Extension Report 37

Protecting Surface Water from Pesticide Contamination in North Dakota – Recommendations for Assessment and Management

A Review and Analysis of Scientific Literature

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Table of Contents

Tables

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▼ Pesticide Occurrence in Surface Water

Evidence from scientific studies shows that a small percentage of the total amount of the pesticides applied for crop protection is entrained in surface runoff and moves into streams and lakes (Stewart et al., 1975; Caro, 1976; White et al., 1976; Wauchope, 1978; Baker et al., 1979; Rhode et al., 1980; Lorber and Mulkey, 1982; Nicholaichuk and Grover, 1983; Wu et al., 1983; Ng et al., 1995). Donald and Syrgiannis (1995) detected lindane, α-HCH, 2,4-D, MCPA, atrazine, and dicamba in water samples and triallate, atrazine, bromoxynil, MCPA, and 2,4-D in sediment samples from prairie lakes in Saskatchewan. The pesticide levels found in this study were well below guideline levels for protection of aquatic life. In a study done in North Dakota, picloram was detected at several sampling points along the Des Lacs and Souris Rivers (Lym and Messersmith, 1988). Atrazine, cyanazine, metolachlor, and triallate were detected in more than 50% of the samples from the Red River and its tributaries (Brigham, 1994; Tornes and Brigham, 1995). A review of pesticide detections from 1970 through 1990 in the Red River and its tributaries found that 2,4-D was detected over the entire period of record in approximately 40% of the samples.

Wauchope's (1978) work defined a general pattern of pesticide loss from cropland. He concluded that 1% of the total foliar applied organochlorine insecticides were lost to surface runoff on average. However, this family of insecticides is no longer used. He also estimated that for pesticides with wettable powder formulations, such as the triazine herbicides, annual runoff losses would be about 2% of the total applied on land with less than 10% slope and about 5% of the total applied on land with greater than 10% slope. Non-organochlorine insecticides, incorporated pesticides, and all other herbicides were estimated to have losses of about 0.5% of the total applied.

The concentrations of organochlorine insecticides in surface waters peaked and began declining in the mid 1960s (Caro, 1976). During the 1960s environmental problems related to high persistence and biomagnification led to restricted or banned use of organochlorine insecticides. Logan (1990) argues that regulatory source-reductions of pesticides have been the most effective way to protect water resources. The concentrations of lindane in samples from the Red River have declined significantly since restrictions were placed on its use in the mid 1980s (Tornes and Brigham, 1994). The concentration of DDT and its metabolites (DDE and DDD) decreased rapidly in tissues of fish from the Red River after DDT was banned in 1972. However, despite the decline in organochlorine insecticide detections, DDE and DDD were the most frequently found pesticides in fish tissue samples from 31 lakes in North Dakota 20 years after the ban on DDT (NDSDH Staff, 1994).

Pesticides developed subsequent to the organochlorine era are much less persistent and most have little potential for biomagnification (Leonard, 1990). Although contamination of streams and lakes with pesticides continues to occur, it is sporadic and declining (Caro, 1976; Leonard, 1990). Rarely does the concentration of pesticides in surface water pose a threat to public health (Caro, 1976; Leonard, 1990; Baker and Richards, 1994; Brigham, 1994; Richards and Baker, 1994). Documented impacts from pesticides, particularly organochlorines, have been observed on aquatic birds, fish, aquatic plants, and invertebrates (Caro, 1976; Madhun and Freed, 1989). Although pesticides other than the organochlorines have environmental impacts, such as the toxic effects of trifluralin on fish (Caro, 1976), fish kills in the Red River have not been observed in recent years (Goldstein, 1995). Wauchope (1978) states that no evidence exists regarding permanent impacts of non-persistent pesticides on aquatic ecosystems.

▼ Pesticide Use in North Dakota

Over 50 different herbicides, 20 different insecticides, and 10 different fungicides were used on crops in North Dakota in 1992 (Zollinger et al., 1993). The total acreage subjected to pesticide use has increased steadily in recent years. Over 17.5 million acres were treated with herbicides in 1992. Nearly 900 thousand acres were treated with insecticides and nearly 600 thousand acres were treated with fungicides. The total acres planted (including crop, pasture, summer fallow, and CRP) was nearly 41 million acres in 1992. According to the 1992 survey the most commonly applied herbicides were 2,4-D, dicamba, MCPA, and trifluralin. The most commonly used insecticides were carbofuran, esfenvalerate, ethyl parathion, and terbufos. The most commonly used fungicides were mancozeb, propiconazole, and triphenyltin hydroxide.

▼ Pesticides and Surface Water Hydrology

When water reaches the soil surface as a liquid it must evaporate, infiltrate, or run off (Branson et al., 1975). Horton (1933) defined infiltration as the entry of water through the soil surface. The rate at which water can enter the soil is influenced by many factors such as surface cover, vegetation canopy, surface crusting, rainfall energy, slope, and surface texture. The maximum infiltration capacity generally occurs at the beginning of a storm and decreases rapidly due to changes in the surface caused by water movement. When the rate of precipitation exceeds the infiltration rate, water accumulates as surface storage, and when the capacity of the surface storage is exceeded, runoff occurs (Branson et al., 1975).

Pesticides are entrained in runoff water in two forms, soluble species and adsorbed species (Caro, 1976; Dean, 1983; Rao et al., 1983; Leonard, 1990). As runoff water moves over the surface soil it interacts with the surface both physically and chemically. The depth of interaction influences the amount of pesticide that moves off-site and varies under different circumstances (Gaynor et al., 1995). Despite the variability, a 10 mm depth of interaction is often used to estimate edge-of-field losses of contaminants (Knisel et al., 1983; Leonard, 1990). These losses include pesticides dissolved in the runoff water and pesticides adsorbed to suspended sediment transported by the runoff.

The availability of pesticides to translocation by runoff is strongly influenced by the characteristics of application, formulation, and chemistry (Caro, 1976; Wauchope, 1978; Leonard, 1990; Baker and Johnson, 1983; Rao et al., 1983; Christensen et al., 1993). Increased knowledge of these factors, has improved the accuracy of predicting edge-of-field losses of pesticides. However, many investigations show that substantial reductions in pesticide concentrations occur between the edge-of-field and streams and lakes (Wauchope, 1978; Rhode, et al., 1980; Wu et al., 1983; Ng et al., 1995)

Pesticide Losses Related to Application

In general, studies show a positive correlation between pesticide application rates and edge-of-field losses (Dean and Mulkey, 1979; Baker and Laflen, 1983; Christensen et al., 1993). Studies also show that the highest losses of pesticides occur in runoff from the first precipitation event after application (White et al., 1976; Baker and Johnson, 1979; Rhode et al., 1980; Baker and Laflen, 1983; Leonard, 1990; Gaynor et al., 1995), particularly within two weeks (Wauchope, 1978; Isensee and Sadeghi, 1993). However, pesticide losses to runoff are reduced substantially if a precipitation event that does not produce runoff occurs prior to a runoff-producing rainfall (Wauchope, 1978; Sigua et al., 1993). Apparently non-runoff-producing precipitation washes pesticides from foliage and soil surfaces into soil pores, where they are not as available to surface runoff. Research shows that pesticides applied to the foliage or soil surface have higher losses in surface runoff compared to pesticides that are incorporated into the soil (Caro, 1976; Baker and Laflen, 1983; Leonard, 1990; Christensen et al., 1993).

Atmospheric contributions of pesticides to surface water are an indirect consequence of pesticide application and are related to volatilization and drift. Pesticide drift accounts for a significant amount of off-site movement (Baker and Johnson, 1979; Himel et al., 1990). Maas et al. (1984) state that volatilization and drift with subsequent deposition appear to be the largest pathways by which pesticides reach aquatic systems. Unfortunately, the contribution of drift losses to surface water contamination has not been well researched, probably because of the complex nature of the problem.

Volatilization losses during and shortly after application can also be significant (Grover et al., 1985; Prueger et al., 1993). These losses depend on many factors and may range from zero to greater than 50% of the total pesticide applied (Guenzi and Beard, 1974). Measurable amounts of volatilized pesticides may return to the earth via rainfall, dry deposition, or dry-vapor deposition (Tabatabai, 1983).

Rainfall observations show that pesticide concentrations are related to local pesticide use and local atmospheric transport processes and are highest during the periods of application (Hatfield et al., 1993a;b). Nations et al. (1993) suggested that long-distance transport was a factor in the pesticide amounts observed in rainfall. The amounts of pesticide observed in rainfall make only a minor contribution to pesticide concentrations in runoff water compared to the contribution from the pesticides applied directly to fields (Tabatabai, 1983).

Pesticide Losses Related to Formulation

Different pesticide formulations have varying interactions with environmental factors, even with the same pesticide. For instance, studies have shown that 2,4-D formulated as an ester has higher runoff losses compared to 2,4-D formulated as an amine salt (Caro, 1976; White et al., 1976; Christensen et al., 1993). The more soluble amine salt moves into the soil with water infiltration and is not as available to move with surface runoff.

Wauchope (1978) concluded after extensive review of research results that long-term pesticide losses can be grouped into three broad categories based on formulation and application: 1) wettable powders 2) foliar-applied organochlorine insecticides; and 3) nonorganochlorine insecticides, incorporated pesticides, and all other herbicides. He estimated annual edge-of-field losses of 2-5%, 1%, and 0.5%, respectively, of the total pesticide applied within these three categories. He theorized that wettable powder formulations leave a dust-coating on the soil surface upon evaporation that is easily entrained in runoff water. Arsenical and cationic pesticides, such as paraquat, may also be prone to losses via dust entrainment in surface runoff.

Wauchope (1978) determined by comparing many study results a trend in pesticide concentrations from edge-of-field runoff related to modes of application and pesticide formulation. Pesticide concentrations in edge-of-field runoff occurred in the following pattern among five pesticide application-formulation categories: incorporated emulsions or granules < insoluble pesticides applied as emulsions to soil surface or crop foliage < soluble pesticides applied as solutions to soil surface << wettable powders applied to soil surface < soluble pesticides applied to crop foliage.

Pesticide Losses Related to Chemistry

Each pesticide has a distinctive vapor pressure, water solubility, partition coefficient, and rate of degradation related to its chemical composition (Cheng, 1990; Leonard, 1990; Wauchope et al., 1992). The mobility of a pesticide depends on its availability for transport, which is influenced to a large extent by its chemical characteristics.

Under the same conditions, pesticides with high vapor pressures are more susceptible to volatilization losses and atmospheric transport compared to pesticides with lower vapor pressures (Taylor and Spencer, 1990). However, other factors have a substantial role in determining the ultimate loss of pesticides from the field due to volatilization. Research results demonstrate that volatilization losses are greatest from moist surfaces, plant or soil (Glotfelty, 1987; Taylor and Spencer, 1990; Prueger et al., 1993). Research also shows that volatilization losses of pesticides within the soil profile are substantially less than losses from bare surfaces (Taylor and Spencer, 1990). Glotfelty (1987) suggested that lower soil temperatures under conservation tillage would reduce pesticide volatilization. A zone of stagnant air within the surface mulch left by no-till management resulted in less volatilization losses from applications of alachlor and atrazine compared to conventionally tilled fields (Weinhold and Gish, 1994; Gish et al., 1995).

Solubility is a measure of the amount of a substance that can be dissolved in water when in equilibrium with the solid phase of the substance. For a given amount of water this is a constant value for any substance, including pesticides (Wauchope et al., 1992). Pesticides with higher solubilities have greater potential to associate with water and translocate as that water moves (Green, 1974). As might be expected, the most soluble pesticides often give the highest concentrations in runoff (Wauchope, 1978). However, studies also show that under some circumstances pesticides with high solubility may move with water that initially infiltrates the soil prior to the onset of runoff, resulting in significant reductions in pesticide concentration in runoff (Caro, 1976; White et al., 1976; Baker and Laflen, 1983; Christensen et al., 1993).

The process of chemical dissolution in water results in dissociation of the substance into species of positive, negative, and no charge (Bohn et al., 1985) Each of these species have different affinities for some of the components that make up soils, such as organic matter and silcate minerals. The positively charged species will be attracted to negatively charged soil clays and organic matter. Soil pH is an important factor in the process of ionic adsorption, because it influences the amount of charge on variable charge materials like organic matter and also influences the distribution percentage of dissociated species. For example, the composition of dissociated triazine and triazole herbicides is dominated by positively charged species in acid soils, and adsorption is higher compared to soils with a neutral or alkaline pH (Caro, 1976). This type of behavior has been observed for other acid herbicides such as 2,4-D and picloram.

Adsorption of pesticides by the soil has been demonstrated to be most closely related to organic matter content (Weed and Weber, 1974; Rao et al., 1983; Bohn et al., 1985). A large component of dissociated pesticide species is often uncharged molecules that are nonpolar. These molecules will have a stronger attraction for a nonpolar medium such as soil organic matter compared to a polar medium such as water (Bohn et al., 1985).

