	-2.9330	0.4869	80	-6.02	<.0001
ws WS_185	20	40	-5.1803	0.4869	80	-10.64	<.0001
ws WS_185	20	50	-7.4573	0.4869	80	-15.32	<.0001
ws WS_185	20	60	-9.0660	0.4869	80	-18.62	<.0001
ws WS_185	20	70	-12.2140	0.4869	80	-25.08	<.0001
ws WS_185	20	80	-14.6097	0.4869	80	-30.00	<.0001
ws WS_185	20	90	-17.7850	0.4869	80	-36.53	<.0001
ws WS_185	20	100	-19.4373	0.4869	80	-39.92	<.0001
ws WS_185	30	40	-2.2473	0.4869	80	-4.62	<.0001
ws WS_185	30	50	-4.5243	0.4869	80	-9.29	<.0001
ws WS_185	30	60	-6.1330	0.4869	80	-12.60	<.0001
ws WS_185	30	70	-9.2810	0.4869	80	-19.06	<.0001
ws WS_185	30	80	-11.6767	0.4869	80	-23.98	<.0001
ws WS_185	30	90	-14.8520	0.4869	80	-30.50	<.0001
ws WS_185	30	100	-16.5043	0.4869	80	-33.90	<.0001
ws WS_185	40	50	-2.2770	0.4869	80	-4.68	<.0001
ws WS_185	40	60	-3.8857	0.4869	80	-7.98	<.0001
ws WS_185	40	70	-7.0337	0.4869	80	-14.45	<.0001
ws WS_185	40	80	-9.4293	0.4869	80	-19.37	<.0001
ws WS_185	40	90	-12.6047	0.4869	80	-25.89	<.0001
ws WS_185	40	100	-14.2570	0.4869	80	-29.28	<.0001
ws WS_185	50	60	-1.6087	0.4869	80	-3.30	0.0014
ws WS_185	50	70	-4.7567	0.4869	80	-9.77	<.0001
ws WS_185	50	80	-7.1523	0.4869	80	-14.69	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_185	50	90	-10.3277	0.4869	80	-21.21	<.0001
ws WS_185	50	100	-11.9800	0.4869	80	-24.60	<.0001
ws WS_185	60	70	-3.1480	0.4869	80	-6.47	<.0001
ws WS_185	60	80	-5.5437	0.4869	80	-11.39	<.0001
ws WS_185	60	90	-8.7190	0.4869	80	-17.91	<.0001
ws WS_185	60	100	-10.3713	0.4869	80	-21.30	<.0001
ws WS_185	70	80	-2.3957	0.4869	80	-4.92	<.0001
ws WS_185	70	90	-5.5710	0.4869	80	-11.44	<.0001
ws WS_185	70	100	-7.2233	0.4869	80	-14.83	<.0001
ws WS_185	80	90	-3.1753	0.4869	80	-6.52	<.0001
ws WS_185	80	100	-4.8277	0.4869	80	-9.91	<.0001
ws WS_185	90	100	-1.6523	0.4869	80	-3.39	0.0011
ws WS_249	0	10	-1.9880	0.4869	80	-4.08	0.0001
ws WS_249	0	20	-4.0413	0.4869	80	-8.30	<.0001
ws WS_249	0	30	-6.8433	0.4869	80	-14.05	<.0001
ws WS_249	0	40	-8.9333	0.4869	80	-18.35	<.0001
ws WS_249	0	50	-11.0207	0.4869	80	-22.63	<.0001
ws WS_249	0	60	-12.4400	0.4869	80	-25.55	<.0001
ws WS_249	0	70	-15.3260	0.4869	80	-31.48	<.0001
ws WS_249	0	80	-17.4923	0.4869	80	-35.92	<.0001
ws WS_249	0	90	-20.3680	0.4869	80	-41.83	<.0001
ws WS_249	0	100	-21.8073	0.4869	80	-44.79	<.0001
ws WS_249	10	20	-2.0533	0.4869	80	-4.22	<.0001
ws WS_249	10	30	-4.8553	0.4869	80	-9.97	<.0001
ws WS_249	10	40	-6.9453	0.4869	80	-14.26	<.0001
ws WS_249	10	50	-9.0327	0.4869	80	-18.55	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_249	10	60	-10.4520	0.4869	80	-21.47	<.0001
ws WS_249	10	70	-13.3380	0.4869	80	-27.39	<.0001
ws WS_249	10	80	-15.5043	0.4869	80	-31.84	<.0001
ws WS_249	10	90	-18.3800	0.4869	80	-37.75	<.0001
ws WS_249	10	100	-19.8193	0.4869	80	-40.70	<.0001
ws WS_249	20	30	-2.8020	0.4869	80	-5.75	<.0001
ws WS_249	20	40	-4.8920	0.4869	80	-10.05	<.0001
ws WS_249	20	50	-6.9793	0.4869	80	-14.33	<.0001
ws WS_249	20	60	-8.3987	0.4869	80	-17.25	<.0001
ws WS_249	20	70	-11.2847	0.4869	80	-23.18	<.0001
ws WS_249	20	80	-13.4510	0.4869	80	-27.62	<.0001
ws WS_249	20	90	-16.3267	0.4869	80	-33.53	<.0001
ws WS_249	20	100	-17.7660	0.4869	80	-36.49	<.0001
ws WS_249	30	40	-2.0900	0.4869	80	-4.29	<.0001
ws WS_249	30	50	-4.1773	0.4869	80	-8.58	<.0001
ws WS_249	30	60	-5.5967	0.4869	80	-11.49	<.0001
ws WS_249	30	70	-8.4827	0.4869	80	-17.42	<.0001
ws WS_249	30	80	-10.6490	0.4869	80	-21.87	<.0001
ws WS_249	30	90	-13.5247	0.4869	80	-27.78	<.0001
ws WS_249	30	100	-14.9640	0.4869	80	-30.73	<.0001
ws WS_249	40	50	-2.0873	0.4869	80	-4.29	<.0001
ws WS_249	40	60	-3.5067	0.4869	80	-7.20	<.0001
ws WS_249	40	70	-6.3927	0.4869	80	-13.13	<.0001
ws WS_249	40	80	-8.5590	0.4869	80	-17.58	<.0001
ws WS_249	40	90	-11.4347	0.4869	80	-23.48	<.0001
ws WS_249	40	100	-12.8740	0.4869	80	-26.44	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_249	50	60	-1.4193	0.4869	80	-2.91	0.0046
ws WS_249	50	70	-4.3053	0.4869	80	-8.84	<.0001
ws WS_249	50	80	-6.4717	0.4869	80	-13.29	<.0001
ws WS_249	50	90	-9.3473	0.4869	80	-19.20	<.0001
ws WS_249	50	100	-10.7867	0.4869	80	-22.15	<.0001
ws WS_249	60	70	-2.8860	0.4869	80	-5.93	<.0001
ws WS_249	60	80	-5.0523	0.4869	80	-10.38	<.0001
ws WS_249	60	90	-7.9280	0.4869	80	-16.28	<.0001
ws WS_249	60	100	-9.3673	0.4869	80	-19.24	<.0001
ws WS_249	70	80	-2.1663	0.4869	80	-4.45	<.0001
ws WS_249	70	90	-5.0420	0.4869	80	-10.35	<.0001
ws WS_249	70	100	-6.4813	0.4869	80	-13.31	<.0001
ws WS_249	80	90	-2.8757	0.4869	80	-5.91	<.0001
ws WS_249	80	100	-4.3150	0.4869	80	-8.86	<.0001
ws WS_249	90	100	-1.4393	0.4869	80	-2.96	0.0041
ws WS_99	0	10	-2.1770	0.4869	80	-4.47	<.0001
ws WS_99	0	20	-4.4060	0.4869	80	-9.05	<.0001
ws WS_99	0	30	-7.3950	0.4869	80	-15.19	<.0001
ws WS_99	0	40	-9.6877	0.4869	80	-19.90	<.0001
ws WS_99	0	50	-11.9863	0.4869	80	-24.62	<.0001
ws WS_99	0	60	-13.5550	0.4869	80	-27.84	<.0001
ws WS_99	0	70	-16.7020	0.4869	80	-34.30	<.0001
ws WS_99	0	80	-19.1320	0.4869	80	-39.29	<.0001
ws WS_99	0	90	-22.4127	0.4869	80	-46.03	<.0001
ws WS_99	0	100	-24.1147	0.4869	80	-49.52	<.0001
ws WS_99	10	20	-2.2290	0.4869	80	-4.58	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_99	10	30	-5.2180	0.4869	80	-10.72	<.0001
ws WS_99	10	40	-7.5107	0.4869	80	-15.42	<.0001
ws WS_99	10	50	-9.8093	0.4869	80	-20.15	<.0001
ws WS_99	10	60	-11.3780	0.4869	80	-23.37	<.0001
ws WS_99	10	70	-14.5250	0.4869	80	-29.83	<.0001
ws WS_99	10	80	-16.9550	0.4869	80	-34.82	<.0001
ws WS_99	10	90	-20.2357	0.4869	80	-41.56	<.0001
ws WS_99	10	100	-21.9377	0.4869	80	-45.05	<.0001
ws WS_99	20	30	-2.9890	0.4869	80	-6.14	<.0001
ws WS_99	20	40	-5.2817	0.4869	80	-10.85	<.0001
ws WS_99	20	50	-7.5803	0.4869	80	-15.57	<.0001
ws WS_99	20	60	-9.1490	0.4869	80	-18.79	<.0001
ws WS_99	20	70	-12.2960	0.4869	80	-25.25	<.0001
ws WS_99	20	80	-14.7260	0.4869	80	-30.24	<.0001
ws WS_99	20	90	-18.0067	0.4869	80	-36.98	<.0001
ws WS_99	20	100	-19.7087	0.4869	80	-40.48	<.0001
ws WS_99	30	40	-2.2927	0.4869	80	-4.71	<.0001
ws WS_99	30	50	-4.5913	0.4869	80	-9.43	<.0001
ws WS_99	30	60	-6.1600	0.4869	80	-12.65	<.0001
ws WS_99	30	70	-9.3070	0.4869	80	-19.11	<.0001
ws WS_99	30	80	-11.7370	0.4869	80	-24.10	<.0001
ws WS_99	30	90	-15.0177	0.4869	80	-30.84	<.0001
ws WS_99	30	100	-16.7197	0.4869	80	-34.34	<.0001
ws WS_99	40	50	-2.2987	0.4869	80	-4.72	<.0001
ws WS_99	40	60	-3.8673	0.4869	80	-7.94	<.0001
ws WS_99	40	70	-7.0143	0.4869	80	-14.41	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 10-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_99	40	80	-9.4443	0.4869	80	-19.40	<.0001
ws WS_99	40	90	-12.7250	0.4869	80	-26.13	<.0001
ws WS_99	40	100	-14.4270	0.4869	80	-29.63	<.0001
ws WS_99	50	60	-1.5687	0.4869	80	-3.22	0.0018
ws WS_99	50	70	-4.7157	0.4869	80	-9.68	<.0001
ws WS_99	50	80	-7.1457	0.4869	80	-14.68	<.0001
ws WS_99	50	90	-10.4263	0.4869	80	-21.41	<.0001
ws WS_99	50	100	-12.1283	0.4869	80	-24.91	<.0001
ws WS_99	60	70	-3.1470	0.4869	80	-6.46	<.0001
ws WS_99	60	80	-5.5770	0.4869	80	-11.45	<.0001
ws WS_99	60	90	-8.8577	0.4869	80	-18.19	<.0001
ws WS_99	60	100	-10.5597	0.4869	80	-21.69	<.0001
ws WS_99	70	80	-2.4300	0.4869	80	-4.99	<.0001
ws WS_99	70	90	-5.7107	0.4869	80	-11.73	<.0001
ws WS_99	70	100	-7.4127	0.4869	80	-15.22	<.0001
ws WS_99	80	90	-3.2807	0.4869	80	-6.74	<.0001
ws WS_99	80	100	-4.9827	0.4869	80	-10.23	<.0001
ws WS_99	90	100	-1.7020	0.4869	80	-3.50	0.0008

Table B. 4. Disturbance percentage and watershed least square means simple effects comparison of runoff amount by watershed: 25-year storm.

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_117	0	10	-2.3870	0.4624	80	-5.16	<.0001
ws WS_117	0	20	-4.8013	0.4624	80	-10.38	<.0001
ws WS_117	0	30	-8.0807	0.4624	80	-17.48	<.0001
ws WS_117	0	40	-10.5660	0.4624	80	-22.85	<.0001
ws WS_117	0	50	-13.0417	0.4624	80	-28.20	<.0001
ws WS_117	0	60	-14.7100	0.4624	80	-31.81	<.0001
ws WS_117	0	70	-18.0823	0.4624	80	-39.11	<.0001
ws WS_117	0	80	-20.6747	0.4624	80	-44.71	<.0001
ws WS_117	0	90	-24.1887	0.4624	80	-52.31	<.0001
ws WS_117	0	100	-26.0007	0.4624	80	-56.23	<.0001
ws WS_117	10	20	-2.4143	0.4624	80	-5.22	<.0001
ws WS_117	10	30	-5.6937	0.4624	80	-12.31	<.0001
ws WS_117	10	40	-8.1790	0.4624	80	-17.69	<.0001
ws WS_117	10	50	-10.6547	0.4624	80	-23.04	<.0001
ws WS_117	10	60	-12.3230	0.4624	80	-26.65	<.0001
ws WS_117	10	70	-15.6953	0.4624	80	-33.94	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_117	10	80	-18.2877	0.4624	80	-39.55	<.0001
ws WS_117	10	90	-21.8017	0.4624	80	-47.15	<.0001
ws WS_117	10	100	-23.6137	0.4624	80	-51.07	<.0001
ws WS_117	20	30	-3.2793	0.4624	80	-7.09	<.0001
ws WS_117	20	40	-5.7647	0.4624	80	-12.47	<.0001
ws WS_117	20	50	-8.2403	0.4624	80	-17.82	<.0001
ws WS_117	20	60	-9.9087	0.4624	80	-21.43	<.0001
ws WS_117	20	70	-13.2810	0.4624	80	-28.72	<.0001
ws WS_117	20	80	-15.8733	0.4624	80	-34.33	<.0001
ws WS_117	20	90	-19.3873	0.4624	80	-41.93	<.0001
ws WS_117	20	100	-21.1993	0.4624	80	-45.85	<.0001
ws WS_117	30	40	-2.4853	0.4624	80	-5.37	<.0001
ws WS_117	30	50	-4.9610	0.4624	80	-10.73	<.0001
ws WS_117	30	60	-6.6293	0.4624	80	-14.34	<.0001
ws WS_117	30	70	-10.0017	0.4624	80	-21.63	<.0001
ws WS_117	30	80	-12.5940	0.4624	80	-27.24	<.0001
ws WS_117	30	90	-16.1080	0.4624	80	-34.84	<.0001
ws WS_117	30	100	-17.9200	0.4624	80	-38.76	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_117	40	50	-2.4757	0.4624	80	-5.35	<.0001
ws WS_117	40	60	-4.1440	0.4624	80	-8.96	<.0001
ws WS_117	40	70	-7.5163	0.4624	80	-16.26	<.0001
ws WS_117	40	80	-10.1087	0.4624	80	-21.86	<.0001
ws WS_117	40	90	-13.6227	0.4624	80	-29.46	<.0001
ws WS_117	40	100	-15.4347	0.4624	80	-33.38	<.0001
ws WS_117	50	60	-1.6683	0.4624	80	-3.61	0.0005
ws WS_117	50	70	-5.0407	0.4624	80	-10.90	<.0001
ws WS_117	50	80	-7.6330	0.4624	80	-16.51	<.0001
ws WS_117	50	90	-11.1470	0.4624	80	-24.11	<.0001
ws WS_117	50	100	-12.9590	0.4624	80	-28.03	<.0001
ws WS_117	60	70	-3.3723	0.4624	80	-7.29	<.0001
ws WS_117	60	80	-5.9647	0.4624	80	-12.90	<.0001
ws WS_117	60	90	-9.4787	0.4624	80	-20.50	<.0001
ws WS_117	60	100	-11.2907	0.4624	80	-24.42	<.0001
ws WS_117	70	80	-2.5923	0.4624	80	-5.61	<.0001
ws WS_117	70	90	-6.1063	0.4624	80	-13.21	<.0001
ws WS_117	70	100	-7.9183	0.4624	80	-17.12	<.0001
ws WS_117	80	90	-3.5140	0.4624	80	-7.60	<.0001
ws WS_117	80	100	-5.3260	0.4624	80	-11.52	<.0001
ws WS_117	90	100	-1.8120	0.4624	80	-3.92	0.0002