The ratio of pesticide concentration associated with the soil phase to the pesticide concentration associated with the water phase is a constant called the partition coefficient K_d (Bohn et al., 1985). As K_d increases, so does the adsorption of the pesticide to the soil. Despite the errors introduced by possible invalid assumptions, K_d can be divided by the organic carbon content to produce the organic carbon partition coefficient (K_{oc}) and has become an accepted method to standardize pesticide adsorption to soils in general (Green and Karickoff, 1990; Wauchope et al., 1992). The adsorption of a pesticide can be described quantitatively as a function of its equilibrium concentration in the soil. At least three equations have been used to describe adsorption data: 1) Langmuir, 2) Freundlich, and 3) Brunauer-Emmett-Teller (Weed and Weber, 1974; Bohn et al., 1985; Green and Karickoff, 1990).

High K_{oc} values show that most of the pesticide is adsorbed to the solid phase of the soil (Baker and Laflen, 1983). This has implications in terms of off-site movement and management methods needed to prevent that movement. Adsorbed pesticides will move with sediment suspended in surface runoff as opposed to dissolved forms of pesticide that will move with runoff water whether sediment is suspended or not. Concentrations of pesticides in the sediment that leaves the field are usually greater than the concentration in the soil to which it was applied

(Dean, 1983). This enrichment process caused by selective deposition of coarser soil particles during sediment transport affects strongly adsorbed pesticides to the greatest degree.

Management practices designed to reduce sediment movement will be most effective for pesticides that are primarily partitioned in the solid phase, such as paraquat and glyphosate (Baker et al., 1987). For pesticides with very low K_{oc} values, most of the pesticide is associated with the water phase. Off-site movement of these pesticides will be determined only by the characteristics of surface runoff; unfortunately, erosion control practices designed for sediment reductions will have minimal effect on pesticide movement in this situation (Dean and Mulkey, 1979).

The relationship between K_{oc} and pesticide transport is confounded by the fact that the total mass of water moved is so much greater than the total mass of sediment moved (Wauchope et al., 1977; Christensen et al., 1993). As a result, even though a greater amount of pesticide may be partitioned to the sediment, the greatest amount of pesticide lost actually occurs in the water phase (Wauchope, 1978; Baker and Johnson, 1979; Steenhuis and Walter, 1979;). Although the K_{oc} might indicate that sediment control practices would be effective in controlling pesticide loss in this situation, in reality these practices would have only minimal effect on the transport of total pesticide mass (Baker et al., 1978; Dean and Mulkey, 1979).

Degradation of a pesticide refers to changes in the basic chemical structure that generally results in loss of the phytotoxic effect. Pesticide degradation occurs through the combined action of several processes such as photolysis, hydrolysis, oxidation, and microbial action (Mulkey and Falco, 1983). Persistence is a relative term used to describe the length of time after application that a given pesticide remains undegraded. A persistent pesticide would exhibit increased potential for off-site movement because it remains undegraded and available to transport processes for a longer period of time (Steenhuis, 1979; Mills and Leonard, 1984). The organochlorine pesticides such as DDT were known for their exceptionally high persistence (Hiltbold, 1974; Leonard, 1990). Even though this group of pesticides was not particularly mobile, high persistence and wide use contributed to environmental impacts that led to their discontinuation. Persistence is expressed quantitatively as half-life or $T_{1/2}$ (Wauchope and Leonard, 1980; Wauchope et al., 1992). This term is an estimate of the time it takes a given quantity of pesticide to degrade to one-half the amount originally applied.

Actual persistence in the environment can be quite variable, for example, total disappearance of picloram may range from 50 days to six years (Caro, 1976). Pesticide half-lives measured under laboratory conditions are often greater than those measured under field conditions (Rao et al., 1983). Organophosphorus insecticides are known to hydrolyze rapidly in surface water. Carbamate insecticides have been shown to degrade in alkaline surface water within a period of four weeks.

The decomposition of many herbicides is primarily biological. For example, 2,4-D persisted in aerobic lake water for 120 days compared to 24 hours in lake mud where biological decomposition was greatest. The rate of decomposition under anaerobic conditions compared to aerobic conditions is greater for many pesticides (Caro, 1976; Rao et al., 1983). Entry and Emmingham (1996) concluded that degradation of 2,4-D at similar temperatures and moisture contents occurs at greater rates in forest ecosystems compared to grasslands. In general, pesticide degradation is expected to be greater under reduced tillage compared to conventional tillage because of increased microbial activity caused by greater moisture and higher organic matter content (Glotfelty, 1987; Helling, 1987).

▼ Assessment of Potential Contamination of Surface Water from Pesticides

Predicting where and when pesticide use may cause damaging concentrations in surface water environments depends on knowledge of local conditions and processes that rule pesticide fate. Research and study have helped to demonstrate the complexity of pesticide contamination but have also identified certain critical elements that are regularly found to influence surface water contamination. Systematic assessment of these elements cannot predict the exact nature of contamination at any given place for any given time without a large risk of error. However, systematic assessment can estimate ordered results that may be used to prioritize management decisions that attempt to address surface water protection.

The following six factors are used to assess the potential for surface water contamination from pesticide use:

1) surface water proximity;
2) pesticide formulation-application;
3) pesticide/solution interaction;
4) pesticide/sediment interaction;
5) land slope;
6) flooding frequency.

These factors were selected based on their observed effects on contaminant transport. Accessibility of data to measure the value of each factor was also a consideration. Other than pesticide properties, information required to determine the pesticide displacement potential for the various factors can be found in the county soil survey report.

Surface Water Proximity

Runoff is not the same from all areas of a watershed, and usually large areas yield no runoff or sediment (Campbell, 1985). In fact, increasing evidence indicates that most stream-transport sediment is derived from a relatively small area of the basin (Stewart et al., 1975; Campbell, 1985). The effective drainage area is affected by a variety of factors including man's activities. Construction of road-side ditches in the North American prairies increased the effective drainage area and changed the hydrology of most prairie streams (Miller and Frink, 1984; Campbell, 1985).

During runoff-producing events, areas contributing water to the channel expand outward from the stream with increasing duration of the event (Satterlund, 1972). This hydrologic phenomenon is responsible for the most regular runoff production being from areas close to stream channels; this is particularly true in drier climates. Stewart et al. (1975) recognized proximity of cropped fields to surface water resources as a critical factor in determining acceptable levels of soil loss from fields. As the density of the network of surface drains increases, so does the amount of sediment delivered to streams (Campbell, 1985). Runoff and sediment losses from watersheds are often dominated by losses via ephemeral streams or gullies (Renard and Lane, 1975; Vandaele and Posen, 1995). Stall (1983) concluded that the density of nonincised channels is a direct indicator of sediment delivery to Midwestern streams. Rill erosion losses were found to be closely related to the system of surface drainage collectors (Ludwig et al., 1995).

Concentrations of pesticides in receiving streams have been shown in many studies to be orders of magnitude smaller than pesticide concentrations in runoff leaving field edges (Caro, 1976; Baker et al., 1979; Leonard, 1990; Wu et al., 1983; Ng et al., 1995). During transport, pesticide concentrations are rapidly attenuated by mechanisms of dilution, deposition and trapping of sediments, adsorption to channel materials, and pesticide degradation (Leonard, 1990). After leaving the field edge, the distance that runoff water must travel before reaching a stream or lake has a significant impact on the total loading to streams or lakes (Christensen et al., 1993). In most studies herbicide residues fall below detectable limits in waters a few hundred yards below sprayed areas (Caro, 1976; Christensen et al., 1993). Rhode et al. (1980) found that nearly 90% of the trifluralin in runoff leaving a field was removed in a waterway 24 m long. Similar results were reported for 2,4-D.

The longer the time and distance of transport, the greater the opportunity for pesticide attenuation to occur; therefore, the proximity of a receiving waterbody to the source of pesticide runoff is a factor that must be determined. This assessment system estimates the proximity factor by accounting for the presence of road ditches, natural and manmade drainageways, rivers, and lakes (Table 1).

Soil mapping unit delineations that have perennial drainageways or that share a boundary with a waterbody (river or lake) have a HIGH potential for pesticide transport to the adjacent waterbody. Soil mapping unit delineations that share a boundary with the areas that meet one of the first two criteria have an INTERMEDIATE potential for pesticide transport. Soil mapping unit delineations with intermittent drainageways other than road or railroad ditches also have INTERMEDIATE potential for pesticide transport. Soil mapping unit delineations that share a boundary with areas that meet the criteria for INTERMEDIATE potential for pesticide transport also have INTERMEDIATE potential if the shared boundary is crossed by a road or railroad ditch. Soil mapping unit delineations that do not meet any of the previous proximity criteria for HIGH or INTERMEDIATE displacement have LOW potential for pesticide transport.

Pesticide Formulation

Wauchope's (1978) conclusions regarding pesticide concentrations in runoff water have been used to predict their general degree of displacement as related to formulation and mode of application (Table 2).

Wettable powders formulations applied to the soil surface and soluble (> 100,000 mg/L) pesticides (Table 3) applied to crop foliage have a HIGH displacement potential. All other formulation-application combinations have LOW displacement potential.

Table 1. Pesticide displacement potential affected by proximity to surface water.

Displacement	Criteria
High	Soil mapping unit (SMU) delineation with a perennial stream or SMU delineation that shares a boundary with a river or lake
Intermediate	SMU delineation with an intermittent drainageway or SMU delineation that shares a boundary with an SMU delineation that meets one of the first two criteria for HIGH displacement or SMU delineation that shares a boundary with an SMU delineation that meets one of the first two criteria for INTERMEDIATE displacement and that boundary is crossed by a road or railroad ditch
Low	SMU delineations that do not meet any of the criteria outlined for HIGH or INTERMEDIATE displacement

Pesticide/Solution Interaction

This factor is a combination of pesticide properties and soil factors important to pesticide transport in the solution phase. Goss and Wauchope (1990), Goss (1992), and Hornsby (1992) demonstrated that pesticide contamination could be addressed systematically by combining selected pesticide and soil properties.

The Goss-Wauchope system is used to determine the potential for pesticide runoff to occur in the solution phase. Pesticide solubility, half-life ($T_{1/2}$), and organic carbon adsorption (K_{oc}) (Appendix I) are used to determine potential runoff (Table 3) in the solution phase. The soil hydrologic group is used as an indicator of the soils influence on pesticide runoff (Table 4) in the solution phase. The hydrologic grouping for each soil is found in the county soil survey report. Soils are grouped into one of four hydrologic categories (A, B, C, D) based on infiltration rates, group A having the highest rates and group D having the lowest.

The potential pesticide displacement via the solution-phase is determined by combining the pesticide properties and soil factor influences (Table 5) [Goss and Wauchope, 1990; Goss, 1992].

Table 2. Pesticide displacement potential affected by formulation and mode of application.

	Displacement	
Formulation-application mode	**LOW**	**HIGH**
Wettable powders on soil		■
Soluble pesticide (> 100,000 mg/L) on foliage		■
ALL OTHER COMBINATIONS	■	

Table 3. Pesticide properties influence on displacement potential via solution phase of transport.

Influence	Criteria
Strong	Pesticide solubility ≥ 1 mg/L and $T_{1/2} > 35$ days and $K_{oc} < 100{,}000$ or Pesticide solubility ≥ 10 mg/L and < 100 mg/L and $K_{oc} \leq 700$
Moderate	All pesticides that don't meet either Strong or Weak influence criteria
Weak	$K_{oc} \geq 100{,}000$ or $K_{oc} \geq 1{,}000$ and $T_{1/2} \leq 1$ day or Pesticide solubility < 0.5 mg/L and $T_{1/2} < 35$ days

Table 4. Soil influence on pesticide displacement potential via the solution phase.

	Influence		
Hydro. Group	Weak	Moderate	Strong
A	■		
B		■	
C			■
D			■

Pesticide/Sediment Interaction

This factor is a combination of pesticide properties and soil factors important to pesticide transport in the suspended sediment phase. Goss and Wauchope (1990), Goss (1992), and Hornsby (1992) demonstrated that pesticide contamination could be addressed systematically by combining selected pesticide and soil properties.

The Goss-Wauchope system (Goss and Wauchope, 1990; Goss, 1992) is used to determine the potential for pesticide runoff to occur in the sediment phase. Pesticide solubility, half-life ($T_{1/2}$), and organic carbon adsorption (K_{oc}) [Appendix I] are used to determine potential runoff in the sediment phase (Table 6).

Table 5. Pesticide-solution interaction displacement potential.

	Pesticide Influence		
Soil Influence	**Weak**	**Moderate**	**Strong**
Weak	low	low	intermediate
Moderate	low	intermediate	high
Strong	intermediate	high	high

Table 6. Pesticide properties influence on displacement potential via the sediment phase of transport.

Influence	Criteria
Strong	$T_{1/2} \geq 40$ days and $K_{oc} \geq 1000$ or $T_{1/2} \geq 40$ days and $K_{oc} \geq 500$ and solubility ≤ 0.5 mg/L
Moderate	All pesticides that do not meet the Strong or Weak influence criteria
Weak	$T_{1/2} \leq 1$ day or $T_{1/2} \leq 2$ days and $K_{oc} \leq 500$ or $T_{1/2} \leq 4$ days and $K_{oc} \leq 900$ and solubility ≥ 0.5 mg/L or $T_{1/2} \leq 40$ days and $K_{oc} \leq 500$ and solubility ≥ 0.5 mg/L or $T_{1/2} \leq 40$ days and $K_{oc} \leq 900$ and solubility ≥ 2 mg/L

Soil indicators of potential pesticide runoff in the sediment phase are hydrologic group and K factor (Table 7).