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_153	0	10	-1.7430	0.4624	80	-3.77	0.0003
ws WS_153	0	20	-3.4177	0.4624	80	-7.39	<.0001
ws WS_153	0	30	-5.6553	0.4624	80	-12.23	<.0001
ws WS_153	0	40	-7.2857	0.4624	80	-15.76	<.0001
ws WS_153	0	50	-8.9657	0.4624	80	-19.39	<.0001
ws WS_153	0	60	-10.1383	0.4624	80	-21.93	<.0001
ws WS_153	0	70	-12.5917	0.4624	80	-27.23	<.0001
ws WS_153	0	80	-14.4603	0.4624	80	-31.27	<.0001
ws WS_153	0	90	-16.8283	0.4624	80	-36.39	<.0001
ws WS_153	0	100	-18.0673	0.4624	80	-39.07	<.0001
ws WS_153	10	20	-1.6747	0.4624	80	-3.62	0.0005
ws WS_153	10	30	-3.9123	0.4624	80	-8.46	<.0001
ws WS_153	10	40	-5.5427	0.4624	80	-11.99	<.0001
ws WS_153	10	50	-7.2227	0.4624	80	-15.62	<.0001
ws WS_153	10	60	-8.3953	0.4624	80	-18.16	<.0001
ws WS_153	10	70	-10.8487	0.4624	80	-23.46	<.0001
ws WS_153	10	80	-12.7173	0.4624	80	-27.50	<.0001
ws WS_153	10	90	-15.0853	0.4624	80	-32.62	<.0001
ws WS_153	10	100	-16.3243	0.4624	80	-35.30	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_153	20	30	-2.2377	0.4624	80	-4.84	<.0001
ws WS_153	20	40	-3.8680	0.4624	80	-8.37	<.0001
ws WS_153	20	50	-5.5480	0.4624	80	-12.00	<.0001
ws WS_153	20	60	-6.7207	0.4624	80	-14.53	<.0001
ws WS_153	20	70	-9.1740	0.4624	80	-19.84	<.0001
ws WS_153	20	80	-11.0427	0.4624	80	-23.88	<.0001
ws WS_153	20	90	-13.4107	0.4624	80	-29.00	<.0001
ws WS_153	20	100	-14.6497	0.4624	80	-31.68	<.0001
ws WS_153	30	40	-1.6303	0.4624	80	-3.53	0.0007
ws WS_153	30	50	-3.3103	0.4624	80	-7.16	<.0001
ws WS_153	30	60	-4.4830	0.4624	80	-9.70	<.0001
ws WS_153	30	70	-6.9363	0.4624	80	-15.00	<.0001
ws WS_153	30	80	-8.8050	0.4624	80	-19.04	<.0001
ws WS_153	30	90	-11.1730	0.4624	80	-24.16	<.0001
ws WS_153	30	100	-12.4120	0.4624	80	-26.84	<.0001
ws WS_153	40	50	-1.6800	0.4624	80	-3.63	0.0005
ws WS_153	40	60	-2.8527	0.4624	80	-6.17	<.0001
ws WS_153	40	70	-5.3060	0.4624	80	-11.48	<.0001
ws WS_153	40	80	-7.1747	0.4624	80	-15.52	<.0001
ws WS_153	40	90	-9.5427	0.4624	80	-20.64	<.0001
ws WS_153	40	100	-10.7817	0.4624	80	-23.32	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_153	50	60	-1.1727	0.4624	80	-2.54	0.0132
ws WS_153	50	70	-3.6260	0.4624	80	-7.84	<.0001
ws WS_153	50	80	-5.4947	0.4624	80	-11.88	<.0001
ws WS_153	50	90	-7.8627	0.4624	80	-17.00	<.0001
ws WS_153	50	100	-9.1017	0.4624	80	-19.68	<.0001
ws WS_153	60	70	-2.4533	0.4624	80	-5.31	<.0001
ws WS_153	60	80	-4.3220	0.4624	80	-9.35	<.0001
ws WS_153	60	90	-6.6900	0.4624	80	-14.47	<.0001
ws WS_153	60	100	-7.9290	0.4624	80	-17.15	<.0001
ws WS_153	70	80	-1.8687	0.4624	80	-4.04	0.0001
ws WS_153	70	90	-4.2367	0.4624	80	-9.16	<.0001
ws WS_153	70	100	-5.4757	0.4624	80	-11.84	<.0001
ws WS_153	80	90	-2.3680	0.4624	80	-5.12	<.0001
ws WS_153	80	100	-3.6070	0.4624	80	-7.80	<.0001
ws WS_153	90	100	-1.2390	0.4624	80	-2.68	0.0089
ws WS_185	0	10	-2.3530	0.4624	80	-5.09	<.0001
ws WS_185	0	20	-4.7317	0.4624	80	-10.23	<.0001
ws WS_185	0	30	-7.9827	0.4624	80	-17.26	<.0001
ws WS_185	0	40	-10.5047	0.4624	80	-22.72	<.0001
ws WS_185	0	50	-12.9677	0.4624	80	-28.04	<.0001
ws WS_185	0	60	-14.6357	0.4624	80	-31.65	<.0001
ws WS_185	0	70	-17.9800	0.4624	80	-38.89	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_185	0	80	-20.5113	0.4624	80	-44.36	<.0001
ws WS_185	0	90	-24.0093	0.4624	80	-51.92	<.0001
ws WS_185	0	100	-25.8133	0.4624	80	-55.83	<.0001
ws WS_185	10	20	-2.3787	0.4624	80	-5.14	<.0001
ws WS_185	10	30	-5.6297	0.4624	80	-12.18	<.0001
ws WS_185	10	40	-8.1517	0.4624	80	-17.63	<.0001
ws WS_185	10	50	-10.6147	0.4624	80	-22.96	<.0001
ws WS_185	10	60	-12.2827	0.4624	80	-26.56	<.0001
ws WS_185	10	70	-15.6270	0.4624	80	-33.80	<.0001
ws WS_185	10	80	-18.1583	0.4624	80	-39.27	<.0001
ws WS_185	10	90	-21.6563	0.4624	80	-46.84	<.0001
ws WS_185	10	100	-23.4603	0.4624	80	-50.74	<.0001
ws WS_185	20	30	-3.2510	0.4624	80	-7.03	<.0001
ws WS_185	20	40	-5.7730	0.4624	80	-12.49	<.0001
ws WS_185	20	50	-8.2360	0.4624	80	-17.81	<.0001
ws WS_185	20	60	-9.9040	0.4624	80	-21.42	<.0001
ws WS_185	20	70	-13.2483	0.4624	80	-28.65	<.0001
ws WS_185	20	80	-15.7797	0.4624	80	-34.13	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_185	20	90	-19.2777	0.4624	80	-41.69	<.0001
ws WS_185	20	100	-21.0817	0.4624	80	-45.59	<.0001
ws WS_185	30	40	-2.5220	0.4624	80	-5.45	<.0001
ws WS_185	30	50	-4.9850	0.4624	80	-10.78	<.0001
ws WS_185	30	60	-6.6530	0.4624	80	-14.39	<.0001
ws WS_185	30	70	-9.9973	0.4624	80	-21.62	<.0001
ws WS_185	30	80	-12.5287	0.4624	80	-27.10	<.0001
ws WS_185	30	90	-16.0267	0.4624	80	-34.66	<.0001
ws WS_185	30	100	-17.8307	0.4624	80	-38.56	<.0001
ws WS_185	40	50	-2.4630	0.4624	80	-5.33	<.0001
ws WS_185	40	60	-4.1310	0.4624	80	-8.93	<.0001
ws WS_185	40	70	-7.4753	0.4624	80	-16.17	<.0001
ws WS_185	40	80	-10.0067	0.4624	80	-21.64	<.0001
ws WS_185	40	90	-13.5047	0.4624	80	-29.21	<.0001
ws WS_185	40	100	-15.3087	0.4624	80	-33.11	<.0001
ws WS_185	50	60	-1.6680	0.4624	80	-3.61	0.0005
ws WS_185	50	70	-5.0123	0.4624	80	-10.84	<.0001
ws WS_185	50	80	-7.5437	0.4624	80	-16.31	<.0001
ws WS_185	50	90	-11.0417	0.4624	80	-23.88	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_185	50	100	-12.8457	0.4624	80	-27.78	<.0001
ws WS_185	60	70	-3.3443	0.4624	80	-7.23	<.0001
ws WS_185	60	80	-5.8757	0.4624	80	-12.71	<.0001
ws WS_185	60	90	-9.3737	0.4624	80	-20.27	<.0001
ws WS_185	60	100	-11.1777	0.4624	80	-24.17	<.0001
ws WS_185	70	80	-2.5313	0.4624	80	-5.47	<.0001
ws WS_185	70	90	-6.0293	0.4624	80	-13.04	<.0001
ws WS_185	70	100	-7.8333	0.4624	80	-16.94	<.0001
ws WS_185	80	90	-3.4980	0.4624	80	-7.57	<.0001
ws WS_185	80	100	-5.3020	0.4624	80	-11.47	<.0001
ws WS_185	90	100	-1.8040	0.4624	80	-3.90	0.0002
ws WS_249	0	10	-2.1690	0.4624	80	-4.69	<.0001
ws WS_249	0	20	-4.3600	0.4624	80	-9.43	<.0001
ws WS_249	0	30	-7.3290	0.4624	80	-15.85	<.0001
ws WS_249	0	40	-9.5940	0.4624	80	-20.75	<.0001
ws WS_249	0	50	-11.8110	0.4624	80	-25.54	<.0001
ws WS_249	0	60	-13.3150	0.4624	80	-28.80	<.0001
ws WS_249	0	70	-16.3310	0.4624	80	-35.32	<.0001
ws WS_249	0	80	-18.5807	0.4624	80	-40.18	<.0001
ws WS_249	0	90	-21.5997	0.4624	80	-46.71	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_249	0	100	-23.1150	0.4624	80	-49.99	<.0001
ws WS_249	10	20	-2.1910	0.4624	80	-4.74	<.0001
ws WS_249	10	30	-5.1600	0.4624	80	-11.16	<.0001
ws WS_249	10	40	-7.4250	0.4624	80	-16.06	<.0001
ws WS_249	10	50	-9.6420	0.4624	80	-20.85	<.0001
ws WS_249	10	60	-11.1460	0.4624	80	-24.11	<.0001
ws WS_249	10	70	-14.1620	0.4624	80	-30.63	<.0001
ws WS_249	10	80	-16.4117	0.4624	80	-35.49	<.0001
ws WS_249	10	90	-19.4307	0.4624	80	-42.02	<.0001
ws WS_249	10	100	-20.9460	0.4624	80	-45.30	<.0001
ws WS_249	20	30	-2.9690	0.4624	80	-6.42	<.0001
ws WS_249	20	40	-5.2340	0.4624	80	-11.32	<.0001
ws WS_249	20	50	-7.4510	0.4624	80	-16.11	<.0001
ws WS_249	20	60	-8.9550	0.4624	80	-19.37	<.0001
ws WS_249	20	70	-11.9710	0.4624	80	-25.89	<.0001
ws WS_249	20	80	-14.2207	0.4624	80	-30.75	<.0001
ws WS_249	20	90	-17.2397	0.4624	80	-37.28	<.0001
ws WS_249	20	100	-18.7550	0.4624	80	-40.56	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_249	30	40	-2.2650	0.4624	80	-4.90	<.0001
ws WS_249	30	50	-4.4820	0.4624	80	-9.69	<.0001
ws WS_249	30	60	-5.9860	0.4624	80	-12.95	<.0001
ws WS_249	30	70	-9.0020	0.4624	80	-19.47	<.0001
ws WS_249	30	80	-11.2517	0.4624	80	-24.33	<.0001
ws WS_249	30	90	-14.2707	0.4624	80	-30.86	<.0001
ws WS_249	30	100	-15.7860	0.4624	80	-34.14	<.0001
ws WS_249	40	50	-2.2170	0.4624	80	-4.79	<.0001
ws WS_249	40	60	-3.7210	0.4624	80	-8.05	<.0001
ws WS_249	40	70	-6.7370	0.4624	80	-14.57	<.0001
ws WS_249	40	80	-8.9867	0.4624	80	-19.44	<.0001
ws WS_249	40	90	-12.0057	0.4624	80	-25.96	<.0001
ws WS_249	40	100	-13.5210	0.4624	80	-29.24	<.0001
ws WS_249	50	60	-1.5040	0.4624	80	-3.25	0.0017
ws WS_249	50	70	-4.5200	0.4624	80	-9.78	<.0001
ws WS_249	50	80	-6.7697	0.4624	80	-14.64	<.0001
ws WS_249	50	90	-9.7887	0.4624	80	-21.17	<.0001
ws WS_249	50	100	-11.3040	0.4624	80	-24.45	<.0001
ws WS_249	60	70	-3.0160	0.4624	80	-6.52	<.0001
ws WS_249	60	80	-5.2657	0.4624	80	-11.39	<.0001
ws WS_249	60	90	-8.2847	0.4624	80	-17.92	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_249	60	100	-9.8000	0.4624	80	-21.19	<.0001
ws WS_249	70	80	-2.2497	0.4624	80	-4.87	<.0001
ws WS_249	70	90	-5.2687	0.4624	80	-11.39	<.0001
ws WS_249	70	100	-6.7840	0.4624	80	-14.67	<.0001
ws WS_249	80	90	-3.0190	0.4624	80	-6.53	<.0001
ws WS_249	80	100	-4.5343	0.4624	80	-9.81	<.0001
ws WS_249	90	100	-1.5153	0.4624	80	-3.28	0.0016
ws WS_99	0	10	-2.3810	0.4624	80	-5.15	<.0001
ws WS_99	0	20	-4.8033	0.4624	80	-10.39	<.0001
ws WS_99	0	30	-8.0907	0.4624	80	-17.50	<.0001
ws WS_99	0	40	-10.6317	0.4624	80	-22.99	<.0001
ws WS_99	0	50	-13.1640	0.4624	80	-28.47	<.0001
ws WS_99	0	60	-14.8807	0.4624	80	-32.18	<.0001
ws WS_99	0	70	-18.3430	0.4624	80	-39.67	<.0001
ws WS_99	0	80	-21.0120	0.4624	80	-45.44	<.0001
ws WS_99	0	90	-24.5767	0.4624	80	-53.15	<.0001
ws WS_99	0	100	-26.3990	0.4624	80	-57.09	<.0001
ws WS_99	10	20	-2.4223	0.4624	80	-5.24	<.0001
ws WS_99	10	30	-5.7097	0.4624	80	-12.35	<.0001
ws WS_99	10	40	-8.2507	0.4624	80	-17.84	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_99	10	50	-10.7830	0.4624	80	-23.32	<.0001
ws WS_99	10	60	-12.4997	0.4624	80	-27.03	<.0001
ws WS_99	10	70	-15.9620	0.4624	80	-34.52	<.0001
ws WS_99	10	80	-18.6310	0.4624	80	-40.29	<.0001
ws WS_99	10	90	-22.1957	0.4624	80	-48.00	<.0001
ws WS_99	10	100	-24.0180	0.4624	80	-51.94	<.0001
ws WS_99	20	30	-3.2873	0.4624	80	-7.11	<.0001
ws WS_99	20	40	-5.8283	0.4624	80	-12.60	<.0001
ws WS_99	20	50	-8.3607	0.4624	80	-18.08	<.0001
ws WS_99	20	60	-10.0773	0.4624	80	-21.79	<.0001
ws WS_99	20	70	-13.5397	0.4624	80	-29.28	<.0001
ws WS_99	20	80	-16.2087	0.4624	80	-35.05	<.0001
ws WS_99	20	90	-19.7733	0.4624	80	-42.76	<.0001
ws WS_99	20	100	-21.5957	0.4624	80	-46.70	<.0001
ws WS_99	30	40	-2.5410	0.4624	80	-5.50	<.0001
ws WS_99	30	50	-5.0733	0.4624	80	-10.97	<.0001
ws WS_99	30	60	-6.7900	0.4624	80	-14.68	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm							
Simple Effect Level	**dist**	**_dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_99	30	70	-10.2523	0.4624	80	-22.17	<.0001
ws WS_99	30	80	-12.9213	0.4624	80	-27.94	<.0001
ws WS_99	30	90	-16.4860	0.4624	80	-35.65	<.0001
ws WS_99	30	100	-18.3083	0.4624	80	-39.60	<.0001
ws WS_99	40	50	-2.5323	0.4624	80	-5.48	<.0001
ws WS_99	40	60	-4.2490	0.4624	80	-9.19	<.0001
ws WS_99	40	70	-7.7113	0.4624	80	-16.68	<.0001
ws WS_99	40	80	-10.3803	0.4624	80	-22.45	<.0001
ws WS_99	40	90	-13.9450	0.4624	80	-30.16	<.0001
ws WS_99	40	100	-15.7673	0.4624	80	-34.10	<.0001
ws WS_99	50	60	-1.7167	0.4624	80	-3.71	0.0004
ws WS_99	50	70	-5.1790	0.4624	80	-11.20	<.0001
ws WS_99	50	80	-7.8480	0.4624	80	-16.97	<.0001
ws WS_99	50	90	-11.4127	0.4624	80	-24.68	<.0001
ws WS_99	50	100	-13.2350	0.4624	80	-28.62	<.0001
ws WS_99	60	70	-3.4623	0.4624	80	-7.49	<.0001
ws WS_99	60	80	-6.1313	0.4624	80	-13.26	<.0001
ws WS_99	60	90	-9.6960	0.4624	80	-20.97	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 25-year storm

Simple Effect Level	dist	_dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_99	60	100	-11.5183	0.4624	80	-24.91	<.0001
ws WS_99	70	80	-2.6690	0.4624	80	-5.77	<.0001
ws WS_99	70	90	-6.2337	0.4624	80	-13.48	<.0001
ws WS_99	70	100	-8.0560	0.4624	80	-17.42	<.0001
ws WS_99	80	90	-3.5647	0.4624	80	-7.71	<.0001
ws WS_99	80	100	-5.3870	0.4624	80	-11.65	<.0001
ws WS_99	90	100	-1.8223	0.4624	80	-3.94	0.0002

Table B. 5. Training intensity and disturbance percentage least squares means simple effects comparison by averaging runoff from watersheds for a 2-year storm.