The soil K factor indicates the susceptibility to sheet and rill erosion. Soil K factors range from 0.02 to 0.69 with the higher values indicating greater potential for erosion losses by water.

The potential for sediment-phase loss of a pesticide is determined by combining the pesticide properties and soil factor influences (Table 8).

Land Slope

A positive correlation exists between the slope of land surface (vertical distance / horizontal distance) and the amount of runoff and eroded sediment (Stewart et al., 1975; Wischmeier, 1976; Wischmeier and Smith, 1978). However, when slopes increase sediment losses increase at a greater rate than runoff amounts (Wischmeier and Smith, 1978). Watersheds with high stream gradients are generally associated with steep slopes and allow transport of a larger portion of the total eroded sediment compared to watersheds with flat slopes (Renfro, 1975). Boyce (1975) suggested that the observation of decreasing efficiency of sediment delivery with increasing watershed area is due to decreased average slope.

The relationship between increasing slope and increasing sediment transport is strongest when runoff occurs primarily as concentrated flow in rills and channels (Foster and Meyer, 1975; Meyer et al., 1975; Quansah, 1984). Runoff and sediment transport via sheetwash in interill areas has been shown to be closely related to rainfall intensity, but not slope (Foster and Meyer, 1975; Meyer et al., 1975). As a result, the differences between slopes dominated by sheetwash and those dominated by concentrated flow affect the potential for adsorbed pesticide transport (Meyer et al., 1975).

When runoff occurs primarily as concentrated flow the source of transported sediment is more likely to include deeper zones in the soil that have little adsorbed pesticide. Consequently, even though steeper slopes may have the greatest potential for increased sediment transport, the largest increase in pesticide transport may be in the solution phase rather than the adsorbed phase. Surface texture of soils affect rill development, sediment detachment, and sediment transport (Loewenherz-Lawrence, 1994; Nearing and Parker, 1994). Quansah (1984) estimated that critical slopes for sediment detachment and transport via concentrated flow increase, respectively, for sand, clay loam, and clay.

Goss and Wauchope (1990), Goss (1992), and Hornsby (1992) recognized the need to adjust potential losses of pesticides upward for soils on steeper slopes. Three categories of slope are used in this assessment system. Slopes greater than or equal to 15% have HIGH potential for pesticide loss with runoff (Table 9).

Slopes less than or equal to 8% have LOW potential for pesticide losses. Slopes between 8% and 15% have INTERMEDIATE potential for pesticide losses to surface water runoff.

Flooding Frequency

SCS Staff (1991) and Hornsby (1992) adjusted upward potential pesticide losses in surface runoff from soils that have more frequent occurrences of flooding. Flooding may remove large quantities of pesticides in solution or adsorbed to sediments in a single event (SCS Staff, 1991). Flooding frequency is grouped into three pesticide runoff loss categories (Table 10).

Table 7. Soil influence on pesticide displacement potential via the sediment phase of transport.

Influence	Criteria
Strong	Hydro. group C and K factor ≥ 0.21 or Hydro. group D and K factor ≥ 0.10
Moderate	All soils that do not meet either the HIGH or LOW displacement criteria
Weak	Hydro. group A or Hydro. group B and K factor ≤ 0.10 or Hydro. group C and K factor ≤ 0.07 or Hydro. group D and K factor ≤ 0.05

Table 8. Pesticide displacement potential via the sediment phase of transport.

	Pesticide Influence		
Soil Influence	**Weak**	**Moderate**	**Strong**
Weak	low	low	intermediate
Moderate	low	intermediate	high
Strong	intermediate	high	high

Table 9. Pesticide displacement potential affected by slope of land.

	Displacement		
Slope (%)	**Low**	**Intermediate**	**High**
≤ 8	▒		
> 8 and < 15		▒	
≥ 15			▒

Table 10. Pesticide displacement potential affected by frequency of flooding.

	Displacement		
Flooding Frequency	Low	Intermediate	High
None to rare			
Occasional			
Frequent			

Frequent flooding has HIGH potential for increased pesticide losses in runoff. None to rare flooding has LOW potential for increased pesticide losses. Occasional flooding has INTERMEDIATE potential for increased pesticide losses.

Surface Water Sensitivity

The six factors used to assess potential contamination of surface water must be combined to arrive at an overall sensitivity rating. Some factors need to be considered together for interpretive purposes, because they represent mechanisms that have opposite effects on pesticide movement to surface water. Under many circumstances both factors will not be HIGH at the same time. This helps reduce unnecessary complexity associated with sensitivity analysis and interpretation for management.

The two pesticide interaction factors (solution and sediment) are considered together, because as a pesticide's association with the soil solids phase (sediment) increases, its association with water phase (solution) decreases. The potential impact to surface water is considered significant whether both pesticide interaction factors are HIGH or if only one factor is HIGH.

Flooding frequency and land slope factors are also considered together, because low slopes are a characteristic of floodplains compared to the occurrence of more sloping land on uplands that do not flood. The following five sensitivity categories are used in this assessment system:

1) VERY HIGH;
2) HIGH;
3) SOMEWHAT HIGH;
4) INTERMEDIATE;
5) LOW.

These sensitivity categories are designed to provide information that can be used to help determine the most appropriate management methods for surface water protection.

Very high

When the potential for pesticide contamination is HIGH with respect to surface water proximity, pesticide formulation-application, pesticide / solution-sediment interaction and flooding-slope factors, sensitivity is VERY HIGH (Table 11).

Management methods to protect surface waters in this category will vary depending on which of the pesticide interaction factors and flooding-slope factors are HIGH. This must be indicated in parenthesis following the category designation, for example VERY HIGH (solution, flooding) or VERY HIGH (solution-sediment, slope).

High

The importance of surface water proximity is reflected in this category. When the potential for pesticide contamination is HIGH with respect to the surface water proximity the sensitivity of surface water is also HIGH (Table 12).

If other factor(s) are HIGH they must be indicated in parenthesis following the category designation, for example, HIGH (formulation, slope) or HIGH (solution). As stated before, these subcategories help to direct management for water protection to the most appropriate methods.

Table 11. Pesticide displacement factor contributions to VERY HIGH sensitivity of surface water resources.

	Displacement		
Displacement Factors	Low	Intermediate	High
Proximity			
Formulation-application			
Pesticide solution-sediment interaction	NO	NO	YES
Flooding-slope			

Table 12. Pesticide displacement factor contributions to HIGH sensitivity of surface water resources.

	Displacement		
Displacement Factors	Low	Intermediate	High
Proximity	No	No	Yes
Formulation-application			
Pesticide solution-sediment interaction	Maybe	Maybe	Maybe
Flooding-slope			

Somewhat high

The proximity factor must have INTERMEDIATE displacement for an area to be placed in this category. In addition, at least one of the other displacement factors must be HIGH (Table 13).

These areas are important with respect to surface water contamination but not as critical because of their distance from local water resources. Those factors that are HIGH must be indicated in parenthesis following the category name, for example, SOMEWHAT HIGH (sediment, slope) or SOMEWHAT HIGH (formulation).

Intermediate

When all pesticide displacement factors are INTERMEDIATE, the pesticide sensitivity of surface water is also INTERMEDIATE (Table 14a).

In addition, areas where the proximity factor is LOW but at least one of the other pesticide displacement factors is HIGH are also placed in the INTERMEDIATE sensitivity category (Table 14b).

The displacement factors that are HIGH must be identified in parenthesis.

Low

All other combinations of pesticide displacement factors that do not meet the criteria listed above result in LOW sensitivity of surface water to contamination (Table 15).

An example of how to use the assessment system to determine pesticide contamination potential for surface water resources is found in Appendix II.

Table 13. Pesticide displacement factor contributions to SOMEWHAT HIGH sensitivity of surface water resources.

	Displacement		
Displacement Factors	Low	Intermediate	High
Proximity	No	Yes	No
Formulation-application			
Pesticide solution sediment interaction	Maybe	Maybe	At least one of these factors
Flooding-slope			

Table 14a. Pesticide displacement factor contributions to INTERMEDIATE sensitivity of surface water resources.

	Displacement		
Displacement Factors	Low	Intermediate	High
Proximity			
Formulation-application			
Pesticide solution sediment interaction	No	Yes	No
Flooding-slope			

Table 14b. Pesticide displacement factor contributions to INTERMEDIATE sensitivity of surface water resources.

	Displacement		
Displacement Factors	Low	Intermediate	High
Proximity	Yes	No	No
Formulation-application			
Pesticide solution sediment interaction	Maybe	Maybe	At least one of these factors
Flooding-slope			

Table 15. Pesticide displacement factor contributions to LOW sensitivity of surface water resources.

	Displacement		
Displacement Factors	Low	Intermediate	High
Proximity			
Formulation-application			
Pesticide solution sediment interaction	Maybe	Maybe	No
Flooding-slope			

▼ Management Practices for Surface Water Protection from Pesticide Contamination

Definition and History

The term "best management practice" was first defined in Public Law 92-500, the Federal Water Pollution Act of 1972 as follows: **"Best Management Practice (BMP) means a practice or combination of practices that is determined by a State (or designated area-wide planning agency) after problem assessment, examination of alternative practices, and appropriate public participation to be the most effective practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals."** (Bailey and Waddell, 1979; Haith and Loehr, 1979; Johnson, 1979).

Bailey and Waddell (1979) state that 1977 amendments to the Clean Water Act place the responsibility of BMP implementation on the USDA and state soil and water conservation districts. However, Crosson (1983) argues that 1972 amendments to Section 208 of the Federal Water Pollution Control Act gives EPA the necessary authority to control nonpoint source pollution. EPA has elected to exercise its authority by promoting the voluntary approach. However, voluntary programs are often not successful in bringing about significant improvement to water quality problems for a variety of reasons (Nowak and Korsching, 1983; Baker, 1987b; Logan, 1990; Clausen et al., 1992; German, 1992; Koerkle, 1992; McCoy and Summers, 1992; Meals, 1992a,b; Schlagel, 1992; Hallberg et al., 1993; Hocking et al., 1993; Jordan and Elnagheeb, 1993; McCallister et al., 1993; Napier, 1993; Rikoon et al., 1993; Sutton, 1993).

The history of nonpoint source water pollution projects indicates that effective use of BMPs is complicated and at the very least requires the following: 1) clear identification of water quality problems and improvements; 2) targeting BMP activities to identified problem areas; 3) one-to-one technical/educational contact with producers; and 4) grassroots ownership of the problem and solution (Christensen, 1983; Logan, 1990; U.S. EPA Staff, 1990; NCSU Water Quality Group, 1993; Watson et al., 1994).

The criterion of demonstrated effectiveness is a critical component of the BMP definition that must not be ignored (Baker and Johnson, 1983; Daniel et al., 1991). Although many soil and water conservation practices appear to meet the requirements for water quality BMPs, research is needed to verify this assumption (Johnson, 1979; Park et al., 1994). This is a major issue that continues to deserve the attention of both agricultural and environmental scientists (Duttweiler and Nicholson, 1983; Schweizer, 1988).

Implicit to the BMP definition is the practical understanding that natural variability precludes the notion of management practices that are universally effective (Stewart et al., 1975; Christensen, 1983; Duttweiler and Nichloson, 1983; Fawcett et al., 1993). Dean and Mulkey (1979) warn that across-the-board implementation of specific management practices is questionable economically and likely will lead to inadequate pollution control. The greatest beneficial effect on water quality will be accomplished by clearly identifying sources of contaminants within a given area and careful design of treatment that specifically addresses those sources (Johnson, 1979). Soil survey information will be essential for planning optimum management methods for each field (Frere, 1976). Site specific management that requires close communication between operators and "experts" is essential to BMP development and implementation (Duttweiler and Nicholson, 1983).

Even when management practices meet the criteria for effectiveness, they are not automatically adopted by producers (Christensen, 1983; Duttweiler and Nicholson, 1983; Logan, 1990). One of the major reasons for low adoption of BMPs is that producers do not bear the cost of off-farm damages from non-point source pollution (Crosson, 1983). Farmers have little incentive to adopt practices that protect society but are not cost-effective for their private operations (Bailey and Waddell, 1979). In an attempt to increase voluntary adoption of BMPs, costly incentive programs have been instituted (Johnson, 1979; Crosson, 1983; Duttweiler and Nicholson; 1983). Crosson (1983) argues that development of new technologies with economic appeal to producers would be a more effective use of public funds compared to the traditional implementation of incentive programs. Significant nonpoint source pollution control will only result when the market is able to harmonize society's interests with producers' interests.

Types of Management Practices

Management practices that help reduce the potential for surface water pollution from pesticides may be grouped into the following categories: 1) farmstead activities; 2) improved application; 3) integrated pest management (IPM); and 4) soil and water conservation practices (SWCP). Seelig (1996) discusses in detail the practices included in each of these categories with respect to groundwater protection from pesticides. Many of these practices are also appropriate for surface water protection, because they reduce the potential for pesticides to move off-site. Relationships between management and surface water quality are much better understood compared to groundwater contamination (Daniel et al., 1991).