Simple Effect Comparisons of ti*dist Least Squares Means By dist

Simple Effect Level	Training Intensity	Training Intensity	Estimate	Standard Error	DF	t Value	Pr > |t|
dist 0	H	M	-344E-17	0.4360	80	-0.00	1.0000
dist 0	L	M	-269E-17	0.4360	80	-0.00	1.0000
dist 10	H	M	-888E-18	0.4360	80	-0.00	1.0000
dist 10	L	M	1.78E-15	0.4360	80	0.00	1.0000
dist 20	H	M	1.0844	0.4360	80	2.49	0.0150
dist 20	L	M	-1.3396	0.4360	80	-3.07	0.0029
dist 30	H	M	6.66E-15	0.4360	80	0.00	1.0000
dist 30	L	M	-2.8434	0.4360	80	-6.52	<.0001
dist 40	H	M	1.2550	0.4360	80	2.88	0.0051
dist 40	L	M	-4.3686	0.4360	80	-10.02	<.0001
dist 50	H	M	1.2436	0.4360	80	2.85	0.0055

Simple Effect Comparisons of ti*dist Least Squares Means By dist

Simple Effect Level	Training Intensity	Training Intensity	Estimate	Standard Error	DF	t Value	Pr > |t|
dist 50	L	M	-4.5632	0.4360	80	-10.47	<.0001
dist 60	H	M	1.3016	0.4360	80	2.99	0.0038
dist 60	L	M	-6.1472	0.4360	80	-14.10	<.0001
dist 70	H	M	2.6026	0.4360	80	5.97	<.0001
dist 70	L	M	-6.3444	0.4360	80	-14.55	<.0001
dist 80	H	M	1.3076	0.4360	80	3.00	0.0036
dist 80	L	M	-9.6748	0.4360	80	-22.19	<.0001
dist 90	H	M	2.7574	0.4360	80	6.32	<.0001
dist 90	L	M	-9.8336	0.4360	80	-22.56	<.0001
dist 100	H	M	2.8882	0.4360	80	6.62	<.0001
dist 100	L	M	-11.5618	0.4360	80	-26.52	<.0001

Table B. 6. Training intensity and disturbance percentage least squares means simple effects comparison by averaging runoff from watersheds for a 10-year storm.

Simple Effect Comparisons of ti*dist Least Squares Means By dist: 10-year storm

Simple Effect Level	ti	_ti	Estimate	Standard Error	DF	t Value	Pr > |t|
dist 0	H	M	-336E-16	0.3772	80	-0.00	1.0000
dist 0	L	M	-48E-15	0.3772	80	-0.00	1.0000
dist 10	H	M	-382E-16	0.3772	80	-0.00	1.0000
dist 10	L	M	-515E-16	0.3772	80	-0.00	1.0000
dist 20	H	M	2.0268	0.3772	80	5.37	<.0001

Simple Effect Comparisons of ti*dist Least Squares Means By dist: 10-year storm							
Simple Effect Level	**ti**	**_ti**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
dist 20	L	M	-2.0130	0.3772	80	-5.34	<.0001
dist 30	H	M	-435E-16	0.3772	80	-0.00	1.0000
dist 30	L	M	-4.0946	0.3772	80	-10.86	<.0001
dist 40	H	M	2.0928	0.3772	80	5.55	<.0001
dist 40	L	M	-6.1676	0.3772	80	-16.35	<.0001
dist 50	H	M	2.1564	0.3772	80	5.72	<.0001
dist 50	L	M	-6.2336	0.3772	80	-16.53	<.0001
dist 60	H	M	2.1628	0.3772	80	5.73	<.0001
dist 60	L	M	-8.3900	0.3772	80	-22.24	<.0001
dist 70	H	M	4.3784	0.3772	80	11.61	<.0001
dist 70	L	M	-8.4850	0.3772	80	-22.50	<.0001
dist 80	H	M	2.1886	0.3772	80	5.80	<.0001
dist 80	L	M	-12.8634	0.3772	80	-34.11	<.0001
dist 90	H	M	4.5616	0.3772	80	12.09	<.0001
dist 90	L	M	-12.9790	0.3772	80	-34.41	<.0001
dist 100	H	M	4.6566	0.3772	80	12.35	<.0001
dist 100	L	M	-15.2364	0.3772	80	-40.40	<.0001

Table B. 7. Training intensity and disturbance percentage least squares means simple effects comparison by averaging runoff from watersheds for a 25-year storm.

Simple Effect Comparisons of ti*dist Least Squares Means By dist							
Simple Effect Level	**ti**	**_ti**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
dist 0	H	M	2.08E-14	0.3582	80	0.00	1.0000
dist 0	L	M	1.75E-14	0.3582	80	0.00	1.0000
dist 10	H	M	-329E-16	0.3582	80	-0.00	1.0000
dist 10	L	M	-284E-16	0.3582	80	-0.00	1.0000
dist 20	H	M	2.2390	0.3582	80	6.25	<.0001
dist 20	L	M	-2.2048	0.3582	80	-6.16	<.0001
dist 30	H	M	-178E-17	0.3582	80	-0.00	1.0000
dist 30	L	M	-4.5244	0.3582	80	-12.63	<.0001
dist 40	H	M	2.2946	0.3582	80	6.41	<.0001
dist 40	L	M	-6.8102	0.3582	80	-19.01	<.0001
dist 50	H	M	2.2872	0.3582	80	6.39	<.0001
dist 50	L	M	-6.8658	0.3582	80	-19.17	<.0001
dist 60	H	M	2.3506	0.3582	80	6.56	<.0001
dist 60	L	M	-9.1530	0.3582	80	-25.56	<.0001
dist 70	H	M	4.7530	0.3582	80	13.27	<.0001
dist 70	L	M	-9.2182	0.3582	80	-25.74	<.0001
dist 80	H	M	2.3936	0.3582	80	6.68	<.0001
dist 80	L	M	-13.9712	0.3582	80	-39.01	<.0001
dist 90	H	M	4.8988	0.3582	80	13.68	<.0001

Simple Effect Comparisons of ti*dist Least Squares Means By dist							
Simple Effect Level	**ti**	**_ti**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
dist 90	L	M	-14.0790	0.3582	80	-39.31	<.0001
dist 100	H	M	4.8904	0.3582	80	13.65	<.0001
dist 100	L	M	-16.5410	0.3582	80	-46.18	<.0001

Table B. 8. Disturbance percentage and watershed comparison of runoff rate for a 2-year storm.

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm							
Simple Effect Level	**dist**	**dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_117	**0**	**10**	-0.3300	0.3877	80	-0.85	0.3972
ws WS_117	**0**	**20**	-0.6833	0.3877	80	-1.76	0.0818
ws WS_117	**0**	**30**	-1.1600	0.3877	80	-2.99	0.0037
ws WS_117	**0**	**40**	-1.5300	0.3877	80	-3.95	0.0002
ws WS_117	**0**	**50**	-1.9033	0.3877	80	-4.91	<.0001
ws WS_117	**0**	**60**	-2.1600	0.3877	80	-5.57	<.0001
ws WS_117	**0**	**70**	-2.6733	0.3877	80	-6.89	<.0001
ws WS_117	**0**	**80**	-3.0767	0.3877	80	-7.94	<.0001
ws WS_117	**0**	**90**	-3.6267	0.3877	80	-9.35	<.0001
ws WS_117	**0**	**100**	-3.9167	0.3877	80	-10.10	<.0001
ws WS_117	**10**	**20**	-0.3533	0.3877	80	-0.91	0.3649
ws WS_117	**10**	**30**	-0.8300	0.3877	80	-2.14	0.0353
ws WS_117	**10**	**40**	-1.2000	0.3877	80	-3.09	0.0027
ws WS_117	**10**	**50**	-1.5733	0.3877	80	-4.06	0.0001
ws WS_117	**10**	**60**	-1.8300	0.3877	80	-4.72	<.0001
ws WS_117	**10**	**70**	-2.3433	0.3877	80	-6.04	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm

Simple Effect Level	dist	dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_117	**10**	**80**	-2.7467	0.3877	80	-7.08	<.0001
ws WS_117	**10**	**90**	-3.2967	0.3877	80	-8.50	<.0001
ws WS_117	**10**	**100**	-3.5867	0.3877	80	-9.25	<.0001
ws WS_117	**20**	**30**	-0.4767	0.3877	80	-1.23	0.2225
ws WS_117	**20**	**40**	-0.8467	0.3877	80	-2.18	0.0319
ws WS_117	**20**	**50**	-1.2200	0.3877	80	-3.15	0.0023
ws WS_117	**20**	**60**	-1.4767	0.3877	80	-3.81	0.0003
ws WS_117	**20**	**70**	-1.9900	0.3877	80	-5.13	<.0001
ws WS_117	**20**	**80**	-2.3933	0.3877	80	-6.17	<.0001
ws WS_117	**20**	**90**	-2.9433	0.3877	80	-7.59	<.0001
ws WS_117	**20**	**100**	-3.2333	0.3877	80	-8.34	<.0001
ws WS_117	**30**	**40**	-0.3700	0.3877	80	-0.95	0.3428
ws WS_117	**30**	**50**	-0.7433	0.3877	80	-1.92	0.0588
ws WS_117	**30**	**60**	-1.0000	0.3877	80	-2.58	0.0117
ws WS_117	**30**	**70**	-1.5133	0.3877	80	-3.90	0.0002
ws WS_117	**30**	**80**	-1.9167	0.3877	80	-4.94	<.0001
ws WS_117	**30**	**90**	-2.4667	0.3877	80	-6.36	<.0001
ws WS_117	**30**	**100**	-2.7567	0.3877	80	-7.11	<.0001
ws WS_117	**40**	**50**	-0.3733	0.3877	80	-0.96	0.3385
ws WS_117	**40**	**60**	-0.6300	0.3877	80	-1.62	0.1081
ws WS_117	**40**	**70**	-1.1433	0.3877	80	-2.95	0.0042
ws WS_117	**40**	**80**	-1.5467	0.3877	80	-3.99	0.0001
ws WS_117	**40**	**90**	-2.0967	0.3877	80	-5.41	<.0001
ws WS_117	**40**	**100**	-2.3867	0.3877	80	-6.16	<.0001
ws WS_117	**50**	**60**	-0.2567	0.3877	80	-0.66	0.5099
ws WS_117	**50**	**70**	-0.7700	0.3877	80	-1.99	0.0505
ws WS_117	**50**	**80**	-1.1733	0.3877	80	-3.03	0.0033

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm							
Simple Effect Level	**dist**	**dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_117	**50**	**90**	-1.7233	0.3877	80	-4.44	<.0001
ws WS_117	**50**	**100**	-2.0133	0.3877	80	-5.19	<.0001
ws WS_117	**60**	**70**	-0.5133	0.3877	80	-1.32	0.1893
ws WS_117	**60**	**80**	-0.9167	0.3877	80	-2.36	0.0205
ws WS_117	**60**	**90**	-1.4667	0.3877	80	-3.78	0.0003
ws WS_117	**60**	**100**	-1.7567	0.3877	80	-4.53	<.0001
ws WS_117	**70**	**80**	-0.4033	0.3877	80	-1.04	0.3014
ws WS_117	**70**	**90**	-0.9533	0.3877	80	-2.46	0.0161
ws WS_117	**70**	**100**	-1.2433	0.3877	80	-3.21	0.0019
ws WS_117	**80**	**90**	-0.5500	0.3877	80	-1.42	0.1599
ws WS_117	**80**	**100**	-0.8400	0.3877	80	-2.17	0.0333
ws WS_117	**90**	**100**	-0.2900	0.3877	80	-0.75	0.4567
ws WS_153	**0**	**10**	-0.03000	0.3877	80	-0.08	0.9385
ws WS_153	**0**	**20**	-0.06667	0.3877	80	-0.17	0.8639
ws WS_153	**0**	**30**	-0.1100	0.3877	80	-0.28	0.7774
ws WS_153	**0**	**40**	-0.1467	0.3877	80	-0.38	0.7062
ws WS_153	**0**	**50**	-0.1800	0.3877	80	-0.46	0.6437
ws WS_153	**0**	**60**	-0.2067	0.3877	80	-0.53	0.5955
ws WS_153	**0**	**70**	-0.2533	0.3877	80	-0.65	0.5154
ws WS_153	**0**	**80**	-0.2900	0.3877	80	-0.75	0.4567
ws WS_153	**0**	**90**	-0.3433	0.3877	80	-0.89	0.3785
ws WS_153	**0**	**100**	-0.3700	0.3877	80	-0.95	0.3428
ws WS_153	**10**	**20**	-0.03667	0.3877	80	-0.09	0.9249
ws WS_153	**10**	**30**	-0.08000	0.3877	80	-0.21	0.8371
ws WS_153	**10**	**40**	-0.1167	0.3877	80	-0.30	0.7643
ws WS_153	**10**	**50**	-0.1500	0.3877	80	-0.39	0.6999
ws WS_153	**10**	**60**	-0.1767	0.3877	80	-0.46	0.6499

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm

Simple Effect Level	dist	dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_153	**10**	**70**	-0.2233	0.3877	80	-0.58	0.5662
ws WS_153	**10**	**80**	-0.2600	0.3877	80	-0.67	0.5044
ws WS_153	**10**	**90**	-0.3133	0.3877	80	-0.81	0.4214
ws WS_153	**10**	**100**	-0.3400	0.3877	80	-0.88	0.3832
ws WS_153	**20**	**30**	-0.04333	0.3877	80	-0.11	0.9113
ws WS_153	**20**	**40**	-0.08000	0.3877	80	-0.21	0.8371
ws WS_153	**20**	**50**	-0.1133	0.3877	80	-0.29	0.7708
ws WS_153	**20**	**60**	-0.1400	0.3877	80	-0.36	0.7190
ws WS_153	**20**	**70**	-0.1867	0.3877	80	-0.48	0.6315
ws WS_153	**20**	**80**	-0.2233	0.3877	80	-0.58	0.5662
ws WS_153	**20**	**90**	-0.2767	0.3877	80	-0.71	0.4776
ws WS_153	**20**	**100**	-0.3033	0.3877	80	-0.78	0.4363
ws WS_153	**30**	**40**	-0.03667	0.3877	80	-0.09	0.9249
ws WS_153	**30**	**50**	-0.07000	0.3877	80	-0.18	0.8572
ws WS_153	**30**	**60**	-0.09667	0.3877	80	-0.25	0.8038
ws WS_153	**30**	**70**	-0.1433	0.3877	80	-0.37	0.7126
ws WS_153	**30**	**80**	-0.1800	0.3877	80	-0.46	0.6437
ws WS_153	**30**	**90**	-0.2333	0.3877	80	-0.60	0.5490
ws WS_153	**30**	**100**	-0.2600	0.3877	80	-0.67	0.5044
ws WS_153	**40**	**50**	-0.03333	0.3877	80	-0.09	0.9317
ws WS_153	**40**	**60**	-0.06000	0.3877	80	-0.15	0.8774
ws WS_153	**40**	**70**	-0.1067	0.3877	80	-0.28	0.7839
ws WS_153	**40**	**80**	-0.1433	0.3877	80	-0.37	0.7126
ws WS_153	**40**	**90**	-0.1967	0.3877	80	-0.51	0.6134
ws WS_153	**40**	**100**	-0.2233	0.3877	80	-0.58	0.5662
ws WS_153	**50**	**60**	-0.02667	0.3877	80	-0.07	0.9453
ws WS_153	**50**	**70**	-0.07333	0.3877	80	-0.19	0.8505

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm

Simple Effect Level	dist	dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_153	**50**	**80**	-0.1100	0.3877	80	-0.28	0.7774
ws WS_153	**50**	**90**	-0.1633	0.3877	80	-0.42	0.6747
ws WS_153	**50**	**100**	-0.1900	0.3877	80	-0.49	0.6254
ws WS_153	**60**	**70**	-0.04667	0.3877	80	-0.12	0.9045
ws WS_153	**60**	**80**	-0.08333	0.3877	80	-0.21	0.8304
ws WS_153	**60**	**90**	-0.1367	0.3877	80	-0.35	0.7254
ws WS_153	**60**	**100**	-0.1633	0.3877	80	-0.42	0.6747
ws WS_153	**70**	**80**	-0.03667	0.3877	80	-0.09	0.9249
ws WS_153	**70**	**90**	-0.09000	0.3877	80	-0.23	0.8170
ws WS_153	**70**	**100**	-0.1167	0.3877	80	-0.30	0.7643
ws WS_153	**80**	**90**	-0.05333	0.3877	80	-0.14	0.8909
ws WS_153	**80**	**100**	-0.08000	0.3877	80	-0.21	0.8371
ws WS_153	**90**	**100**	-0.02667	0.3877	80	-0.07	0.9453
ws WS_185	**0**	**10**	-0.7100	0.3877	80	-1.83	0.0708
ws WS_185	**0**	**20**	-1.4300	0.3877	80	-3.69	0.0004
ws WS_185	**0**	**30**	-2.4133	0.3877	80	-6.22	<.0001
ws WS_185	**0**	**40**	-3.1800	0.3877	80	-8.20	<.0001
ws WS_185	**0**	**50**	-3.9467	0.3877	80	-10.18	<.0001
ws WS_185	**0**	**60**	-4.4767	0.3877	80	-11.55	<.0001
ws WS_185	**0**	**70**	-5.5333	0.3877	80	-14.27	<.0001
ws WS_185	**0**	**80**	-6.4467	0.3877	80	-16.63	<.0001
ws WS_185	**0**	**90**	-7.5433	0.3877	80	-19.46	<.0001
ws WS_185	**0**	**100**	-8.0133	0.3877	80	-20.67	<.0001
ws WS_185	**10**	**20**	-0.7200	0.3877	80	-1.86	0.0670
ws WS_185	**10**	**30**	-1.7033	0.3877	80	-4.39	<.0001
ws WS_185	**10**	**40**	-2.4700	0.3877	80	-6.37	<.0001
ws WS_185	**10**	**50**	-3.2367	0.3877	80	-8.35	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm							
Simple Effect Level	**dist**	**dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_185	**10**	**60**	-3.7667	0.3877	80	-9.71	<.0001
ws WS_185	**10**	**70**	-4.8233	0.3877	80	-12.44	<.0001
ws WS_185	**10**	**80**	-5.7367	0.3877	80	-14.80	<.0001
ws WS_185	**10**	**90**	-6.8333	0.3877	80	-17.62	<.0001
ws WS_185	**10**	**100**	-7.3033	0.3877	80	-18.84	<.0001
ws WS_185	**20**	**30**	-0.9833	0.3877	80	-2.54	0.0132
ws WS_185	**20**	**40**	-1.7500	0.3877	80	-4.51	<.0001
ws WS_185	**20**	**50**	-2.5167	0.3877	80	-6.49	<.0001
ws WS_185	**20**	**60**	-3.0467	0.3877	80	-7.86	<.0001
ws WS_185	**20**	**70**	-4.1033	0.3877	80	-10.58	<.0001
ws WS_185	**20**	**80**	-5.0167	0.3877	80	-12.94	<.0001
ws WS_185	**20**	**90**	-6.1133	0.3877	80	-15.77	<.0001
ws WS_185	**20**	**100**	-6.5833	0.3877	80	-16.98	<.0001
ws WS_185	**30**	**40**	-0.7667	0.3877	80	-1.98	0.0514
ws WS_185	**30**	**50**	-1.5333	0.3877	80	-3.95	0.0002
ws WS_185	**30**	**60**	-2.0633	0.3877	80	-5.32	<.0001
ws WS_185	**30**	**70**	-3.1200	0.3877	80	-8.05	<.0001
ws WS_185	**30**	**80**	-4.0333	0.3877	80	-10.40	<.0001
ws WS_185	**30**	**90**	-5.1300	0.3877	80	-13.23	<.0001
ws WS_185	**30**	**100**	-5.6000	0.3877	80	-14.44	<.0001
ws WS_185	**40**	**50**	-0.7667	0.3877	80	-1.98	0.0514
ws WS_185	**40**	**60**	-1.2967	0.3877	80	-3.34	0.0013
ws WS_185	**40**	**70**	-2.3533	0.3877	80	-6.07	<.0001
ws WS_185	**40**	**80**	-3.2667	0.3877	80	-8.43	<.0001
ws WS_185	**40**	**90**	-4.3633	0.3877	80	-11.25	<.0001
ws WS_185	**40**	**100**	-4.8333	0.3877	80	-12.47	<.0001
ws WS_185	**50**	**60**	-0.5300	0.3877	80	-1.37	0.1755

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm							
Simple Effect Level	**dist**	**dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_185	**50**	**70**	-1.5867	0.3877	80	-4.09	0.0001
ws WS_185	**50**	**80**	-2.5000	0.3877	80	-6.45	<.0001
ws WS_185	**50**	**90**	-3.5967	0.3877	80	-9.28	<.0001
ws WS_185	**50**	**100**	-4.0667	0.3877	80	-10.49	<.0001
ws WS_185	**60**	**70**	-1.0567	0.3877	80	-2.73	0.0079
ws WS_185	**60**	**80**	-1.9700	0.3877	80	-5.08	<.0001
ws WS_185	**60**	**90**	-3.0667	0.3877	80	-7.91	<.0001
ws WS_185	**60**	**100**	-3.5367	0.3877	80	-9.12	<.0001
ws WS_185	**70**	**80**	-0.9133	0.3877	80	-2.36	0.0209
ws WS_185	**70**	**90**	-2.0100	0.3877	80	-5.18	<.0001
ws WS_185	**70**	**100**	-2.4800	0.3877	80	-6.40	<.0001
ws WS_185	**80**	**90**	-1.0967	0.3877	80	-2.83	0.0059
ws WS_185	**80**	**100**	-1.5667	0.3877	80	-4.04	0.0001
ws WS_185	**90**	**100**	-0.4700	0.3877	80	-1.21	0.2290
ws WS_249	**0**	**10**	-0.5400	0.3877	80	-1.39	0.1676
ws WS_249	**0**	**20**	-1.0800	0.3877	80	-2.79	0.0067
ws WS_249	**0**	**30**	-1.8167	0.3877	80	-4.69	<.0001
ws WS_249	**0**	**40**	-2.3933	0.3877	80	-6.17	<.0001
ws WS_249	**0**	**50**	-2.9733	0.3877	80	-7.67	<.0001
ws WS_249	**0**	**60**	-3.3733	0.3877	80	-8.70	<.0001
ws WS_249	**0**	**70**	-4.1667	0.3877	80	-10.75	<.0001
ws WS_249	**0**	**80**	-4.7800	0.3877	80	-12.33	<.0001
ws WS_249	**0**	**90**	-5.6033	0.3877	80	-14.45	<.0001
ws WS_249	**0**	**100**	-6.0233	0.3877	80	-15.54	<.0001
ws WS_249	**10**	**20**	-0.5400	0.3877	80	-1.39	0.1676
ws WS_249	**10**	**30**	-1.2767	0.3877	80	-3.29	0.0015
ws WS_249	**10**	**40**	-1.8533	0.3877	80	-4.78	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm

Simple Effect Level	dist	dist	Estimate	Standard Error	DF	t Value	Pr > |t|
ws WS_249	**10**	**50**	-2.4333	0.3877	80	-6.28	<.0001
ws WS_249	**10**	**60**	-2.8333	0.3877	80	-7.31	<.0001
ws WS_249	**10**	**70**	-3.6267	0.3877	80	-9.35	<.0001
ws WS_249	**10**	**80**	-4.2400	0.3877	80	-10.94	<.0001
ws WS_249	**10**	**90**	-5.0633	0.3877	80	-13.06	<.0001
ws WS_249	**10**	**100**	-5.4833	0.3877	80	-14.14	<.0001
ws WS_249	**20**	**30**	-0.7367	0.3877	80	-1.90	0.0610
ws WS_249	**20**	**40**	-1.3133	0.3877	80	-3.39	0.0011
ws WS_249	**20**	**50**	-1.8933	0.3877	80	-4.88	<.0001
ws WS_249	**20**	**60**	-2.2933	0.3877	80	-5.91	<.0001
ws WS_249	**20**	**70**	-3.0867	0.3877	80	-7.96	<.0001
ws WS_249	**20**	**80**	-3.7000	0.3877	80	-9.54	<.0001
ws WS_249	**20**	**90**	-4.5233	0.3877	80	-11.67	<.0001
ws WS_249	**20**	**100**	-4.9433	0.3877	80	-12.75	<.0001
ws WS_249	**30**	**40**	-0.5767	0.3877	80	-1.49	0.1409
ws WS_249	**30**	**50**	-1.1567	0.3877	80	-2.98	0.0038
ws WS_249	**30**	**60**	-1.5567	0.3877	80	-4.01	0.0001
ws WS_249	**30**	**70**	-2.3500	0.3877	80	-6.06	<.0001
ws WS_249	**30**	**80**	-2.9633	0.3877	80	-7.64	<.0001
ws WS_249	**30**	**90**	-3.7867	0.3877	80	-9.77	<.0001
ws WS_249	**30**	**100**	-4.2067	0.3877	80	-10.85	<.0001
ws WS_249	**40**	**50**	-0.5800	0.3877	80	-1.50	0.1386
ws WS_249	**40**	**60**	-0.9800	0.3877	80	-2.53	0.0135
ws WS_249	**40**	**70**	-1.7733	0.3877	80	-4.57	<.0001
ws WS_249	**40**	**80**	-2.3867	0.3877	80	-6.16	<.0001
ws WS_249	**40**	**90**	-3.2100	0.3877	80	-8.28	<.0001
ws WS_249	**40**	**100**	-3.6300	0.3877	80	-9.36	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm							
Simple Effect Level	**dist**	**dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_249	**50**	**60**	-0.4000	0.3877	80	-1.03	0.3053
ws WS_249	**50**	**70**	-1.1933	0.3877	80	-3.08	0.0029
ws WS_249	**50**	**80**	-1.8067	0.3877	80	-4.66	<.0001
ws WS_249	**50**	**90**	-2.6300	0.3877	80	-6.78	<.0001
ws WS_249	**50**	**100**	-3.0500	0.3877	80	-7.87	<.0001
ws WS_249	**60**	**70**	-0.7933	0.3877	80	-2.05	0.0440
ws WS_249	**60**	**80**	-1.4067	0.3877	80	-3.63	0.0005
ws WS_249	**60**	**90**	-2.2300	0.3877	80	-5.75	<.0001
ws WS_249	**60**	**100**	-2.6500	0.3877	80	-6.83	<.0001
ws WS_249	**70**	**80**	-0.6133	0.3877	80	-1.58	0.1176
ws WS_249	**70**	**90**	-1.4367	0.3877	80	-3.71	0.0004
ws WS_249	**70**	**100**	-1.8567	0.3877	80	-4.79	<.0001
ws WS_249	**80**	**90**	-0.8233	0.3877	80	-2.12	0.0368
ws WS_249	**80**	**100**	-1.2433	0.3877	80	-3.21	0.0019
ws WS_249	**90**	**100**	-0.4200	0.3877	80	-1.08	0.2820
ws WS_99	**0**	**10**	-0.3300	0.3877	80	-0.85	0.3972
ws WS_99	**0**	**20**	-0.6867	0.3877	80	-1.77	0.0804
ws WS_99	**0**	**30**	-1.1833	0.3877	80	-3.05	0.0031
ws WS_99	**0**	**40**	-1.5667	0.3877	80	-4.04	0.0001
ws WS_99	**0**	**50**	-1.9333	0.3877	80	-4.99	<.0001
ws WS_99	**0**	**60**	-2.1933	0.3877	80	-5.66	<.0001
ws WS_99	**0**	**70**	-2.7267	0.3877	80	-7.03	<.0001
ws WS_99	**0**	**80**	-3.1300	0.3877	80	-8.07	<.0001
ws WS_99	**0**	**90**	-3.6833	0.3877	80	-9.50	<.0001
ws WS_99	**0**	**100**	-3.9700	0.3877	80	-10.24	<.0001
ws WS_99	**10**	**20**	-0.3567	0.3877	80	-0.92	0.3604
ws WS_99	**10**	**30**	-0.8533	0.3877	80	-2.20	0.0306

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm							
Simple Effect Level	**dist**	**dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_99	**10**	**40**	-1.2367	0.3877	80	-3.19	0.0020
ws WS_99	**10**	**50**	-1.6033	0.3877	80	-4.14	<.0001
ws WS_99	**10**	**60**	-1.8633	0.3877	80	-4.81	<.0001
ws WS_99	**10**	**70**	-2.3967	0.3877	80	-6.18	<.0001
ws WS_99	**10**	**80**	-2.8000	0.3877	80	-7.22	<.0001
ws WS_99	**10**	**90**	-3.3533	0.3877	80	-8.65	<.0001
ws WS_99	**10**	**100**	-3.6400	0.3877	80	-9.39	<.0001
ws WS_99	**20**	**30**	-0.4967	0.3877	80	-1.28	0.2039
ws WS_99	**20**	**40**	-0.8800	0.3877	80	-2.27	0.0259
ws WS_99	**20**	**50**	-1.2467	0.3877	80	-3.22	0.0019
ws WS_99	**20**	**60**	-1.5067	0.3877	80	-3.89	0.0002
ws WS_99	**20**	**70**	-2.0400	0.3877	80	-5.26	<.0001
ws WS_99	**20**	**80**	-2.4433	0.3877	80	-6.30	<.0001
ws WS_99	**20**	**90**	-2.9967	0.3877	80	-7.73	<.0001
ws WS_99	**20**	**100**	-3.2833	0.3877	80	-8.47	<.0001
ws WS_99	**30**	**40**	-0.3833	0.3877	80	-0.99	0.3258
ws WS_99	**30**	**50**	-0.7500	0.3877	80	-1.93	0.0566
ws WS_99	**30**	**60**	-1.0100	0.3877	80	-2.60	0.0110
ws WS_99	**30**	**70**	-1.5433	0.3877	80	-3.98	0.0002
ws WS_99	**30**	**80**	-1.9467	0.3877	80	-5.02	<.0001
ws WS_99	**30**	**90**	-2.5000	0.3877	80	-6.45	<.0001
ws WS_99	**30**	**100**	-2.7867	0.3877	80	-7.19	<.0001
ws WS_99	**40**	**50**	-0.3667	0.3877	80	-0.95	0.3472
ws WS_99	**40**	**60**	-0.6267	0.3877	80	-1.62	0.1100
ws WS_99	**40**	**70**	-1.1600	0.3877	80	-2.99	0.0037
ws WS_99	**40**	**80**	-1.5633	0.3877	80	-4.03	0.0001
ws WS_99	**40**	**90**	-2.1167	0.3877	80	-5.46	<.0001

Simple Effect Comparisons of ws*dist Least Squares Means By ws: 2-yr storm							
Simple Effect Level	**dist**	**dist**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
ws WS_99	**40**	**100**	-2.4033	0.3877	80	-6.20	<.0001
ws WS_99	**50**	**60**	-0.2600	0.3877	80	-0.67	0.5044
ws WS_99	**50**	**70**	-0.7933	0.3877	80	-2.05	0.0440
ws WS_99	**50**	**80**	-1.1967	0.3877	80	-3.09	0.0028
ws WS_99	**50**	**90**	-1.7500	0.3877	80	-4.51	<.0001
ws WS_99	**50**	**100**	-2.0367	0.3877	80	-5.25	<.0001
ws WS_99	**60**	**70**	-0.5333	0.3877	80	-1.38	0.1728
ws WS_99	**60**	**80**	-0.9367	0.3877	80	-2.42	0.0180
ws WS_99	**60**	**90**	-1.4900	0.3877	80	-3.84	0.0002
ws WS_99	**60**	**100**	-1.7767	0.3877	80	-4.58	<.0001
ws WS_99	**70**	**80**	-0.4033	0.3877	80	-1.04	0.3014
ws WS_99	**70**	**90**	-0.9567	0.3877	80	-2.47	0.0157
ws WS_99	**70**	**100**	-1.2433	0.3877	80	-3.21	0.0019
ws WS_99	**80**	**90**	-0.5533	0.3877	80	-1.43	0.1574
ws WS_99	**80**	**100**	-0.8400	0.3877	80	-2.17	0.0333
ws WS_99	**90**	**100**	-0.2867	0.3877	80	-0.74	0.4619

Figure B. 19. Watershed comparison for runoff (mm), 2-year storm with light use.