Farmstead management practices

Farmstead management practices have been recommended largely to address groundwater contamination and wells (Seelig, 1996; Nowatzki et al., 1996). However, many of the these practices also reduce potential contamination to surface water, because they result in greater control of pesticides. Sloppy mixing, handling, and storage practices result in increased availability of pesticides for off-site transport. The following practices are recommended to reduce potential surface water contamination with pesticides around farmsteads:

1) **As a precaution against spillage, sprayer tanks should never be left unattended during filling.**
2) **Whenever possible, mix, load, and rinse pesticides over an impermeable surface that is designed to drain to a sealed catchment.**
3) **Rinse chemical containers thoroughly using the triple rinse method or a pressure rinser.** Rinsate should be used as part of the make-up water in the sprayer tank.
4) **Clean the pesticide sprayer properly.** In the farmyard, clean over an impermeable surface. Rinse water can be recovered from a sealed catchment and used as part of the makeup-water the next time the pesticide is applied.
5) **Use closed-handling systems for mixing pesticides where practical.**
6) **Do not stockpile empty pesticide containers.** Even though properly rinsed, these containers remain a potential source of pesticide residue that may cause surface water contamination. As the size of the stockpile grows with the length of time to disposal, so does the potential for off-site transport of pesticides.
7) **Dispose of unused pesticides that have been banned or are no longer wanted to reduce the overall contamination potential from the farmstead.**
8) **Store pesticides in a secure, properly ventilated location where product usefulness can be maintained and spillage can easily be contained.**
9) **Attend to all pesticide spills immediately.**

Improved pesticide application management practices

The size of the spray droplet is important in relation to the transport, penetration, and deposition of pesticides on the target (Bode, 1987). Himel et al. (1990) defined efficiency of pesticide delivery as the mass of pesticide that reaches the target divided by the total spray mass. Spray physics theory and experimental observation have shown that efficiency of pesticide delivery is limited by the size of the spray droplets. For nonsystemic insecticides and fungicides, the upper limit of spray droplets that produce efficient delivery ranges from 100 to 150 μm (Himel et al., 1990). For herbicides, the upper limit of spray droplets that produce efficient delivery is near 250 μm. Droplets larger than the size defined by these upper limits are most likely to reach peripheral foliage or the soil instead of the target.

Bode (1987) also recognizes greater efficiency related to the delivery of small spray droplets to the target, but maintains that droplets less than 100 μm will be subject to significant drift and evaporation due to a slow time of fall caused by a low terminal velocity. The recommended lower limit of droplet size that minimizes drift ranges from 150 to 200 μm. With present application systems drift losses account for 3 to 5% of the total mass of pesticide spray applied (Bode, 1987; Himel et al., 1990). Although drift losses are a relatively small amount of the total mass applied, they are still greater than losses of pesticide attributed to edge-of-field runoff (Leonard, 1990).

Himel et al. (1990) concluded that most pesticide-spray systems produce a significant percentage of droplets larger than the upper limit for efficient delivery, and only 5% to 34% of the pesticide mass reaches the intended target. They suggest the major reason for low pesticide efficiency is impingement of large droplets on locations other than the target, not drift of small droplets as is commonly thought.

Maas et al. (1984) credit improvements in application efficiency of pesticides with the greatest potential for reductions in pesticide losses to water resources. Opportunities exist to reduce off-site losses of pesticides through the use of the following practices:

1) **Use pesticides with low mobility and persistence.** Pesticides that meet these criteria are less available for off-site transport.
2) **Use pesticide formulations that reduce drift losses.** Generally granules and pellets reduce drift compared to dusts, wettable powders, and fine liquid sprays.
3) **Adjust spray equipment to give the range in droplet size for optimum coverage of the target.** The optimum range in droplet size will reach the target pest with efficiency and reduce drift to a minimum.
4) **Release pesticide spray within the range of height recommended for the crop growth stage and target pest.** Pesticide released either too low or too high above the crop may result in ineffective coverage of the pest and increased pesticide availability for off-site transport.

5) **Never apply pesticides during weather conditions that may cause significant drift of small droplets away from the spray target.** Windy conditions will contribute to pesticide drift. Recommendations regarding wind speeds should be followed according to crop growth stage and application equipment. Also stable air conditions, usually in early morning, created by a temperature inversion (cold air trapped between the soil surface and warmer air above) will reduce vertical movement and increase lateral movement of small droplets.

6) **Calibrate application equipment regularly to ensure that the proper amount of pesticide is applied.**

7) **Add petroleum or modified vegetable oil adjuvants to herbicide mixes, when recommended.** Adjuvants have been shown to increase the effectiveness of many herbicides and may allow lower rates or fewer applications for weed control.

8) **Use banded applications of pesticides when possible.** This will reduce the amount of pesticide used compared to broadcast applications. However, this practice generally requires greater mechanical weed control that may lead to greater amounts of water runoff.

9) **Use methods of pesticide application that target individual pests or improve uniformity of application.**

10) **When possible, use pesticides that can be incorporated into the soil.** However, incorporation will reduce plant residue on the soil surface, thus increasing the potential for erosion and runoff.

11) **Avoid pesticide applications immediately prior to intense rainfall events.**

12) **Avoid using mix-water with a pH and/or mineral content that will reduce pesticide efficacy.**

Integrated Pest Management (IPM) practices

In general, cultural, mechanical, biological, ecological, and chemical methods are components of an all-encompassing system of pest control known as integrated pest management (IPM) (Schweizer, 1988). When compared to systems of pest control that depend solely on the pesticide component, application of IPM techniques often reduces the amount of pesticide used. Maas et al. (1984) rated IPM practices as more effective than soil and water conservation practices (SWCP) in controlling pesticide losses to water resources.

1) **Plant pest-resistant cultivars if available.** Many plant diseases can be avoided by growing tolerant or resistant cultivars.

2) **Maintain vigorous, competitive plant growth through the regular use of good agronomic practices.**

3) **Use crop rotation to break pest life-cycles.**

4) **Control volunteer plants that serve as hosts for certain diseases and insects.**

5) **Use tillage to control pests where appropriate.** The effect of tillage on runoff and erosion needs to be considered as part of the decision to use this practice.

6) **Use biological control of pests when possible.** This option is more likely to be viable on rangeland as opposed to cropland.

7) **Use preemptive techniques for pest control when needed.** Preemptive management measures are applied in advance of actual observation of pests; therefore, their use is appropriate only when supported by recommendations from individuals with expertise to assess potential pest problems based on observation of other factors.

8) **Optimize timing of pesticide applications by regular scouting to determine life cycles and economic thresholds of damage.**

9) **Rotate pesticides to prevent development of pest resistance. Chemical compounds with different modes of action should be used in alternate years.**

Soil and water conservation management practices

In general, soil and water conservation practices (SWCP) have been demonstrated to reduce the total load of agricultural chemicals that leave cropped fields (Stewart et al., 1975; Beyerlein and Donigian, 1979; Shoemaker and Harris, 1979). However, SWCPs are often not very effective in controlling losses of chemicals in solution compared to chemicals adsorbed to sediment (Baker et al., 1978; Baker et al., 1979; Beyerlein and Donigian, 1979; Smith et al., 1979; Wu et al., 1983; Wauchope, 1987).

The success in reducing pesticide losses with the implementation of SWCPs has been variable. For example, in many studies, conservation tillage protected surface water quality by reducing runoff and erosion due to improved infiltration (Edwards and Amerman, 1984; Dick et al., 1986; Mielke et al., 1986; Baker, 1987a; Donigian and Carsel, 1987; Edwards et al., 1988; Francis et al., 1988; Hatfield and Prueger, 1993; Hall and Mumma, 1994). However, other studies showed greater losses of pesticides from fields with conservation tillage compared to conventionally tilled fields (Baker and Laflen, 1983; Baker, 1987a; Foy and Hiranpradit, 1989; Sander et al., 1989; Christensen et al., 1993; Wagger et al., 1993).

Many factors must be considered to determine the relationship between SWCPs and water quality at a specific site (Wauchope et al., 1977; Haith and Loehr, 1979). Rainfall timing and intensity affect water infiltration and in some studies had a greater influence on pesticide losses than conservation practices (Leonard, 1990; Isensee and Sadeghi, 1993; Gaynor et al., 1995). Baker and Laflen (1983) proposed the following reasons for their observations of increased pesticide losses in runoff from fields under conservation tillage: 1) lack of tillage for weed control resulted in increased use of herbicides; 2) reduced tillage resulted in greater herbicide concentrations near the surface for translocation by runoff; and 3) unincorporated crop residue intercepted herbicides, causing increased availability to runoff.

SWCPs have variable effects on pesticide losses, because each practice has a different influence on soil properties that affect pesticide fate in soils. Glotfelty (1987) and Helling (1987) report pesticide degradation rates higher under conservation tillage compared to conventional tillage. Pesticide volatilization has been observed to be higher (Dao, 1987; Glotfelty, 1987; Prueger et al., 1993) and also lower (Weinhold and Gish, 1994; Gish et al., 1995) under conservation tillage compared to conventional tillage. Many SWCPs improve soil organic matter levels, which increases pesticide attenuation (Wagger et al., 1993). Increased organic matter will have the greatest influence on strongly adsorbed pesticides (Steenhuis and Walter, 1979).

Practices commonly used to control erosion and sediment delivery cannot be applied with the same confidence for water quality protection (Woolhiser, 1976; Johnson, 1979; Haith and Loehr, 1979; Wineman et al., 1979; Gaynor et al., 1995). Practical limits of erosion losses designed to sustain soil productivity should not be expected to be applicable to the protection of water resources (Stewart et al., 1975). Productivity depends on the total loss of soil eroded; water quality depends on the amount of material that actually reaches water resources. Stewart et al. (1975) pointed out that commonly used average soil erosion tolerance of 5 t/ac/year could not be used to limit peak-year soil losses without drastic reductions in crop production on extensive areas of highly productive land.

Vegetative filter strips and sediment retention structures are designed and applied specifically for water quality protection, not erosion control (Maas et al., 1984; Leeds et al., 1993; Hickman et al., 1994; Regehr et al., 1996). Grassed waterways are sometimes included under the general category of filter strips; however, with respect to erosion control and water quality protection they accomplish quite different objectives.

The difference between these two practices requires clarification. Although grassed waterways are strips of vegetation intended for water transport, the similarity to vegetative filter strips ends there. Grassed waterways are designed primarily to transport water off fields as concentrated flow without the detrimental effects of gully formation (Maas et al., 1984; Hickman et al., 1994). Any benefits to water quality through sedimentation or adsorption of contaminants in the waterway are purely incidental and often minimal (Hickman et al., 1994). On the other hand, vegetative filter strips are applied specifically for the purpose of filtering sediments and adsorbed contaminants as runoff water from field edges passes through them.

Research indicates that vegetative filter strips have varying potential to improve surface water quality, depending on the landscape position, the composition of vegetative species, the thickness of the strip, the contaminant of concern, and other natural factors such as climate (Dillaha, 1989; Parsons et al., 1990; Davis, 1993; Fabis et al., 1993; Pinay et al., 1993; Parsons et al., 1994). Vegetative filter strips were shown to be most effective in removing sediment from edge-of-field runoff (Dillaha, 1989; Parsons et al., 1990; Fabis et al., 1993). Filter strip attenuation of soluble phases of nutrients and pesticides via infiltration and adsorption processes does not occur as readily as sediment deposition. Also over time, vegetative filter strips lost effectiveness with respect to filtration as sediment accumulated in the strip (Dillaha, 1989). For these reasons, vegetative filter strips cannot be considered a stand-alone remedy for surface water quality problems associated with agricultural systems (Leeds et al., 1993; Hickman et al., 1994; Regehr et al., 1996).

Recent studies show the value of riparian zones and their unique vegetation in terms of water protection (Chaney et al., 1990; Welsch, 1991; Pinay et al., 1993; Hill, 1996). These vegetative strips have been demonstrated to provide water purification functions beyond just the physical filtration of sediments. The soils, vegetation, and hydrology of a riparian zone offer an environment that has significant capacity to degrade, adsorb, and transform nutrients and pesticides compared to the environment in cultivated upland fields (Davis, 1993).

The function of riparian areas differs among physiographic and climatic regions (Chaney et al., 1990; Welsch, 1991). Management recommendations for riparian areas adjacent to farmland in the eastern U.S. (Welsch, 1991) are quite different compared to riparian areas adjacent to rangeland in the western U.S. (Chaney et al., 1990). Vegetative filter strip design and maintenance should be dependent on site conditions, not a rigid set of standards (Chaney et al., 1990; Davis, 1993). On some western rangelands, the level of deterioration of the riparian zone may have the greatest influence on management strategy (Chaney et al., 1990).

The various types of vegetative filter strips have significantly different impacts on water quality. A simple grass buffer strip separating cropped fields on the contour is drastically different than the vegetative strip that runs adjacent to the riparian area of a stream or river. The standards for width, vegetative composition, and maintenance of filter strips will depend on the intended impact on water quality (Ward, 1985; Welsch, 1991; NRCS Staff, 1995).

The importance of matching the most appropriate SWCP to each type of pesticide is clear. Beyerlein and Donigian (1979) showed that a system of contours and terraces was substantially better at reducing atrazine losses compared to contours alone or minimum tillage. Terraces on the contour will help reduce translocation of pesticides in the solution phase because they reduce both runoff and sediment movement (Shoemaker and Harris, 1979).