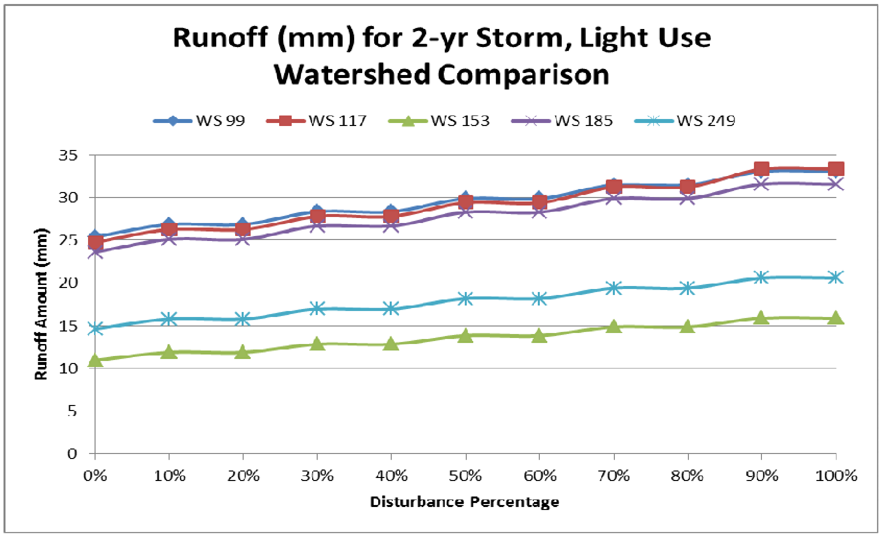


Figure B. 20. Watershed comparison for runoff (mm), 2-year storm with moderate use.

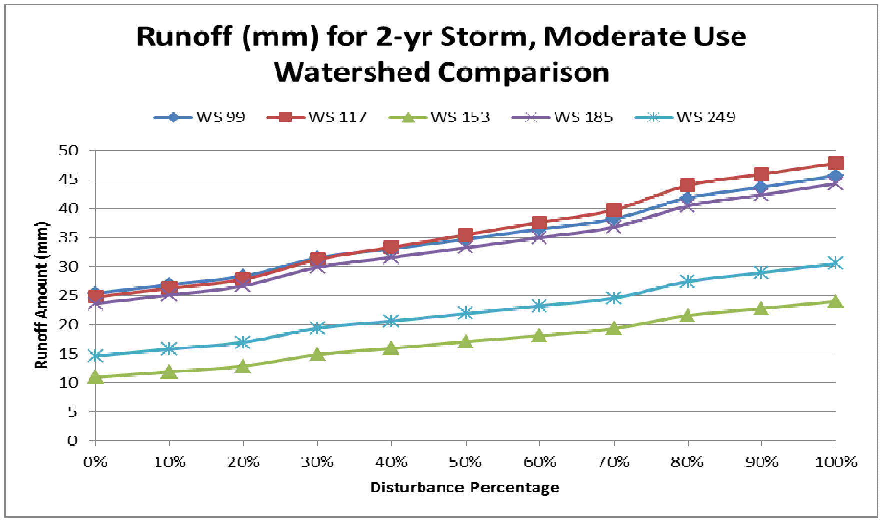


Figure B. 21. Watershed comparison for runoff (mm), 2-year storm with heavy use.

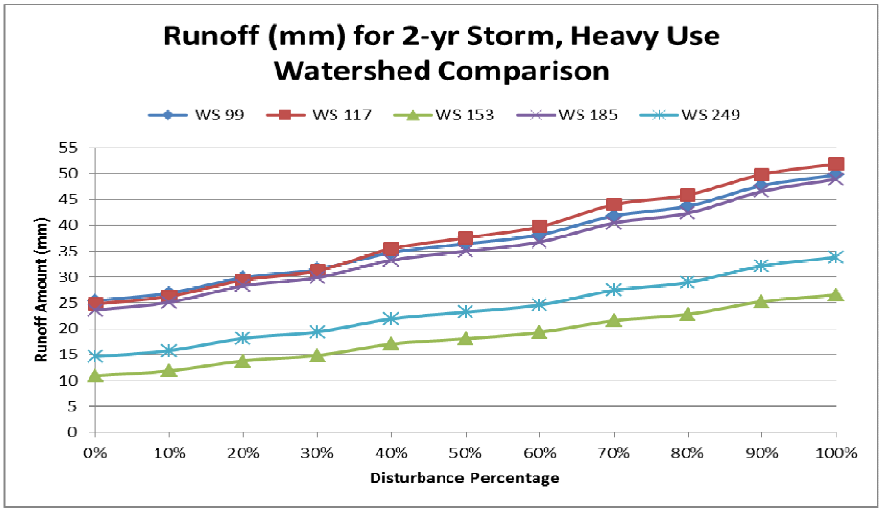


Figure B. 22. Watershed comparison for runoff (mm), 10-year storm with light use.

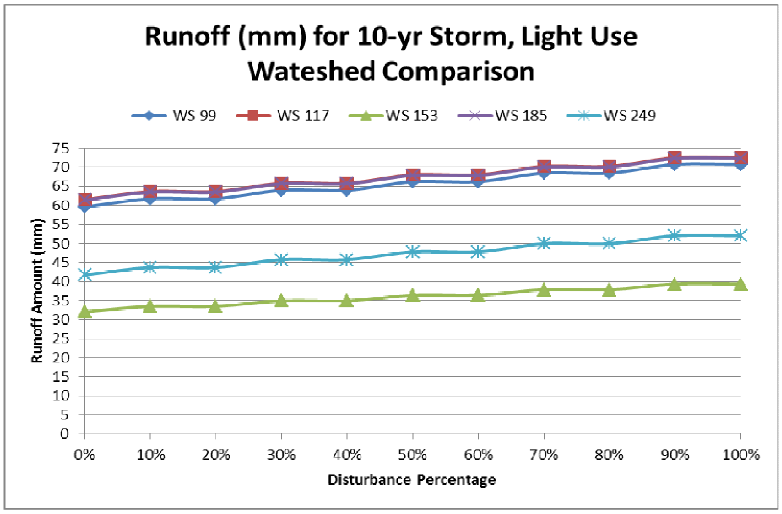


Figure B. 23. Watershed comparison for runoff (mm), 10-year storm with moderate use.

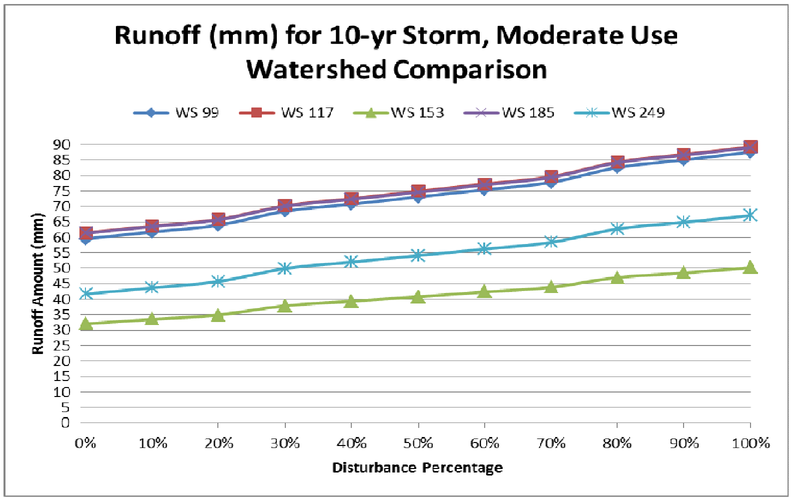


Figure B. 24. Watershed comparison for runoff (mm), 10-year storm with heavy use.

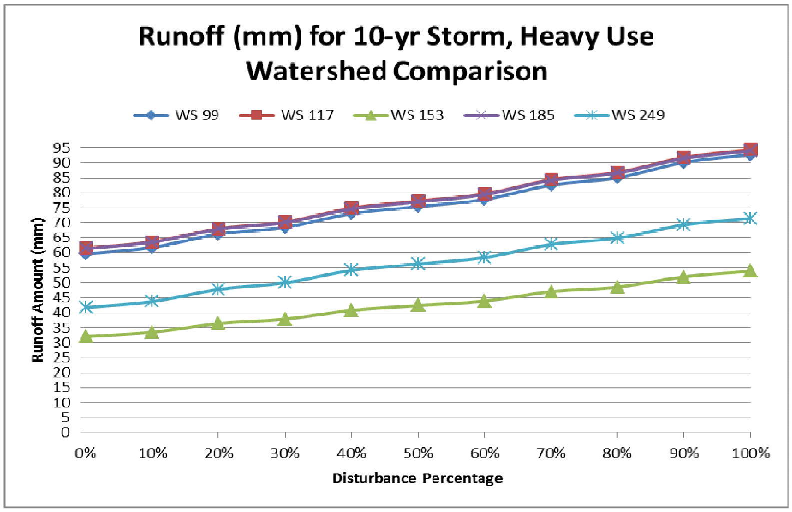


Figure B. 25. Watershed comparison for runoff (mm), 25-year storm with light use.

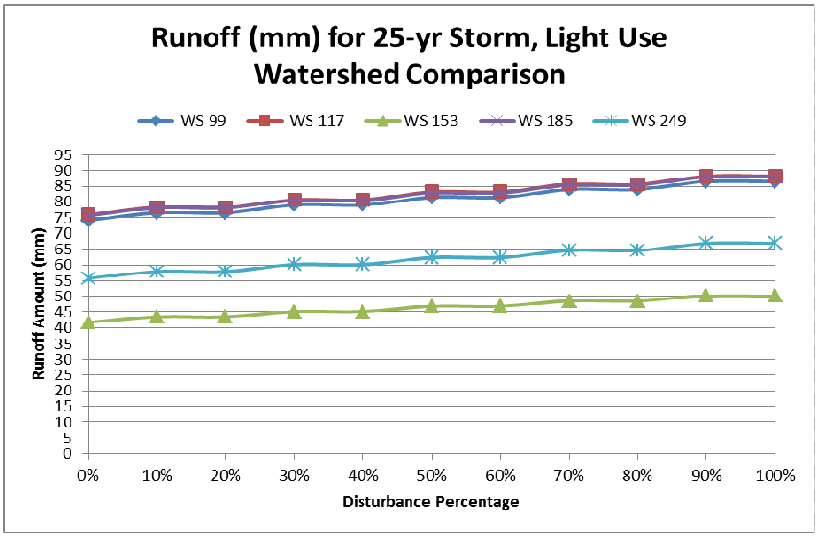


Figure B. 26. Watershed comparison for runoff (mm), 25-year storm with moderate use.

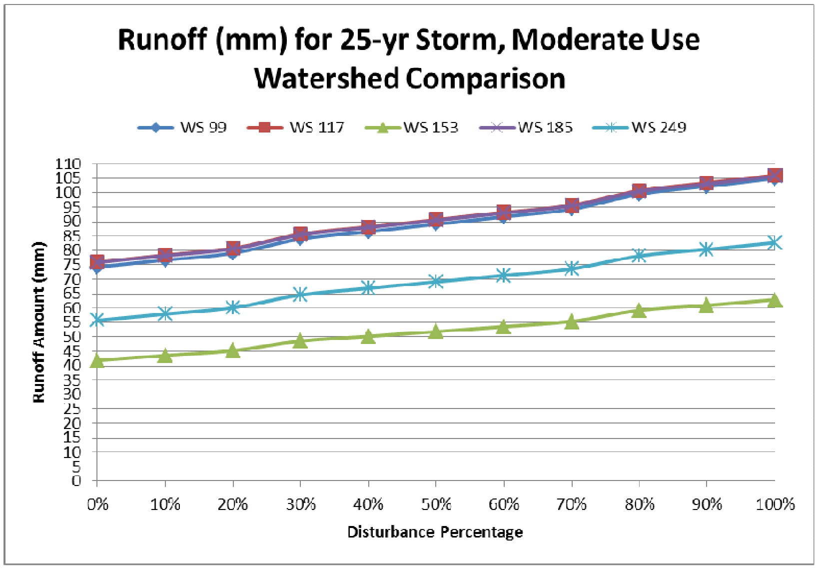


Figure B. 27. Watershed comparison for runoff (mm), 25-year storm with heavy use.

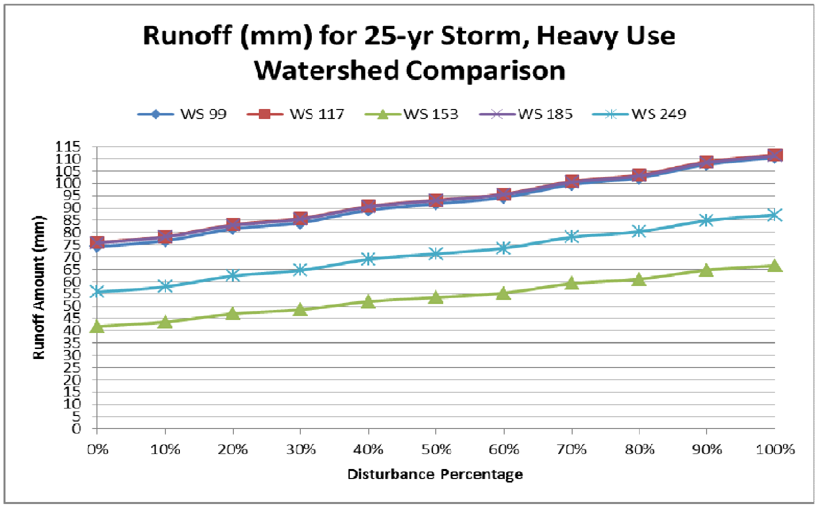


Figure B. 28. Training intensity comparison runoff amount, WS 99 2-year storm.

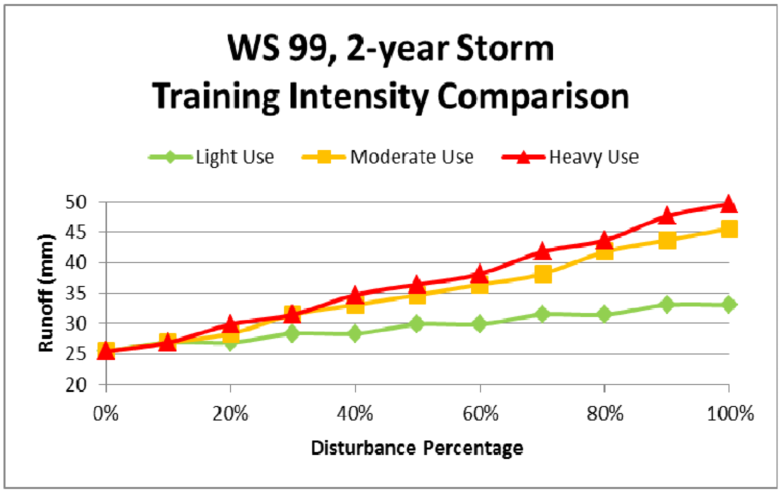


Figure B. 29. Training intensity comparison runoff amount, WS 117 2-year storm.

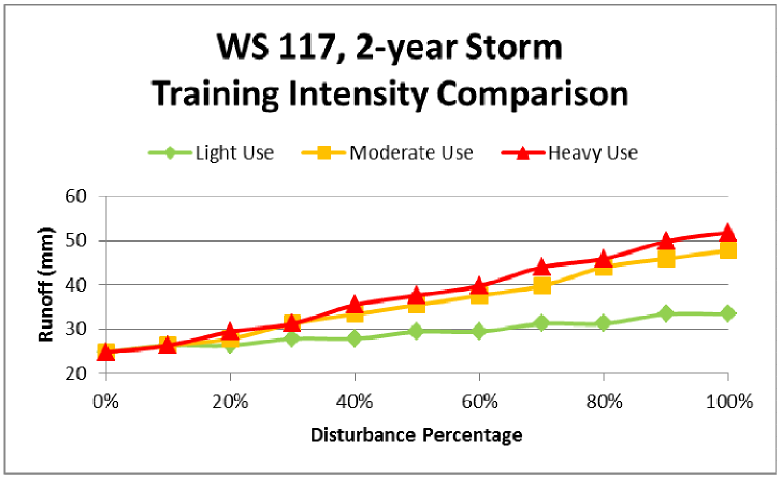


Figure B. 30. Training intensity comparison runoff amount, WS 153 2-year storm.

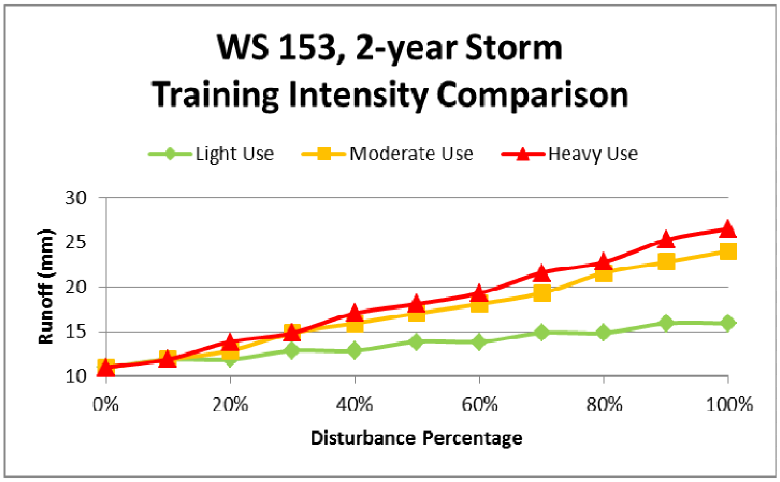


Figure B. 31. Training intensity comparison runoff amount, WS 185 2-year storm.

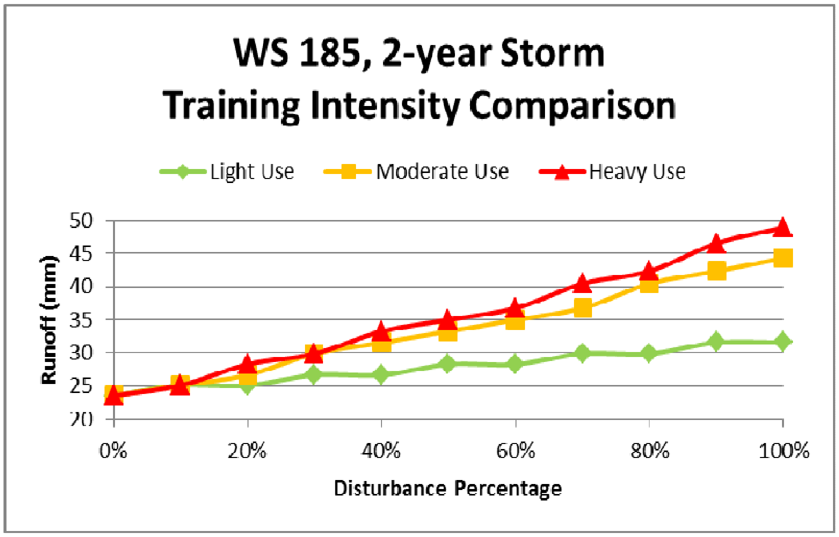


Figure B. 32. Training intensity comparison runoff amount, WS 249 2-year storm.

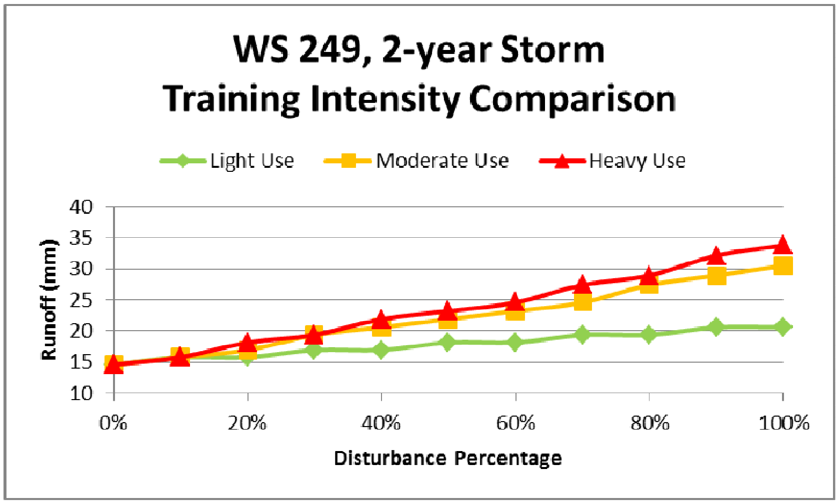


Figure B. 33. Training intensity comparison runoff amount, WS 99 10-year storm.

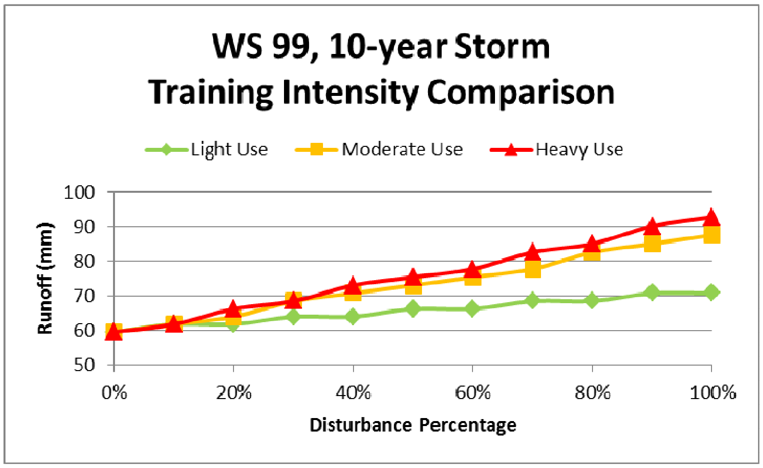


Figure B. 34. Training intensity comparison runoff amount, WS 117 10-year storm.

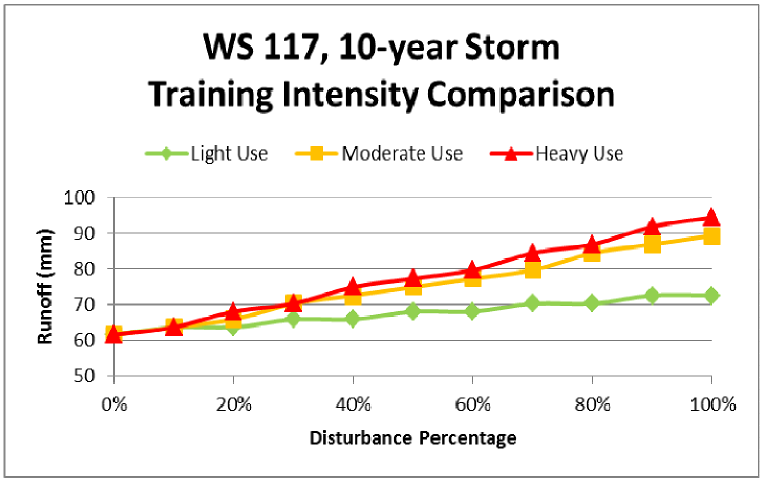


Figure B. 35. Training intensity comparison runoff amount, WS 153 10-year storm.

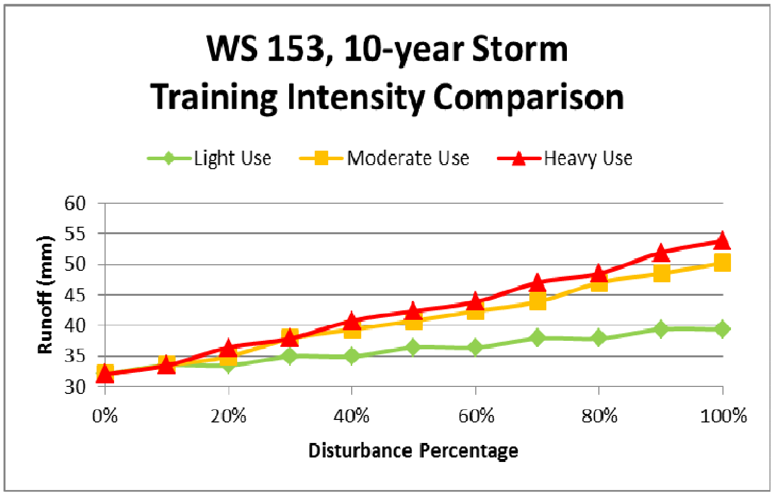


Figure B. 36. Training intensity comparison runoff amount, WS 185 10-year storm.

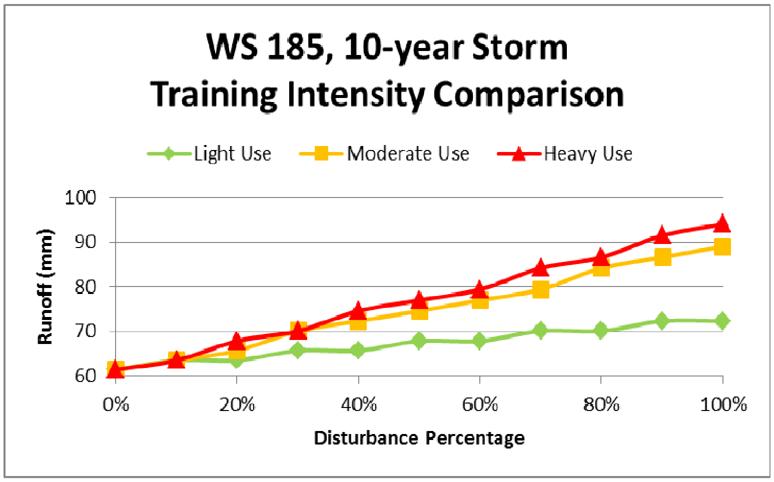


Figure B. 37. Training intensity comparison runoff amount, WS 249 10-year storm.

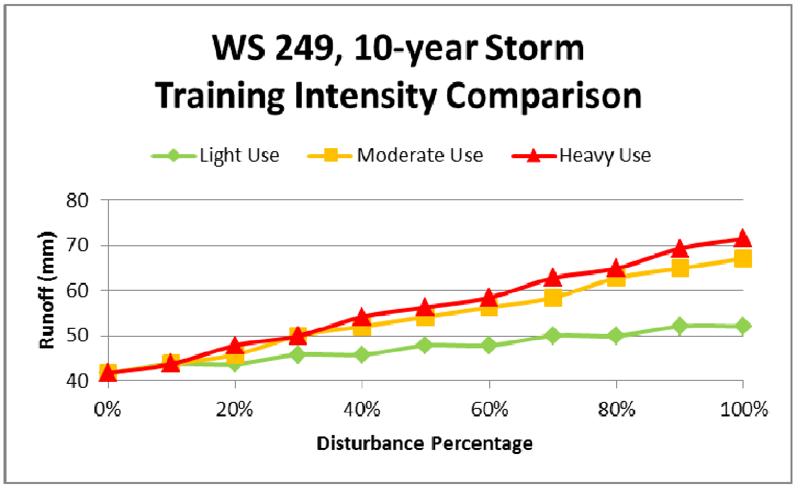


Figure B. 38. Training intensity comparison runoff amount, WS 99 25-year storm.

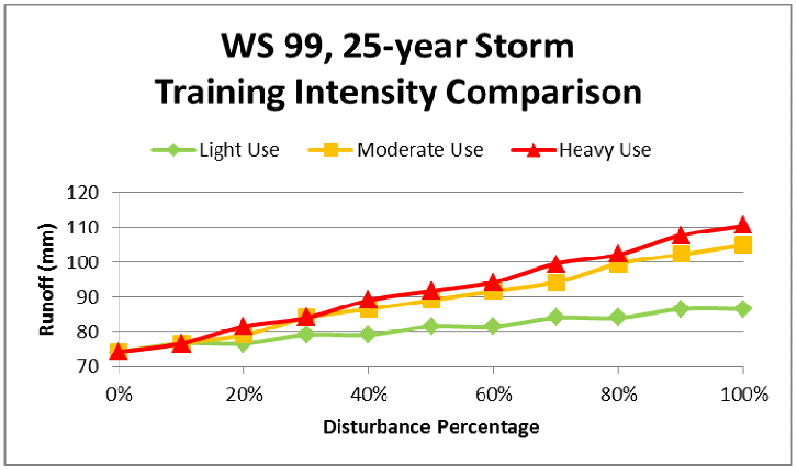


Figure B. 39. Training intensity comparison runoff amount, WS 117 25-year storm.

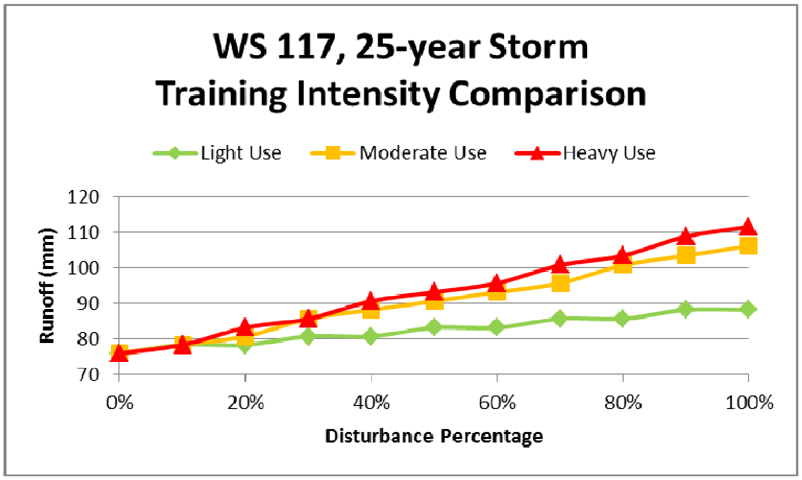


Figure B. 40. Training intensity comparison runoff amount, WS 153 25-year storm.

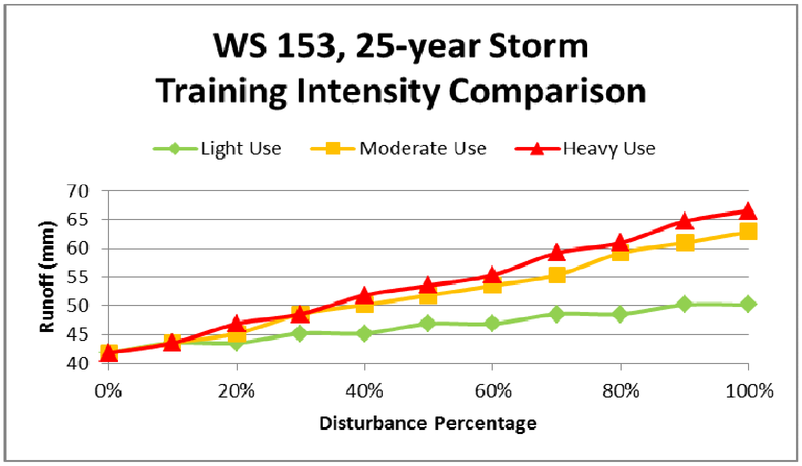


Figure B. 41. Training intensity comparison runoff amount, WS 185 25-year storm.