Baker et al. (1978) found that reduced tillage minimized fonofos losses in sediment to a greater extent than the losses of alachlor and cyanazine. Conservation tillage was not found to be effective in reducing atrazine or alachlor movement in several watersheds studied in Maryland (Wu, et al., 1983). Baker et al. (1987) suggested that conservation tillage would be effective in reducing losses of glyphosate and paraquat, because they have greater adsorption to sediment. Christensen et al. (1993) reported that concentrations of picloram, diuron summital, 2,4-D, and 2,4,5-T in runoff dropped below detection levels after passing over a few hundred yards of untreated ground. Trifluralin and 2,4-D concentrations were reduced by 96% and 70%, respectively, as runoff passed through an 80 ft grassed waterway (Rhode et al., 1980).

Surface water and groundwater protection may be counteractive for certain SWCPs (Hickman et al., 1994). Many studies have shown that when runoff was reduced through increased infiltration the result was greater recharge to groundwater and increased contamination potential (Edwards and Amerman, 1984; Dick et al., 1986; Mielke et al., 1986; Baker, 1987a; Donigian and Carsel, 1987; Edwards et al., 1988; Francis et al., 1988; Hatfield and Prueger, 1993; Hall and Mumma, 1994). In particular, no-till systems and some types of terraces (Frere, 1976) are most likely to exhibit large contrasts between groundwater and surface water protection. Tile drainage has been observed to intercept leached water and contaminants, thus protecting groundwater at the expense of surface water quality (Baker, 1987b; Logan, 1987; Keim et al., 1989; Keeney and Deluca, 1993; Czapar et al., 1994).

The economics of using SWCPs will influence their adoption and need to be determined individually for different situations (Smith et al., 1979). Conservation tillage has the most potential for adoption due to the low cost/benefit ratio (Sharp and Berkowitz, 1979; Smith et al., 1979). Contouring and strip cropping are other SWCPs that have been shown to be cost effective (Smith et al., 1979).

In general, the cost effectiveness of terraces, substituting sod crops for row crops, and land idling has been found to be comparatively low due to increased marginal costs. Stewart et al. (1975) stated that rotation options, particularly with meadow, produced significantly lower net returns compared to continuous corn.

Smith et al. (1979) suggested that application of SWCPs for water quality control may be more cost effective than for erosion control, because special management needs are often confined to relatively small problem areas. The cost/benefit ratio of implementing SWCPs increases on less productive soils, because these soils generally have greater management needs with respect to erosion and sediment control (Stewart and Woolhiser, 1976).

SWCPs used for the purpose of surface water protection will require a more site specific approach (Stewart and Woolhiser, 1976), particularly when compared to the practices outlined in the first three BMP categories. Direct reduction of contamination to water resources is the result of implementation of BMPs in the first three categories, because they reduce the amount of pesticide used, handled, or spilled. Unfortunately, SWCPs do not consistently produce lower pesticide levels in surface water resources, because environmental variability changes the cause-and-effect relationship at each location (Christensen, 1983; Fawcett et al., 1993).

Effective water quality protection through the implementation of SWCPs will first require analysis of various site factors (Bailey and Waddell, 1979). The following are SWCP recommendations that can be used to help reduce the contamination of surface water resources under certain circumstances:

1) **Use conservation tillage systems to reduce runoff and movement of pesticides across field boundaries.** The effectiveness of conservation tillage in reducing pesticide movement to surface water bodies has been variable. This practice is likely to be most successful in reducing the translocation of strongly adsorbed pesticides such as glyphosate and paraquat. Because some forms of conservation tillage such as no-till substantially reduce runoff due to significant increases in infiltration, groundwater contamination may result. Conservation tillage has been most successful on well drained soils with slopes greater than 2%. Although conservation tillage may not be particularly effective in eliminating losses of many commonly used pesticides, it is likely to be an attractive option due to the low costs of implementation.

2) **Include high residue crops in crop rotation to reduce soil erosion runoff.** Crop rotation has a two-fold benefit. Including high residue crops in the rotation reduces soil erodibility, which helps reduce runoff and increase infiltration, so pesticide movement off-site is decreased. Crop rotation also helps reduce the overall use of pesticides because it will control certain pests by breaking their lifecycle. Although sod-forming crops used in rotation are highly effective in terms of water quality protection, the cost/benefit ratio is not likely to be attractive.

3) **Plant cover crops to reduce erosion and runoff during uncropped periods when erosion potential is high.**

4) **Farm on the contour to reduce runoff and movement of pesticides across field boundaries.** This practice is most effective in areas of uniform slopes and considered to have a good cost/benefit ratio. The combination of this practice with strip cropping, terracing, and grassed waterways is particularly effective for water quality protection, but the cost/benefit is not as attractive.

5) **Divide large fields with irregular slopes into smaller units aligned in a transverse direction across the slope gradient to reduce runoff and erosion.** Alternate the smaller fields with small grains, edible legumes, and fallow. This practice is recommended in areas where small grains are dominantly grown and the complexity of slopes does not allow contouring or terracing.

6) **Manage concentrated field runoff by constructing and maintaining grassed waterways.** Grassed waterways are often combined with other practices such as contour farming and terraces. They help reduce gully erosion in areas where runoff becomes concentrated flow. Although grassed waterways are not designed for sedimentation or infiltration, some reductions in both adsorbed and soluble pesticides may occur. Grassed waterways generally are not recommended for steep slopes where erosion control cannot be accomplished or on flat slopes where excessive sedimentation will occur. The total land area lost to waterway development has been determined to be essentially the same as the area that would be abandoned due to uncrossable gullies. However, the maintenance of waterways in critical areas does provide for relatively unimpeded access for equipment compared to land with uncrossable gullies.

7) **Use terraces to reduce runoff and movement of pesticides across field boundaries.** Terraces affect runoff and water quality because they act as an impedance or impoundment for surface water flow. Depending on how water is diverted behind the terrace, some amount of deposition and infiltration will occur. Gradient terraces divert water to grassed waterways and are most effective in areas of uniform slope of gentle to moderate steepness. Because grassed waterways are designed for water transport, the benefits to water quality would not be expected to be great. Level terraces are designed to store water and depend on significant infiltration for water removal. Because of increased water storage and infiltration, these types of terraces have a greater potential to remove both adsorbed and soluble pesticides from surface water. Unfortunately, for the same reasons, these terraces also have greater potential to contribute to groundwater contamination. Storage terraces depend on subsurface diversion to remove stored surface water. Some removal of pesticides may occur during impoundment behind the terrace; however, the potential is high for transfer of pesticides to surface water at diversion outlets. When terraces are added to fields farmed on the contour water quality protection is enhanced. Although terraces by themselves or in combination with other practices have been shown to be effective in reducing pesticide movement off farm fields, the cost/benefit of terraces is not very attractive.

8) **Use vegetative filter strips on the contour in cropland, at the lower edge of fields, or adjacent to water bodies (streams, ponds, or lakes) to reduce the rate of runoff and increase sedimentation, infiltration, and pesticide adsorption/degradation.** Vegetative filter strips are of many different types depending on environmental conditions and their intended purpose. The one thing that all vegetative filter strips have in common is movement of runoff water through them in a direction transverse to the length or across the width. They should be used in locations where runoff occurs as uniform sheet flow. If runoff occurs as concentrated flow across filter strips little deposition or infiltration will occur and the purpose is defeated. Concentrated flow that breaches vegetated filter strips becomes a problem as they become filled with sediment. The life and function of a vegetated filter strip can be extended by utilizing other management practices upslope to control runoff and erosion.

   Filter strips composed only of grasses are most effective in removing sediment from runoff compared to nutrients or pesticides. Cool season grasses that are sod forming provide the best filter. The width of grass filter strips separating contoured crops should expand as the slope of the land increases. For land slopes of < 1%, 1-10%, 10-20%, and 20-30%, respectively, minimum filter widths of 10 ft, 15 ft, 20 ft, and 25 ft are recommended. These strips need to be wide enough to allow 30 minutes of contact time and non-erosive storm flow rates. For widths greater than 50 ft, 6 inch high dikes are required to provide uniform flow of runoff. Grass filter strips on the lower edges of cropped fields should have widths of at least 30 to 45 ft to accommodate turning of farm equipment.

When filter strips are adjacent to streams and lakes, effective widths are generally much greater than field filter strips and may be several hundred feet wide. The ratio of field drainage area to filter area should be no greater than 50:1 and preferably within the range of 3:1 to 8:1. When upland soils have high clay contents, the width should be expanded to accommodate the greater distance needed for clay deposition. These types of vegetative strips have greater adsorptive capacity for soluble nutrients and pesticides and often include a woody vegetation component.

The riparian vegetated filter strip usually consists of the following three zones: 1) undisturbed forest; 2) managed forest; and 3) grass. The minimum recommended widths for these zones are 15 ft, 60 ft, and 20 ft, respectively. The width of the managed forest zone should include all soils in hydrologic group D and hydrologic group C that are frequently flooded. The managed forest zone should have a width that allows the combined width with the undisturbed forest zone to be at least 1/3 of the distance from the stream-bank or shoreline to the top of the adjacent upland slope. The managed forest zone should have a width that when combined with the undisturbed forest zone is a minimum of 75 ft for soils in capability classes I, IIe/s, and V; 100 ft for capability classes IIIe/s, and IVe/s; and 150 ft for capability classes VIe/s and VIIe/s.

Maintenance of riparian filter strips includes bank channel stabilization with rip-rap, revetments, weirs, and/or limiting livestock access to water by fencing or herding. The use of grade stabilization structures may be beneficial in maintaining stream-bank integrity by controlling gully erosion. Grazing in riparian areas needs to be closely managed. Dividing pastures into riparian areas and upland areas helps to manage livestock to meet the needs of both types of vegetation. Livestock should never graze stream banks during periods of high vulnerability to soil erosion. Longer periods of rest added to the grazing cycle may be required for restoration of severely degraded riparian areas. Livestock should be excluded from the two forest zones and occasionally from the grass zone if no managed forest zone is present. Regular nutrient removal from the grassed zone is required through managed grazing or haying. Grazing and crop management for runoff and erosion control in upland areas should be used as secondary methods for riparian area maintenance.

9) **Use sediment control basins to trap sediment moving through minor drainage ways prior to entry into a stream or lake.** These structures will provide more control for adsorbed pesticides compared to soluble pesticides.

10) **Use constructed wetlands for sediment control and pesticide adsorption/processing prior to runoff entry into a stream or lake.** Constructed wetlands function as settling basins but also function in contaminant degradation due to active processes in the wetland environment. Although the greatest impact is on adsorbed pesticides, constructed wetlands have greater potential for processing of soluble pesticides than sediment settling basins.

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APPENDIX I

PESTICIDE PROPERTIES INFLUENCING DISPLACEMENT POTENTIAL
(after Hornsby et al., 1995 and Zollinger et al., 1998)

Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
HERBICIDES							
2,4,5-T ACID	nu	278	30	80	Low	Moderate	Weak
2,4,5-T AMINE SALTS	nu	500,000	24	80	High	Moderate	Weak
2,4,5-T ESTERS	nu	50	30	80	Low	Strong	Weak
2,4-D ACID	AGSCO 400 ? Class 80A WSP ? Hi-Dep ? Scorpion III Weedone 638	890	10	20	Low	Moderate	Weak
2,4-D DIMETHYLAMINE SALT	2,4-D amine AGSCO 400 ? Class 80A WSP ? Curtail Formula 40 Hi-Dep ? Landmaster BW Savage Weedar Weed Master	796,000	10	20	High	Moderate	Weak
2,4-D ESTERS OR OIL-SOL. AMINES	2,4-D ester AGSCO 400 ? Aqua Kleen Class 80A WSP ? Crossbow Emulsamine Hi-Dep ? LV ester Salvo Shotgun Tiller Weedone LV4 Weedone Lo Vol 6 Weedone 638	100	10	20	Low	Moderate	Weak
2,4-DB ACID	nu	46	5	440	Low	Strong	Weak
2,4-DB BUTOXYETHYL ESTER	Butyrac ester	8	7	500	Low	Moderate	Weak
2,4-DB DIMETHYLAMINE SALT	Butyrac	709,000	10	20	High	Moderate	Weak
ACETOCHLOR	DoublePlay Harness Harness Xtra Surpass Surpass 100 TopNotch	nd	nd	nd	nd	nd	nd
ACIFLUORFEN SODIUM SALT	Blazer Galaxy Status Storm	250,000	14	113	High/Low	Moderate	Weak

? unsure of chemical formulation
nd no data available from Hornsby et. al., 1995
nu not used in North Dakota according to 1996 Pesticide Use Survey (Zollinger et al., 1998)

Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
ACROLEIN	nu	208,000	14	0.5	High	Moderate	Weak
ALACHLOR	Bullet Crop Star GB Freedom Lariat Lasso Lasso II Lasso Micro-Tech Partner	240	15	170	Low	Moderate	Weak
AMETRYN	nu	185	60	300	High/Low	Strong	Moderate
AMITROLE (Aminotriazole)	Amitrole-T	360,000	14	100	High	Moderate	Weak
AMS (Ammonium Sulfamate)	nu	684,000	14	3	High	Moderate	Weak
ASULAM SODIUM SALT	nu	550,000	7	40	High	Moderate	Weak
ATRAZINE	Atrazine Bicep II Bromox + Atrazine Buctril + Atrazine Bullet Cy-Pro AT Extrazine II Guardsman Harness Xtra Laddok S-12 Lariat Marksman Shotgun Surpass 100	33	60	100	High/Low	Strong	Moderate
BARBAN	nu	11	5	1,000	Low	Moderate	Moderate
BENEFIN (Benfluralin)	Balan	0.1	40	9,000	Low	Moderate	Strong
BENSULFURON METHYL	nu	120	5	370	High/Low	Moderate	Weak
BENSULIDE	nu	5.6	120	1,000	Low	Strong	Strong
BENTAZON SODIUM SALT	Basagran Galaxy Laddok S-12 Rezult Prodigy Storm	2,300,000	20	34	High	Moderate	Weak
BIFENOX	nu	0.398	7	10,000	High/Low	Weak	Moderate
BROMACIL ACID	Krovar I Weed Blast ?	700	60	32	High/Low	Strong	Moderate
BROMACIL LITHIUM SALT	Hyvar XL Weed Blast ?	700	60	32	Low	Strong	Moderate
BROMOXYNIL BUTYRATE ESTER	Bromox ? Bromox MCP Ester ? Bromox - MCPA 2-2? Bromox + Atrazine ? Laser ? Moxynil ?	27	7	1,079	Low	Moderate	Moderate

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
BROMOXYNIL OCTANOATE ESTER	B-4 Bison Bromox ? Bromox MCP Ester ? Bromox - MCPA 2-2? Bromox + Atrazine ? Bronate Buctril Buctril + Atrazine Laser ? Moxynil ?	0.08	7	10,000	Low	Weak	Moderate
BUTACHLOR	nu	23	12	700	Low	Strong	Weak
BUTYLATE	nu	44	13	400	Low	Strong	Weak
CDAA (Allidochlor)	nu	20,000	10	20	High/Low	Moderate	Weak
CHLORAMBEN SALTS	nu	900,000	14	15	Low	Moderate	Weak
CHLORBROMURON	nu	35	40	500	High/Low	Strong	Weak
CHLORIMURON ETHYL	Classic Concert Reliance STS	1,200	40	110	Low	Strong	Weak
CHLOROXURON	nu	2.5	60	3,000	High	Strong	Strong
CHLORPROPHAM (CIPC)	nu	89	30	400	Low	Strong	Strong
CHLORSULFURON	Finesse	7,000	40	40	Low	Strong	Strong
CINMETHYLIN	nu	63	30	300	Low	Moderate	Weak
CLETHODIM	Prism Select	nd	nd	nd	nd	nd	nd
CLOMAZONE (Dimethazone)	nu	1,100	24	300	Low	Moderate	Weak
CLOPYRALID AMINE SALT	Broadstrike Plus Curtail Hornet Scorpion III Stinger Transline	300,000	40	6	High	Strong	Weak
CYANAZINE	Bladex Cy-Pro Cy-Pro AT Extrazine II	170	14	190	High/Low	Moderate	Weak
CYCLOATE	Ro-Neet	95	30	430	Low	Strong	Strong
DALAPON SODIUM SALT	nu	900,000	30	1	High	Moderate	Weak
DCPA (Chlorthal-dimethyl)	Dacthal	0.5	100	5,000	High	Moderate	Strong
DESMEDIPHAM	Betamix Betamix Progress Betanex	8	30	1,500	Low	Moderate	Moderate
DI-ALLATE	nu	14	30	500	Low	Strong	Weak
DICAMBA SALT	Banvel Banvel SGF Clarity Fallow Master Marksman Resolve CP Resolve SG Weed Master	400,000	14	2	High/Low	Moderate	Weak

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
DICHLOBENIL	Casoron	21.2	60	400	High/Low	Strong	Moderate
DICHLORPROP (2,4-DP) ESTER	nu	50	10	1,000	Low	Moderate	Moderate
DICLOFOP-METHYL	Hoelon	0.8	30	16,000	Low	Moderate	Moderate
DIETHATYL-ETHYL	nu	105	30	1,400	Low	Moderate	Moderate
DIFENZOQUAT METHYLSULFATE SALT	Avenge	817,000	100	54,500	High	Strong	Strong
DIMETHENAMID	Frontier Guardsman	nd	nd	nd	nd	nd	nd
DIMETHYLARSENIC ACID	nu	2,000,000	50	1,000	High	Strong	Strong
DINITRAMINE	nu	1.1	30	4,000	Low	Moderate	Moderate
DINOSEB	nu	52	30	30	Low	Strong	Weak
DINOSEB PHENOL	nu	50	20	500	Low	Strong	Weak
DINOSEB SALTS	nu	2,200	20	63	Low	Moderate	Weak
DIPHENAMID	nu	260	30	210	High/Low	Moderate	Weak
DIPROPETRYN	nu	16	30	900	High	Moderate	Weak
DIQUAT DIBROMIDE SALT	Diquat	718,000	1,000	1,000,000	High	Weak	Strong
DIURON	Karmex Krovar I Weed Blast	42	90	480	High/Low	Strong	Moderate
DSMA	nu	250,000	180	7,000	High	Strong	Strong
ENDOTHALL (Endothal) SALT	Herbicide 273	100,000	7	20	High	Moderate	Weak
EPTC	DoublePlay Eptam Eradicane	344	6	200	Low	Moderate	Weak
ETHALFLURALIN	Sonalan	0.3	60	4,000	Low	Moderate	Strong
ETHOFUMESATE	Betamix Progress Nortron SC	50	30	340	Low	Strong	Weak
FENAC (Chlorfenac) SALT	nu	500,000	180	20	High/Low	Strong	Moderate
FENOPROP (2,4,5-TP)(SILVEX)	nu	140	21	300	Low	Moderate	Weak
FENOXAPROP-ETHYL	Acclaim Cheyenne TP Dakota Fusion Laser Option II Puma Silverado Tiller	0.8	9	9,490	Low	Moderate	Moderate
FENURON	nu	3,850	60	42	High/Low	Strong	Moderate
FLUAZIFOP-BUTYL	nu	2	21	3,000	Low	Moderate	Moderate
FLUAZIFOP-P-BUTYL	Fusilade DX Fusion	2	15	5,700	Low	Moderate	Moderate
FLUCHLORALIN	nu	0.9	60	3,000	Low	Moderate	Strong

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
FLUMETSULAM	Broadstrike + Dual Broadstrike + Treflan Broadstrike Plus Hornet Scorpion III	nd	nd	nd	nd	nd	nd
FLUMICLORAC	Resource Stellar	nd	nd	nd	nd	nd	nd
FLUOMETURON	nu	110	85	100	High/Low	Strong	Moderate
FLURIDONE	nu	10	21	1,000	Low	Moderate	Moderate
FOMESAFEN SODIUM SALT	nu	700,000	100	60	High	Strong	Moderate
FOSAMINE AMMONIUM SALT	Krenite	1,790,000	8	150	High	Moderate	Weak
GLUFOSINATE AMMONIUM SALT	Liberty	1,370,000	7	100	High	Moderate	Weak
GLYPHOSATE ISOPROPYLAMINE SALT	Fallow Master Glyphos Landmaster BW Pond Master Ranger Rodeo Roundup Roundup RT Roundup Ultra Roundup Ultra RT Touchdown	900,000	47	24,000	High	Strong	Strong
HALOSULFURON	Permit	nd	nd	nd	nd	nd	nd
HALOXYFOP-METHYL	nu	43	55	75	Low	Strong	Moderate
HEXAZINONE	Velpar	33,000	90	54	Low	Strong	Moderate
IMAZAMETH	Plateau	nd	nd	nd	nd	nd	nd
IMAZAMETHABENZ-METHYL (m-isomer)	Assert	1,370	45	66	Low	Strong	Moderate
IMAZAMETHABENZ-METHYL (p-isomer)	Assert	857	45	35	Low	Strong	Moderate
IMAZAMOX	Raptor	nd	nd	nd	nd	nd	nd
IMAZAPYR ACID	Contain ?	11,000	90	100	Low	Strong	Moderate
IMAZAPYR ISOPROPYLAMINE SALT	Arsenal Contain ?	500,000	90	100	High/Low	Strong	Moderate
IMAZAQUIN ACID	nu	60	60	20	Low	Strong	Moderate
IMAZAQUIN AMMONIUM SALT	nu	160,000	60	20	High/Low	Strong	Moderate
IMAZETHAPYR (AC 263, 499)	Passport Pursuit Pursuit Plus Resolve CP Resolve SG	200,000	90	10	High/Low	Strong	Moderate
ISOPROPALIN	nu	0.1	100	10,000	Low	Moderate	Strong
ISOXABEN	nu	1	100	1,400	Low	Moderate	Strong
ISOZAFLUTOLE	Balance	nd	nd	nd	nd	nd	nd

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
LACTOFEN	Cobra Stellar	0.1	3	10,000	Low	Weak	Moderate
LINURON	Lorox	75	60	400	High/Low	Strong	Moderate
MCPA DIMETHYLAMINE SALT	MCPA amine MEC Amine-D MCPP 4K Turf MXL ?	866,000	25	2,000	High	Moderate	Moderate
MCPA ESTER	B-4 Bison Bromox MCP Ester Bromox - MCPA 2-2 Bronate Cheyenne TP Dakota Laser MCPA ester MXL ? Rhonox MCP Ester Sword Tiller	5	25	1,000	Low	Moderate	Moderate
MCPB SODIUM SALT	nu	200,000	14	20	High	Moderate	Weak
MECOPROP (MCPP) DIMETHYLAMINE SALT	nu	660,000	21	20	High	Moderate	Weak
MEFLUIDIDE	nu	180	4	200	Low	Moderate	Weak
METHAM (METAM) SODIUM SALT	nu	963,000	7	10	Low	Moderate	Weak
METHANEARSONIC ACID SODIUM SALT	nu	1,400,000	1,000	100,000	High	Weak	Strong
METHAZOLE	nu	1.5	14	3,000	High/Low	Moderate	Moderate
METOLACHLOR	Bicep II Broadstrike + Dual Dual II Pennant Turbo	530	90	200	Low	Strong	Moderate
METRIBUZIN	Lexone Salute Sencor Turbo	1,220	40	60	Low	Strong	Weak
METSULFURON-METHYL	Ally Escort Finesse	9,500	30	35	Low	Moderate	Weak
MOLINATE	nu	970	21	190	Low	Moderate	Weak
MONOLINURON	nu	735	60	200	High/Low	Strong	Moderate
MONURON	nu	230	170	150	High/Low	Strong	Moderate
MSMA	nu	1,000,000	180	7,000	High	Strong	Strong
NAPROPAMIDE	nu	74	70	700	Low	Strong	Moderate
NAPTALAM SODIUM SALT	nu	231,000	14	20	Low	Moderate	Weak
NEBURON	nu	5	120	2,500	High/Low	Strong	Strong
NICOSULFURON	Accent	22,000	21	30	Low	Moderate	Weak

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
NITROFEN	nu	1	30	10,000	High/Low	Moderate	Moderate
NORFLURAZON	nu	28	30	700	Low	Moderate	Weak
ORYZALIN	Surflan	2.5	20	600	High/Low	Moderate	Weak
OXADIAZON	Ronstar	0.7	60	3,200	Low	Moderate	Strong
OXYFLUORFEN	Goal	0.1	35	100,000	Low	Weak	Moderate
PARAQUAT DICHLORIDE SALT	Cyclone CF Gramoxone Extra	620,000	1,000	1,000,000	High	Weak	Strong
PEBULATE	nu	100	14	430	Low	Moderate	Weak
PENDIMETHALIN	Pendulum Pentagon Prowl Pursuit Plus Stomp	0.275	90	5,000	Low	Moderate	Strong
PERFLUIDONE	nu	500,000	30	30	High	Moderate	Weak
PETROLEUM OIL	nu	100	10	1,000	Low	Moderate	Moderate
PHENMEDIPHAM	Betamix Betamix Progress	4.7	30	2,400	Low	Moderate	Moderate
PICLORAM SALT	Tordon 22K	200,000	90	16	High	Strong	Moderate
PRIMISULFURON-METHYL	Beacon Exceed	70	30	50	Low	Strong	Weak
PRODIAMINE	nu	0.013	120	13,000	Low	Moderate	Strong
PROFLURALIN	nu	0.1	110	10,000	Low	Moderate	Strong
PROMETON	Pramitol	720	500	150	Low	Strong	Moderate
PROMETRYN	nu	33	60	400	Low	Strong	Moderate
PRONAMIDE (Propyzamide)	Kerb	15	60	800	High	Strong	Moderate
PROPACHLOR	Ramrod	613	6.3	80	Low	Moderate	Weak
PROPANIL	Stampede	200	1	149	Low	Moderate	Weak
PROPAZINE	nu	8.6	135	154	Low	Strong	Moderate
PROPHAM (IPC)	nu	250	10	200	High/Low	Moderate	Weak
PROSULFURON	Exceed Peak	nd	nd	nd	nd	nd	nd
PYRAZON (Chloridazon)	Pyramin	400	21	120	Low	Moderate	Weak
PYRIDATE	Tough	nd	nd	nd	nd	nd	nd
QUIZALOFOP-ETHYL	Assure II	0.31	60	510	Low	Moderate	Strong
RIMSULFURON	Basis Matrix	nd	nd	nd	nd	nd	nd
SECBUMETON	nu	600	60	150	High	Strong	Moderate
SETHOXYDIM	Poast Poast Plus Prestige Rezult Prodigy Ultima 160 Vantage	4,390	5	100	Low	Moderate	Weak