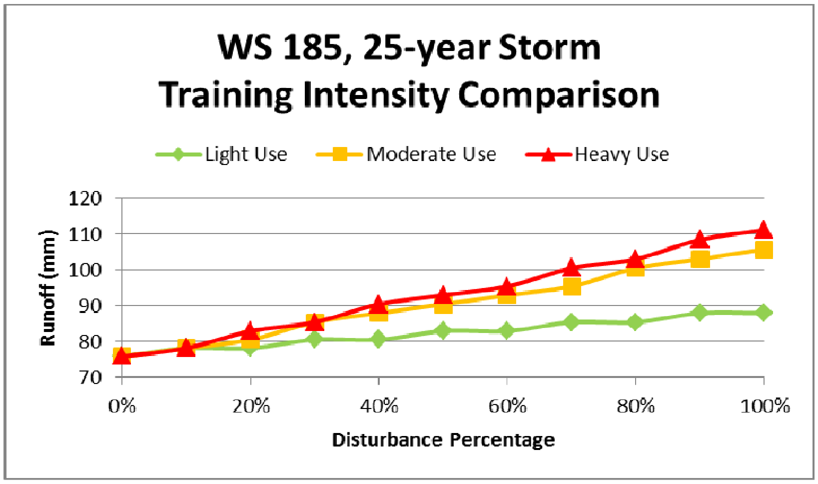


Figure B. 42. Training intensity comparison runoff amount, WS 249 25-year storm.

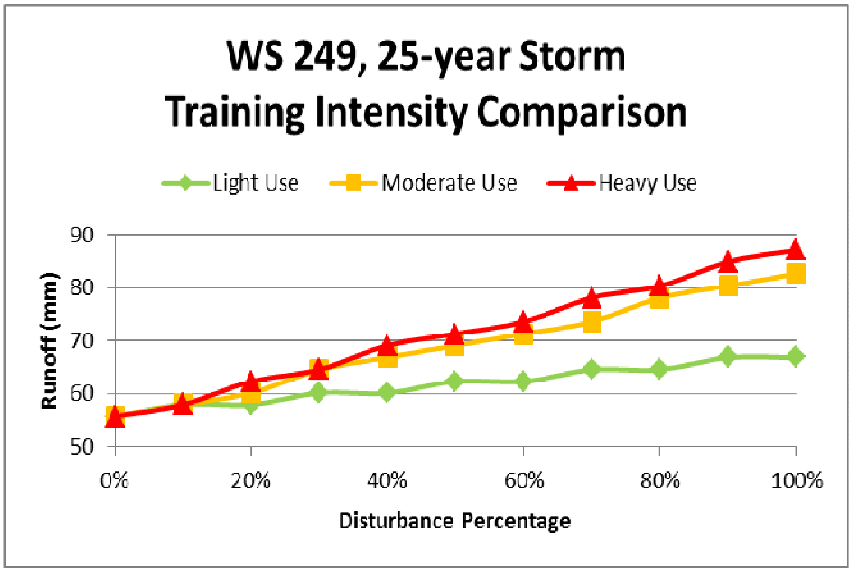


Figure B. 43. Watershed comparison runoff rate (m^3s^{-1}), for 2-year storm with light use.

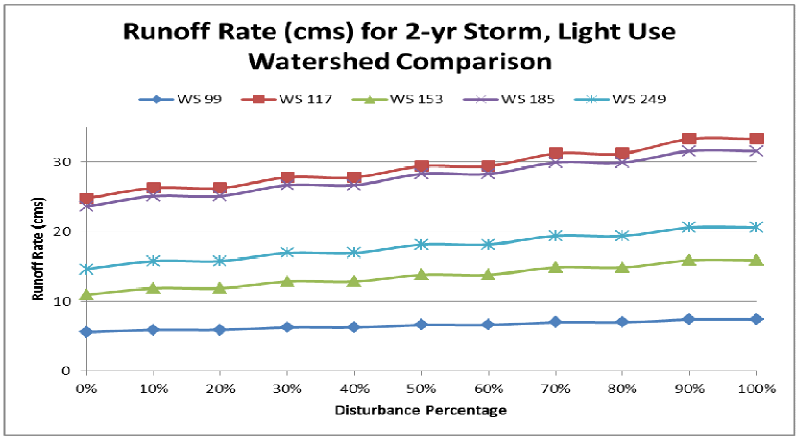


Figure B. 44. Watershed comparison runoff rate (m³s⁻¹), for 2-year storm with moderate use.

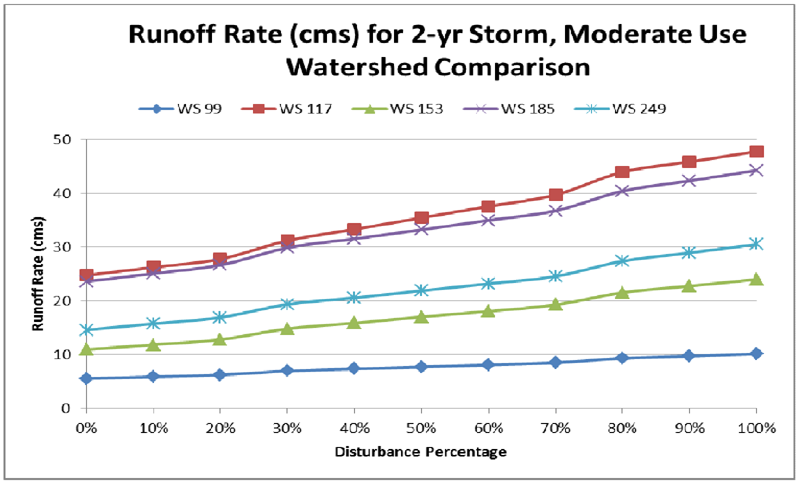


Figure B. 45. Watershed comparison runoff rate (m³s⁻¹), for 2-year storm with heavy use.

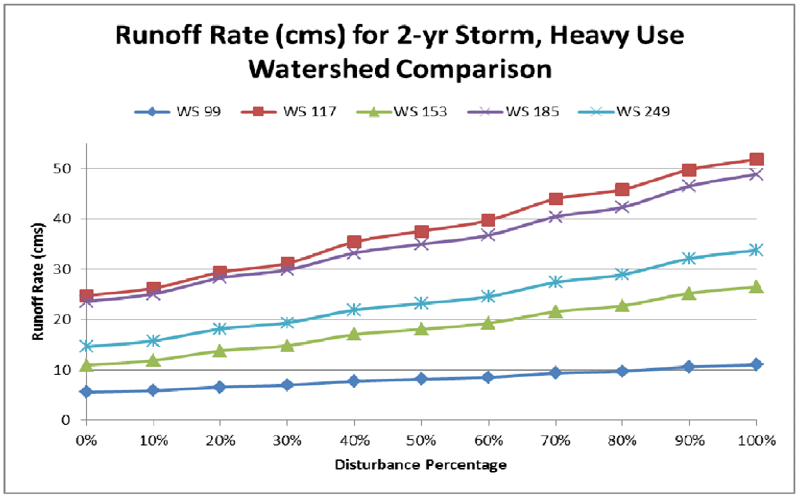


Figure B. 46. Watershed comparison runoff rate (m³s⁻¹), for 10-year storm with light use.

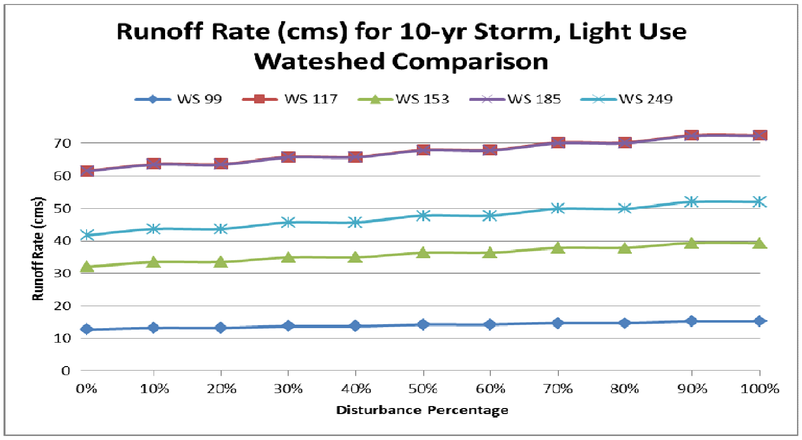


Figure B. 47. Watershed comparison runoff rate (m³s⁻¹), for 10-year storm with moderate use.

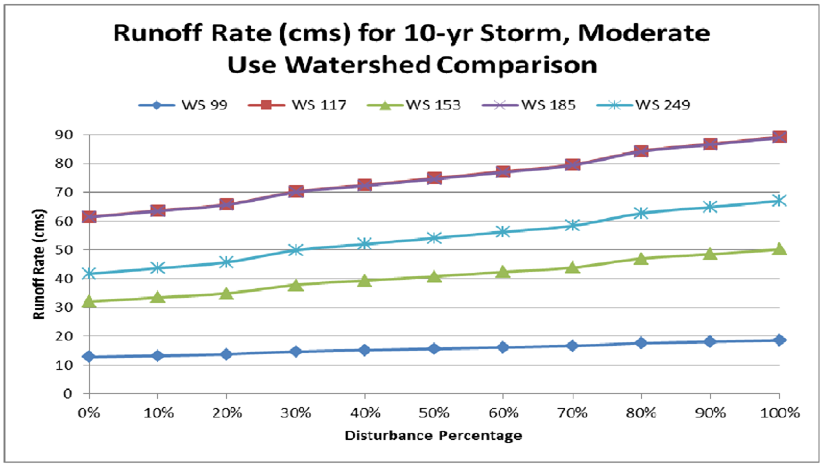


Figure B. 48. Watershed comparison runoff rate (m³s⁻¹), for 10-year storm with heavy use.

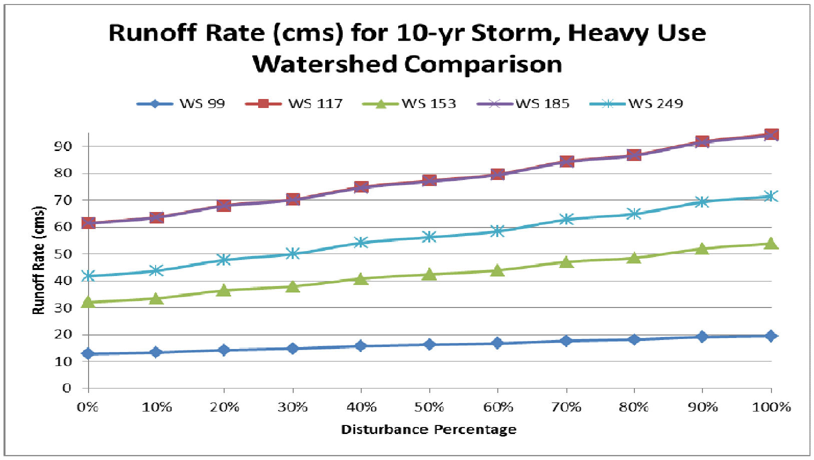


Figure B. 49. Watershed comparison runoff rate (m^3s^{-1}), for 25-year storm with light use.

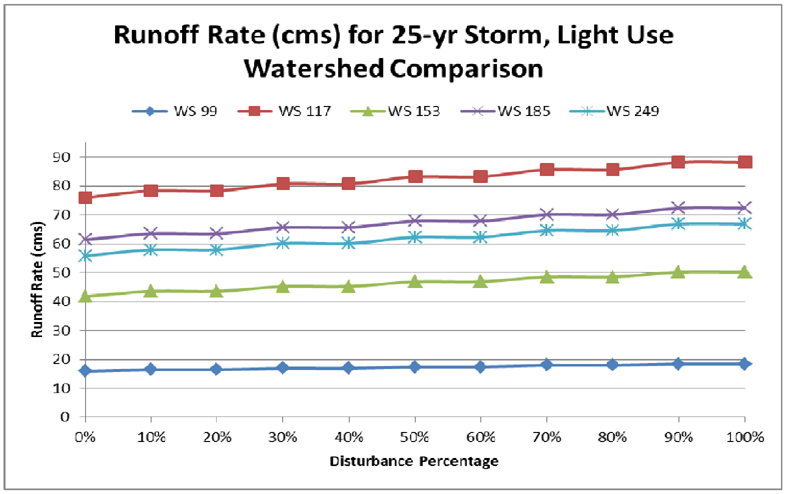


Figure B. 50. Watershed comparison runoff rate (m^3s^{-1}), for 25-year storm with moderate use.

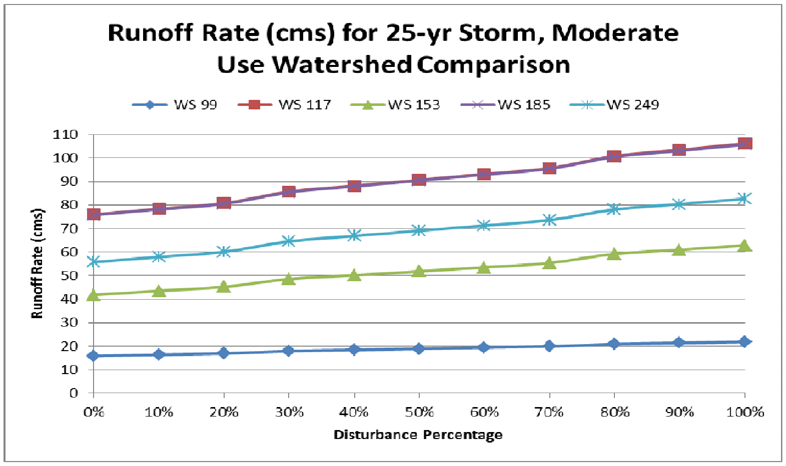


Figure B. 51. Watershed comparison runoff rate (m^3s^{-1}), for 25-year storm with heavy use.

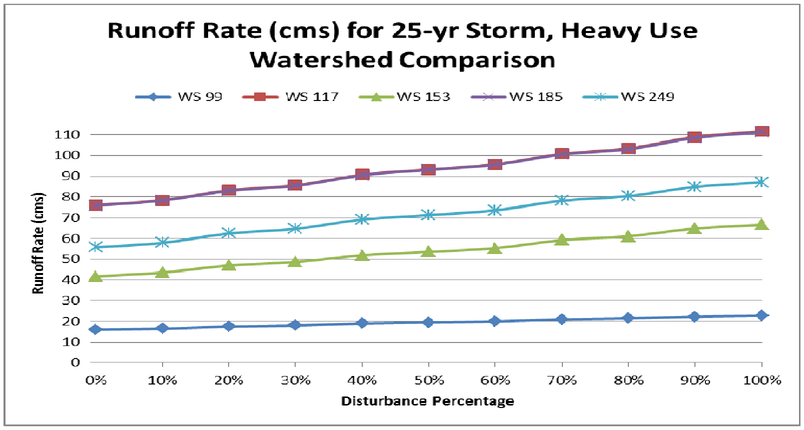


Figure B. 52. Training intensity comparison runoff rate, WS 99 2-year storm.

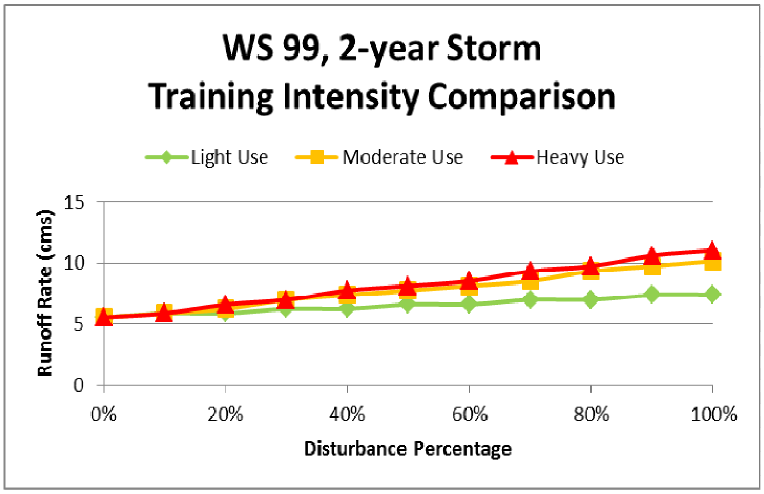


Figure B. 53. Training intensity comparison runoff rate, WS 117 2-year storm.

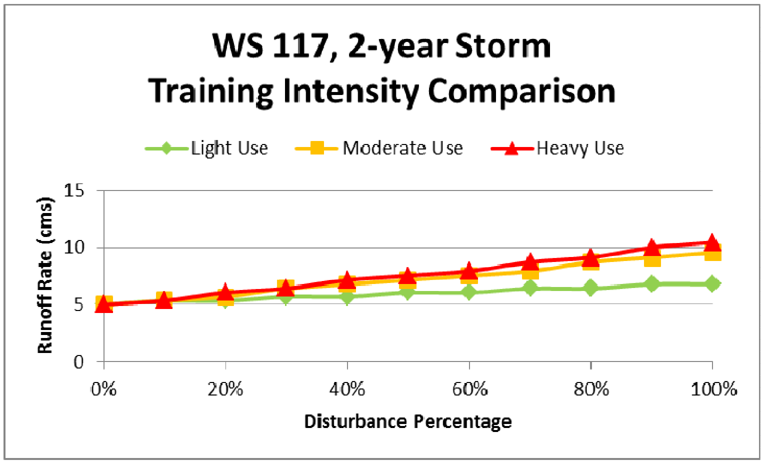


Figure B. 54. Training intensity comparison runoff rate, WS 153 2-year storm.