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
SIDURON	nu	18	90	420	High	Moderate	Moderate
SIMAZINE	Pramitol Princep Caliber 90	6.2	60	130	High/Low	Moderate	Moderate
SIMETRYN	nu	450	60	200	Low	Strong	Moderate
SODIUM CHLORATE	Defol 6 Des-I-Cate Pramitol	100,000	200	10	High/Low	Strong	Moderate
SODIUM METABORATE	Pramitol	nd	nd	nd	nd	nd	nd
SULFENTRAZONE	Authority	nd	nd	nd	nd	nd	nd
SULFOMETURON-METHYL	Oust	70	20	78	Low	Strong	Weak
TCA	nu	1,200,000	21	3	High/Low	Moderate	Weak
TEBUTHIURON	Spike	2,500	360	80	Low	Strong	Moderate
TERBACIL	Sinbar	710	120	55	High	Strong	Moderate
TERBUTRYN	nu	22	42	2,000	High/Low	Strong	Strong
THIFENSULFURON-METHYL	Basis Concert Harmony Extra Pinnacle Reliance STS	2,400	12	45	Low	Moderate	Weak
THIOBENCARB	nu	28	21	900	Low	Moderate	Weak
TRALKOXYDIM	Achieve	nd	nd	nd	nd	nd	nd
TRIALLATE	Buckle Far-Go	4	82	2,400	Low	Moderate	Strong
TRIASULFURON	Amber	nd	nd	nd	nd	nd	nd
TRIBENURON METHYL	Express Harmony Extra	280	10	46	Low	Moderate	Weak
TRICLOPYR AMINE SALT	nu	2,100,000	46	20	High	Strong	Moderate
TRICLOPYR ESTER	Crossbow Turflon Ester	23	46	780	Low	Strong	Moderate
TRIDIPHANE	nu	1.8	28	5,600	Low	Moderate	Moderate
TRIFLURALIN	Broadstrike + Treflan Buckle Freedom Passport Salute Treflan Treflan Pro-5 Treflan Treflan Trific Trilin Tri-4 Trifluralin/Trust	0.3	60	8,000	Low	Moderate	Strong
TRIFLUSULFURON	UpBeet	nd	nd	nd	nd	nd	nd
VERNOLATE	nu	108	12	260	Low	Moderate	Weak

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.

INSECTICIDES, FUNGICIDES, NEMATACIDES, etc.

Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
1,2-DICHLOROPROPANE	nu	2,700	700	50	Low	Strong	Moderate
1,3-DICHLOROPROPENE	nu	2,250	10	32	Low	Moderate	Weak
ABAMECTIN (Avermectin)	nu	5	28	5,000	Low	Moderate	Moderate
ACEPHATE	Orthene	818,000	3	2	High	Moderate	Weak
ALDICARB	Temik	6,000	30	30	Low	Moderate	Weak
ALDOXYCARB (Aldicarb sulfone)	nu	10,000	20	10	Low	Moderate	Weak
ALDRIN	nu	0.027	365	5,000	High/Low	Moderate	Strong
AMINOCARB	nu	915	6	100	Low	Moderate	Weak
AMITRAZ	nu	1	2	1,000	Low	Moderate	Weak
ANILAZINE	nu	8	1	1,000	Low	Weak	Weak
AZINPHOS-METHYL	Guthion	29	10	1,000	Low	Moderate	Moderate
BACILLUS THURINGIENSIS	Dipel	nd	nd	nd	nd	nd	nd
BENALAXYL	nu	37	30	1,000	High/Low	Moderate	Moderate
BENDIOCARB	nu	40	5	570	High/Low	Strong	Weak
BENODANIL	nu	20	25	700	High/Low	Strong	Weak
BENOMYL	Benlate	2	67	1,900	Low	Strong	Strong
BIFENTHRIN	Capture	0.1	26	240,000	Low	Weak	Moderate
CAPTAFOL	nu	1.4	7	3,000	Low	Moderate	Moderate
CAPTAN	Agrosol Agrox 2-Way Captan 50-WP Captan 80-WP Captec 4L Nu-Gro Captan Nu-Gro Soybean Seed Protect	5.1	2.5	200	Low	Moderate	Weak
CARBARYL	Sevin	120	10	300	Low	Moderate	Weak
CARBENDAZIM (MBC)	nu	8	120	400	Low	Strong	Moderate
CARBOFURAN	Furadan	351	50	22	Low	Strong	Moderate
CARBON DISULFIDE	nu	2,300	1.5	60	Low	Moderate	Weak
CARBOPHENOTHION	nu	0.34	30	50,000	Low	Weak	Moderate
CARBOXIN	DB Green + Vitavax Enhance Plus Germate Plus RTU-Vitavax-Thiram Vitavax Vitavax 200 Vitavax Pour-on VTL	195	3	260	Low	Moderate	Weak
CHLORDANE	nu	0.06	350	20,000	Low	Moderate	Strong
CHLORDIMEFORM HYDROCHLORIDE	nu	500,000	60	100,000	High	Weak	Strong
CHLOROBENZILATE	nu	13	20	2,000	Low	Moderate	Moderate
CHLORONEB	nu	8	130	1,650	High/Low	Strong	Strong

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
CHLOROPICRIN	nu	2,270	1	62	Low	Moderate	Weak
CHLOROTHALONIL	Bravo Ridomil/Bravo	0.6	30	1,380	Low	Moderate	Moderate
CHLORPYRIFOS	Lorsban 30 Lorsban 50-SL	0.4	30	6,070	Low	Moderate	Moderate
CHLORPYRIFOS-METHYL	Reldan	4	7	3,000	Low	Moderate	Moderate
CHLOZOLINATE	nu	1	2	10,000	Low	Moderate	Moderate
CLOFENTEZINE	nu	0.1	40	45,000	Low	Moderate	Strong
COPPER	Basicop Champ Champion Kocide Top Cop Tribasi	nd	nd	nd	nd	nd	nd
CRYOLITE	nu	420	3,000	10,000	High/Low	Strong	Strong
CYFLUTHRIN	Baythroid	0.002	30	100,000	Low	Weak	Moderate
CYHEXATIN	nu	1	50	4,000	High/Low	Strong	Strong
CYMOXANIL	unknown	nd	nd	nd	nd	nd	nd
CYPERMETHRIN	nu	0.004	30	100,000	Low	Weak	Moderate
CYROMAZINE	nu	136,000	150	200	High	Strong	Moderate
DAZOMET	nu	3,000	7	10	Low	Moderate	Weak
DBCP	nu	1,000	180	70	Low	Strong	Moderate
DCNA (Dicloran)	nu	7	60	1,000	Low	Strong	Strong
DDD (TDE)	nu	0.02	1,000	100,000	Low	Weak	Strong
DDE	nu	0.1	1,000	50,000	Low	Moderate	Strong
DDT	nu	0.0055	2,000	2,000,000	Low	Weak	Strong
DEMETON	nu	60	15	70	Low	Strong	Weak
DIAZINON	Diazinon Germate Plus	60	40	1,000	High/Low	Strong	Strong
DICHLONE	nu	0.1	10	10,000	High/Low	Weak	Moderate
DICHLORVOS (DDVP)	nu	10,000	0.5	30	Low	Moderate	Weak
DICOFOL	nu	0.8	45	5,000	Low	Moderate	Strong
DICROTOPHOS	nu	1,000,000	20	75	High	Moderate	Weak
DIELDRIN	nu	0.2	1,000	12,000	Low	Moderate	Strong
DIENOCHLOR	nu	25	300	600	Low	Strong	Moderate
DIFENOCONAZOLE	Dividend	nd	nd	nd	nd	nd	nd
DIFLUBENZURON	nu	0.08	10	10,000	Low	Weak	Moderate
DIMETHIRIMOL	nu	1,200	120	90	Low	Strong	Moderate
DIMETHOATE	Cygon	39,800	7	20	Low	Moderate	Weak
DINOCAP	nu	4	5	550	Low	Moderate	Weak
DIOXACARB	nu	6,000	2	40	High/Low	Moderate	Weak
DISULFOTON	Di-Syston	25	30	600	Low	Strong	Weak
DNOC SODIUM SALT	nu	100,000	20	20	High	Moderate	Strong
DODINE ACETATE	nu	700	20	100,000	Low	Weak	Moderate

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
ENDOSULFAN	Phaser Thiodan	0.32	50	12,400	Low	Moderate	Strong
ENDRIN	nu	0.23	4,300	10,000	Low	Moderate	Strong
EPN	nu	0.5	15	4,000	Low	Moderate	Moderate
ESFENVALERATE	Asana XL	0.002	35	5,300	Low	Moderate	Moderate
ETHION	nu	1.1	150	10,000	Low	Strong	Strong
ETHOPROP (Ethoprophos)	Mocap	750	25	70	Low	Moderate	Weak
ETHYLENE DIBROMIDE (EDB)	nu	4,300	100	34	High/Low	Strong	Moderate
ETRIDIAZOLE	nu	50	103	1,000	High/Low	Strong	Strong
FENAMINOSULF	nu	20,000	2	15	High/Low	Moderate	Weak
FENAMIPHOS	nu	400	50	100	Low	Strong	Moderate
FENARIMOL	nu	14	360	600	Low	Strong	Moderate
FENBUTATIN OXIDE	nu	0.0127	90	2,300	Low	Moderate	Strong
FENFURAM	nu	100	42	300	Low	Strong	Moderate
FENITROTHION	nu	30	4	2,000	Low	Moderate	Moderate
FENOXYCARB	nu	6	1	1,000	Low	Weak	Weak
FENPROPATHRIN	nu	0.33	5	5,000	Low	Weak	Moderate
FENSULFOTHION	nu	1,540	30	300	Low	Moderate	Moderate
FENTHION	nu	4.2	34	1,500	Low	Moderate	Moderate
FENVALERATE	Pydrin	0.002	35	5,300	Low	Moderate	Moderate
FERBAM	nu	120	17	300	Low	Moderate	Weak
FLUCYTHRINATE	nu	0.06	21	100,000	Low	Weak	Moderate
FLUVALINATE	nu	0.005	7	1,000,000	Low	Weak	Moderate
FONOFOS	Dyfonate	16.9	40	870	Low	Moderate	Moderate
FORMALDEHYDE	Formaldeyde	nd	nd	nd	nd	nd	nd
FORMETANATE HYDROCHLORIDE SALT	nu	500,000	100	1,000,000	High	Strong	Strong
FOSETYL-ALUMINUM	nu	120,000	0.1	20	High	Moderate	Weak
HEPTACHLOR	nu	0.056	250	24,000	Low	Moderate	Strong
HEXACHLOROBENZENE (HCB)	nu	0.005	1,000	50,000	Low	Moderate	Strong
HEXYTHIAZOX	nu	0.5	30	6,200	Low	Moderate	Moderate
HYDRAMETHYLNON (Amdro)	nu	0.006	10	730,000	Low	Weak	Moderate
IMAZALIL	Double R Nuzone	1,400	150	4,000	Low	Strong	Strong
IMIDACLOPRID	Gaucho Admire Provado	nd	nd	nd	nd	nd	nd
IPRODIONE	nu	13.9	14	700	Low	Strong	Weak
ISAZOFOS	nu	69	34	100	Low	Strong	Weak
ISOFENPHOS	nu	24	150	600	Low	Strong	Moderate
LAMBDA-CYHALOTHRIN	Warrior	0.005	30	180,000	Low	Weak	Moderate

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Common Name	Trade Name	Solubility mg/L	$T_{1/2}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
LINDANE	Lindane DB Green + Vitavax Enhance Plus Germate Plus Granol NM Maneb + Lindane Maneb-Lindane Seed Mate Maneb Lindane VTL	7	400	1,100	High/Low	Strong	Strong
MALATHION	Malathion	130	1	1,800	High/Low	Weak	Weak
MANCOZEB	Dithane Grain Guard Mancozeb Manex II Manzate Penncozeb Spud Bark	6	70	2,000	Low	Strong	Strong
MANEB	Blite Out Plus DB Green DB Green + Vitavax Dustret A Enhance Plus Granol NM Granox Plus Maneb 75DF Maneb 80 WP Maneb + Lindane Maneb-Lindane Pro-Tex Seed Mate Maneb Lindane Seed Treatment For Potatoes LD	6	70	2,000	Low	Strong	Strong
METALAXYL	Apron Ridomil Ridomil/Bravo	8,400	70	50	High/Low	Strong	Moderate
METALDEHYDE	nu	230	10	240	Low	Moderate	Weak
METHAM (METAM) SODIUM SALT	nu	963,000	7	10	Low	Moderate	Weak
METHAMIDOPHOS	Monitor	1,000,000	6	5	High	Moderate	Weak
METHIDATHION	Supracide	220	7	400	Low	Moderate	Weak
METHIOCARB (Mercaptodimethur)	nu	24	30	300	Low	Strong	Weak
METHOMYL	Lannate	58,000	30	72	High	Moderate	Weak
METHOXYCHLOR	nu	0.1	120	80,000	Low	Moderate	Strong
METHYL BROMIDE	nu	13,400	55	22	Low	Strong	Moderate
METHYL ISOTHIOCYANATE	nu	7,600	7	6	Low	Moderate	Weak
METHYL PARATHION	Methyl Parathion Penncap M	60	5	5,100	Low	Moderate	Moderate
METIRAM	nu	0.1	20	500,000	Low	Weak	Moderate
MEVINPHOS	nu	600,000	3	44	High	Moderate	Weak
MEXACARBATE	nu	100	10	300	Low	Moderate	Weak
MIREX	nu	0.00007	3,000	1,000,000	Low	Weak	Strong