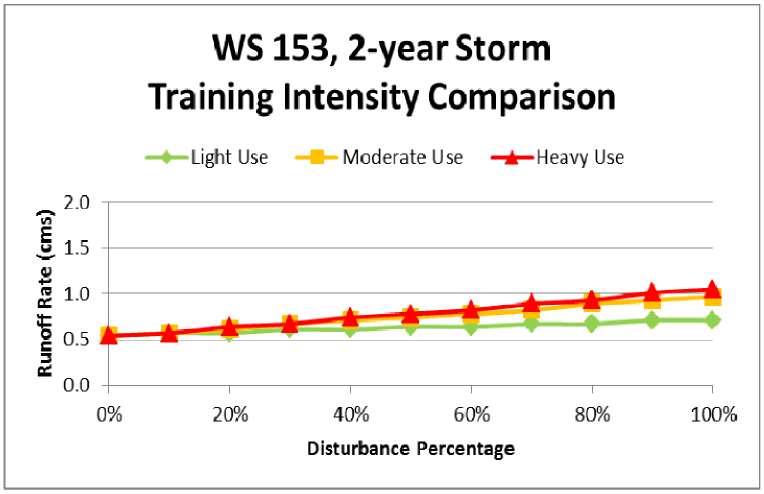


Figure B. 55. Training intensity comparison runoff rate, WS 185 2-year storm.

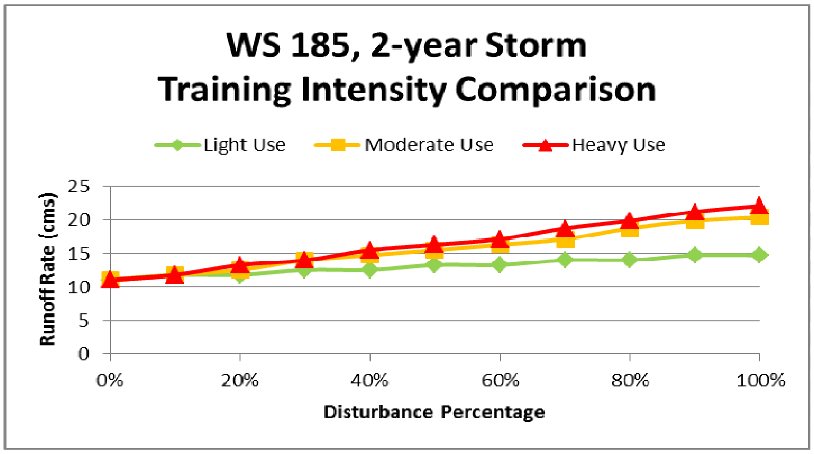


Figure B. 56. Training intensity comparison runoff rate, WS 249 2-year storm.

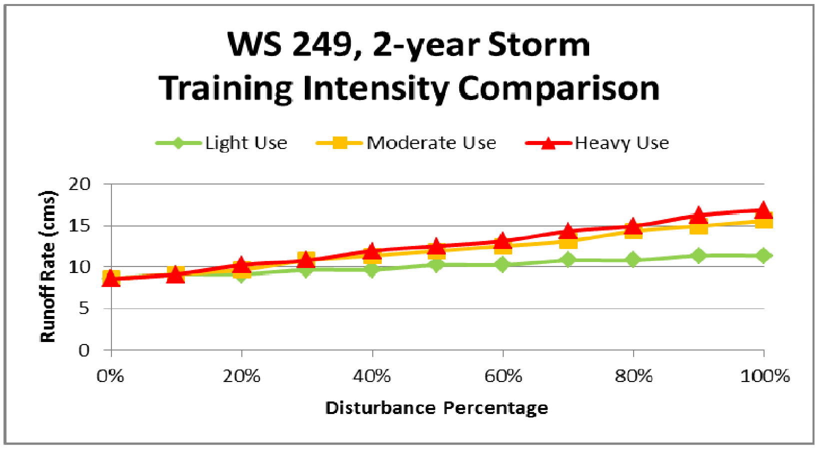


Figure B. 57. Training intensity comparison runoff rate, WS 99 10-year storm.

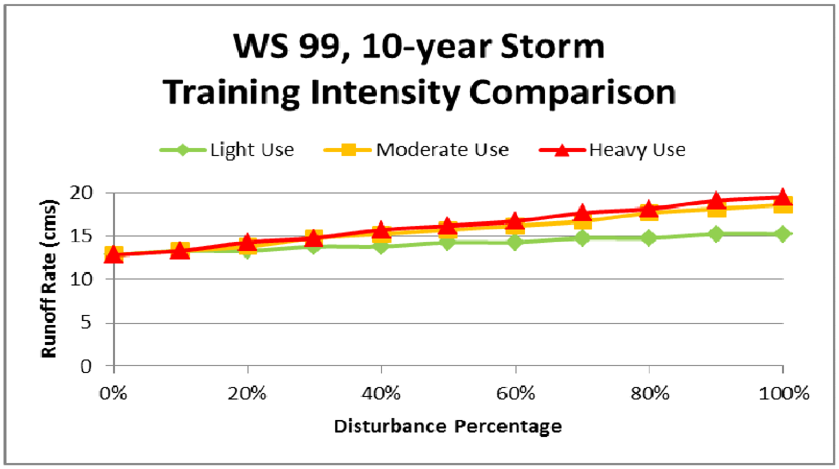


Figure B. 58. Training intensity comparison runoff rate, WS 117 10-year storm.

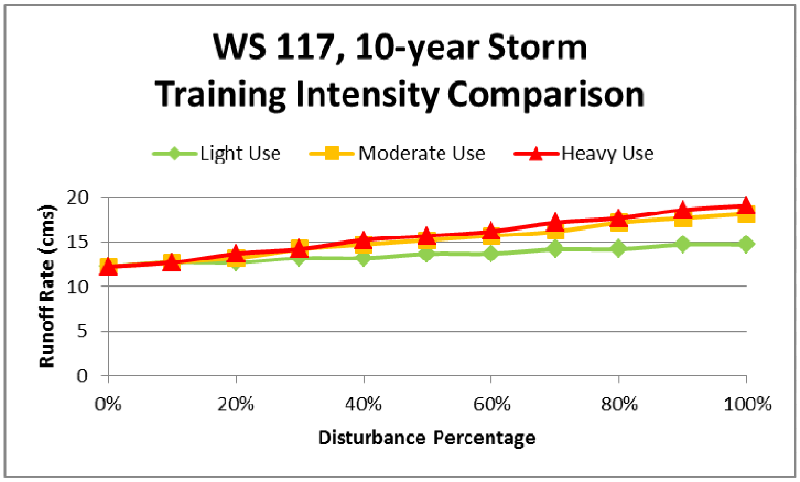


Figure B. 59. Training intensity comparison runoff rate, WS 153 10-year storm.

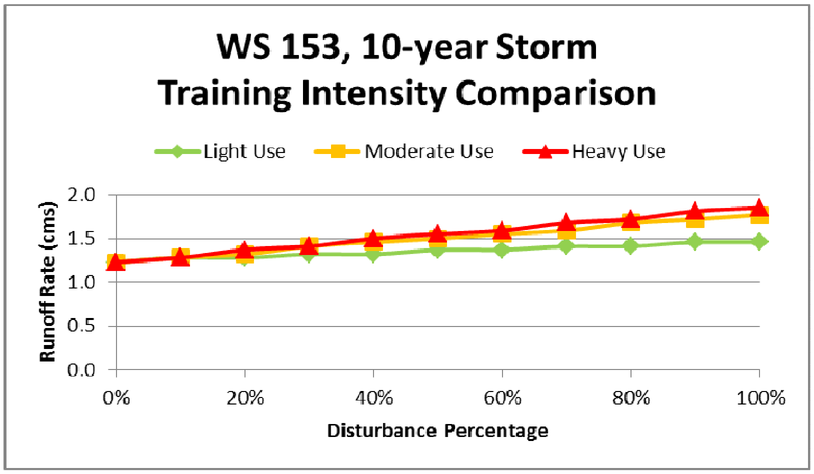


Figure B. 60. Training intensity comparison runoff rate, WS 185 10-year storm.

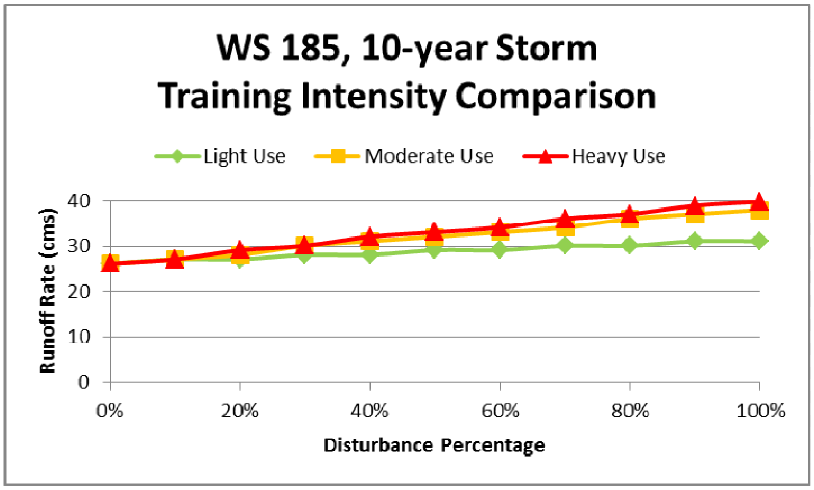


Figure B. 61. Training intensity comparison runoff rate, WS 249 10-year storm.

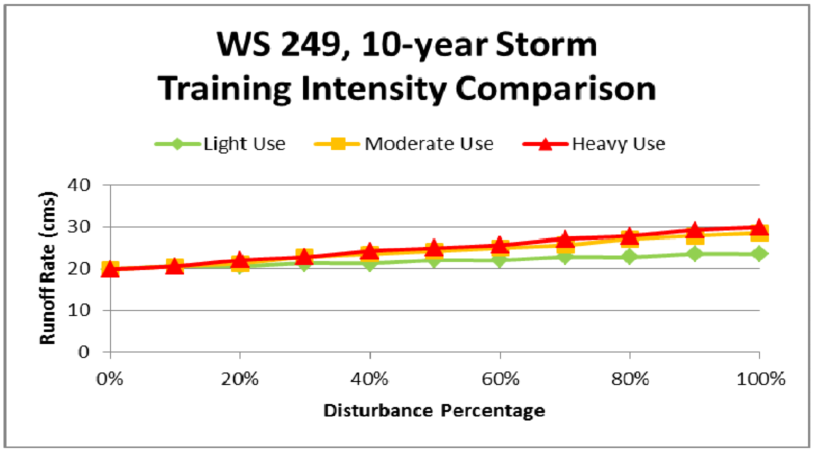


Figure B. 62. Training intensity comparison runoff rate, WS 99 25-year storm.

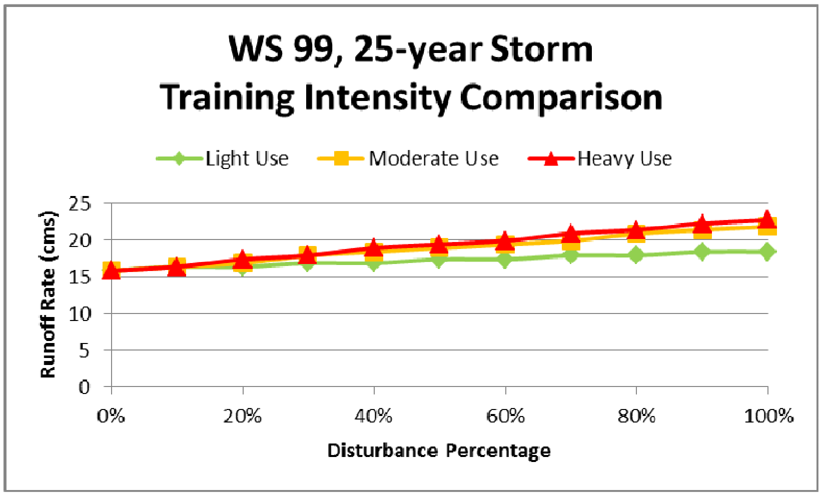


Figure B. 63. Training intensity comparison runoff rate, WS 117 25-year storm.

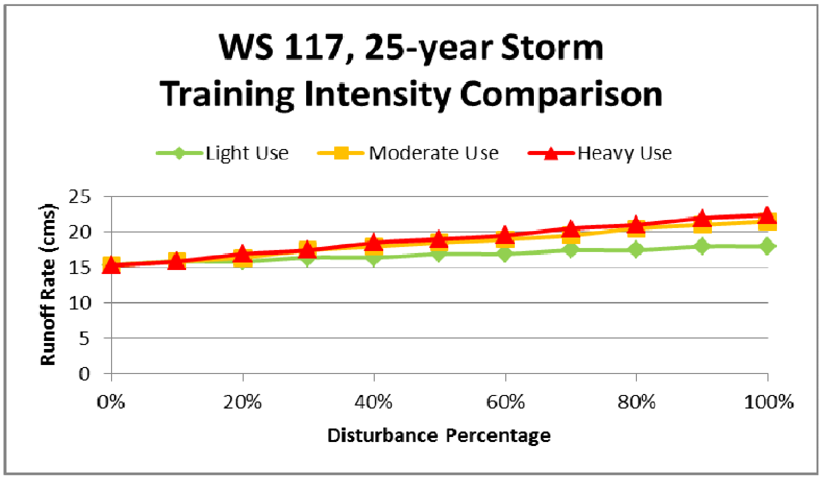


Figure B. 64. Training intensity comparison runoff rate, WS 153 25-year storm.

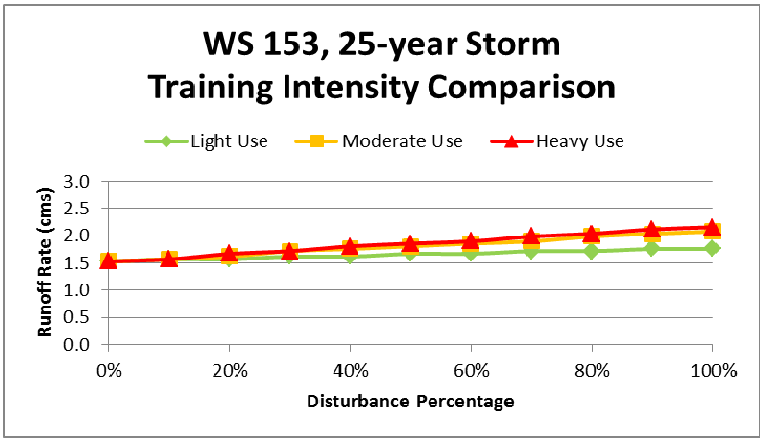


Figure B. 65. Training intensity comparison runoff rate, WS 185 25-year storm.

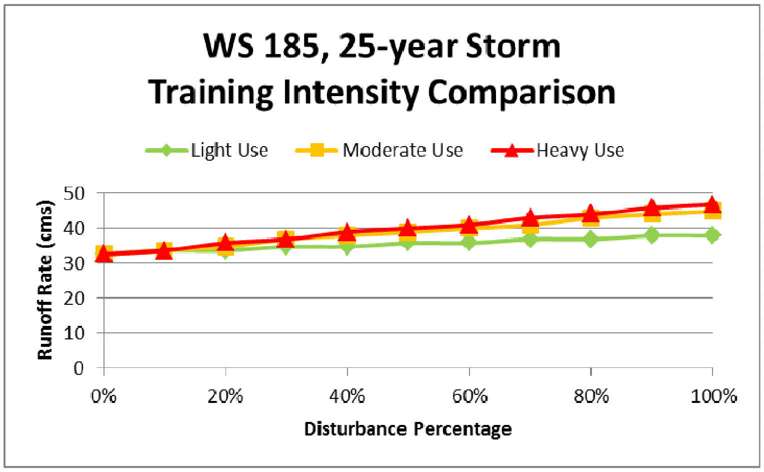


Figure B. 66. Training intensity comparison runoff rate, WS 249 25-year storm.