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
MONOCROTOPHOS	nu	1,000,000	30	1	High	Moderate	Weak
MYCLOBUTANIL	nu	142	66	500	Low	Strong	Moderate
NALED	nu	2,000	1	180	Low	Moderate	Weak
NAPHTHALENE	nu	30	30	500	Low	Strong	Weak
NITRAPYRIN	nu	40	10	570	Low	Strong	Weak
NOSEMA LACUSTAE FUNGUS	NOLO® Bait	nd	nd	nd	nd	nd	nd
OXAMYL	Vydate	282,000	4	25	High/Low	Moderate	Weak
OXYCARBOXIN	nu	1,000	20	95	Low	Moderate	Weak
OXYDEMETON-METHYL	nu	1,000,000	10	10	High	Moderate	Weak
OXYTHIOQUINOX (Quinomethionate)	nu	1	30	2,300	Low	Moderate	Moderate
PARATHION (Ethyl parathion)	Parathion	24	14	5,000	Low	Moderate	Moderate
PCNB	Terra Coat	0.44	21	5,000	High/Low	Weak	Moderate
PENTACHLOROPHENOL	nu	100,000	48	30	High/Low	Strong	Moderate
PERMETHRIN	Ambush Pounce	0.006	30	100,000	Low	Weak	Moderate
PETROLEUM OIL	nu	100	10	1,000	Low	Moderate	Moderate
PHENTHOATE	nu	11	35	1,000	Low	Moderate	Moderate
PHORATE	Thimet	22	60	1,000	Low	Strong	Strong
PHOSALONE	nu	3	21	1,800	Low	Moderate	Moderate
PHOSMET	nu	20	19	820	Low	Moderate	Weak
PHOSPHAMIDON	Phosphamidon	1,000,000	17	7	High	Moderate	Weak
PIPERALIN	nu	20	30	5,000	Low	Moderate	Moderate
PIRIMICARB	nu	2,700	10	23	High/Low	Moderate	Weak
PIRIMIPHOS-ETHYL	nu	93	45	300	Low	Strong	Moderate
PIRIMIPHOS-METHYL	nu	9	10	1,000	Low	Moderate	Moderate
PROCHLORAZ	nu	34	120	500	Low	Strong	Moderate
PROCYMIDONE	nu	4.5	7	1,500	High/Low	Moderate	Moderate
PROFENOFOS	nu	28	8	2,000	Low	Moderate	Moderate
PROMECARB	nu	91	20	200	Low	Strong	Weak
PROPAMOCARB HYDROCHLORIDE	unknown	1,000,000	30	1,000,000	High	Weak	Moderate
PROPARGITE	nu	0.5	56	4,000	Low	Moderate	Strong
PROPICONAZOLE	Tilt	110	110	650	Low	Strong	Moderate
PROPOXUR	nu	1,800	30	30	Low	Moderate	Weak
PYRETHRINS	Pyrenone	0.001	12	100,000	High/Low	Weak	Moderate
RESMETHRIN	nu	0.01	30	100,000	Low	Weak	Moderate
ROTENONE	nu	0.2	3	10,000	Low	Weak	Moderate
STREPTOMYCIN	Dustret A Seed Treatment For Potatoes LD	nd	nd	nd	nd	nd	nd

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Common Name	Trade Name	Solubility mg/L	$T_{½}$ Days	K_{oc}	Formulation-application displ. potential	Influence on pest.-solution interaction displ. potent.	Influence on pest.-sed. interaction displ. potent.
SULFUR	Kumulus DF Liquid Sulfur Six Microthiol Special Sulfur DF Super Six Thiolux DF Uniflow	nd	nd	nd	nd	nd	nd
SULPROFOS	nu	0.31	140	12,000	Low	Moderate	Strong
TEFLUTHRIN	Force	nd	nd	nd	nd	nd	nd
TEMEPHOS	nu	0.001	30	100,000	Low	Weak	Moderate
TERBUFOS	Counter	5	5	500	Low	Moderate	Weak
TETRACHLORVINPHOS	nu	11	2	900	Low	Moderate	Moderate
THIABENDAZOLE	Agrosol Granox Plus Mertect Sim-Tec Plus	50	403	2,500	Low	Strong	Strong
THIOCYCLAM-HYDROGEN OXALATE	nu	84,000	1	20	Low	Moderate	Weak
THIODICARB	nu	19.1	7	350	Low	Strong	Weak
THIOPHANATE-METHYL	Topsin Tops 2.5D Dustret T	3.5	10	1,830	Low	Moderate	Moderate
THIRAM	Triple Noctic Vitavax 200 Vitavax Pour-On VTL Yield Shield	30	15	670	Low	Strong	Weak
TOLCLOFOS-METHYL	nu	0.3	30	2,000	High/Low	Weak	Moderate
TOXAPHENE	nu	3	9	100,000	Low	Weak	Moderate
TRALOMETHRIN	Scout X-TRA	0.001	27	100,000	Low	Weak	Moderate
TRIADIMEFON	nu	71.5	26	300	Low	Moderate	Weak
TRIADIMENOL	nu	47	300	800	High/Low	Strong	Moderate
TRICHLORFON	nu	120,000	10	10	High	Moderate	Weak
TRICHLORONAT	nu	50	139	400	Low	Strong	Moderate
TRICYLAZOLE	nu	1,600	21	1,200	High/Low	Moderate	Moderate
TRIFLUMIZOLE	nu	12,500	14	40	Low	Moderate	Weak
TRIFORINE	nu	30	21	540	Low	Strong	Weak
TRIMETHACARB	nu	58	20	400	Low	Strong	Weak
TRIPHENYLTIN HYDROXIDE	Du-Ter Pro-Tex Super Tin	1	75	23,000	Low	Strong	Strong
VINCLOZOLIN	nu	1,000	20	100	Low	Moderate	Weak
ZINC	Maneb Plus Zinc F4	nd	nd	nd	nd	nd	nd
ZINEB	nu	10	30	1,000	High/Low	Moderate	Moderate
ZIRAM	nu	65	30	400	Low	Moderate	Weak

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▼ APPENDIX II
Example: Surface Water Contamination Potential Assessment
Sec. 8, 9, 10, T.138N, R.58W. Barnes Co., ND

Step 1

Determine soil map unit (SMU) delineations that have perennial streams or that border rivers or lakes as indicated in the Barnes Co. Soil Survey Report. (Opdahl et al., 1990)

There are no areas that meet these criteria in Sec. 8 and 9. A delineation of SMU 56 shares a border with the Sheyenne River in Sec. 10 (Fig. II1). This delineation of SMU 56 will have a HIGH pesticide displacement potential with respect to the proximity factor (Fig. II2). There is an area in Sec. 10 where a delineation of SMU 83F shares a border with the river (Fig II1); however, the length is too short to be of significance and will be ignored. There are no SMU delineations with perennial streams.

Step 2

Determine if any SMU delineations share a boundary with areas defined in STEP 1.

In Sec. 10 there are delineations of SMU 9, 9B, 9D, and 83F (Fig. II1) that share a boundary with areas of HIGH displacement potential for the proximity factor. These areas have INTERMEDIATE displacement potential with respect to the proximity factor (Fig. II2).

Step 3

Determine if any SMU delineations have intermittent drainageways other than road or railroad ditches.

In Sec. 9 and 10 delineations of SMU 9B, 9D, and 83F have natural intermittent drainageways that pass through them (Fig. II1). These areas have INTERMEDIATE displacement potential with respect to the proximity factor (Fig. II2).

Step 4

Determine which SMU delineations that share a boundary with those SMU delineations that meet the criteria outlined in STEPS 2 and 3 and if the shared boundary is crossed by a road or railroad ditch.

Following the criteria outlined in STEP 4 will result in an extension of the areas of INTERMEDIATE displacement potential with respect to the proximity factor (Fig. II2). For example, a delineation of SMU 63 in the NE 1/4, Sec. 10 shares a boundary with a delineation of SMU 83F. The boundary shared by these two SMU delineations is crossed by a road ditch. Since the delineation of SMU 83F has an INTERMEDIATE displacement potential as defined in STEP 3, the delineation of SMU 63 also has an INTERMEDIATE displacement potential with respect to the proximity factor.

Step 5

Determine the pesticide displacement potential with respect to the formulation-application factor for the pesticide of interest.

It is assumed that leafy spurge is a problem in road ditches and pastureland in all three sections. Therefore, the potential effects of picloram use needs to be assessed with respect to surface water resources. There is a general relationship between a combination of pesticide formulation and application and the pesticide displacement potential (Table 2). Picloram is applied to plant foliage as a solution. The solubility of picloram is 200,000 mg/L (Appendix I). With respect to the formulation-application factor, the displacement potential for picloram is HIGH (Appendix I).

Step 6

Determine the displacement potential for the pesticide-solution interaction factor by applying the Goss-Wauchope matrix to the use of picloram.

Information from Appendix I can be used with the criteria from Table 3 to determine that the influence of pesticide properties on pesticide-solution interaction factor is strong. Soils also influence pesticide-solution interaction factor (Table 4) and is shown by SMU in Table II1. It should be noted that only the dominant soil of a complex mapping unit is considered for interpretation. The soil and pesticide property influences on the pesticide-solution interaction factor are combined (Table 5) to determine the displacement potential (Table II2) and are displayed schematically in Fig. II3.

Table II1. Soil properties (after Opdahl et at., 1990) influencing pesticide displacement potential to surface water resources in Sec. 8, 9, 10, T.138N., R.58W. Barnes County.

Soil Mapping Units		*Soil Properties					
		Hydro group	K fact	Influence pest.-solution	Influence pest.-sediment	▲% slope	Flood freq
2	Tonka	D	0.32	Strong	Strong	0.5	None
9	Nutley 0-2%	C	0.28	Strong	Strong	1	None
9B	Nutley 2-6%	C	0.28	Strong	Strong	4	None
9D	Nutley 6-15%	C	0.28	Strong	Strong	10.5	None
14B	Barnes-Buse 3-6 %	B	0.28	Moder.	Moder.	4.5	None
14C	Barnes-Buse 6-9%	B	0.28	Moder.	Moder.	7.5	None
17B	Barnes-Svea 2-6%	B	0.28	Moder.	Moder.	4	None
40B	Gardena-Zell 3-6%	B	0.28	Moder.	Moder.	4.5	None
43	Gardena	B	0.28	Moder.	Moder.	0.5	None
56	LaDelle	B	0.28	Moder.	Moder.	0.5	Occas.
63	Renshaw	B	0.28	Moder.	Moder.	0.5	None
64	Pits, gravel	NA	NA	NA	NA	NA	NA
65	Svea-Barnes 0-2%	B	0.28	Moder.	Moder.	1	None
77	Vallers, saline	C	0.28	Strong	Strong	0.5	None
81B	Edgeley 2-6%	C	0.28	Strong	Strong	4	None
83F	Kloten-Buse 9-35%	D	0.32	Strong	Strong	22	None
86	Overly-Nahon	C	0.32	Strong	Strong	0.5	None
87	Svea-Cavour 0-3%	B	0.28	Moder.	Moder.	1.5	None

* Only the first soil in the mapping unit was used for interpretation
▲ Mean of the range of slope %
NA Not applicable

Table II2. Pesticide displacement potential related to soil mapping unit delineations in Sec. 8, 9, 10, T.138N, R.58W.

Soil Mapping Unit		Factor Displacement Potential			
		Pest.-solution Interaction	Pest.-sediment Interaction	Slope	Flooding
2	Tonka	HIGH	HIGH	LOW	LOW
9	Nutley 0-2%	HIGH	HIGH	LOW	LOW
9B	Nutley 2-6%	HIGH	HIGH	LOW	LOW
9D	Nutley 6-15%	HIGH	HIGH	INTERMED.	LOW
14B	Barnes-Buse 3-6%	HIGH	INTERMED.	LOW	LOW
14C	Barnes-Buse 6-9%	HIGH	INTERMED.	LOW	LOW
17B	Barnes-Svea 2-6%	HIGH	INTERMED.	LOW	LOW
40B	Gardena-Zell 3-6%	HIGH	INTERMED.	LOW	LOW
43	Gardena	HIGH	INTERMED.	LOW	LOW
56	LaDelle	HIGH	INTERMED.	LOW	INTERMED.
63	Renshaw	HIGH	INTERMED.	LOW	LOW
64	Pits, gravel	NA	NA	NA	NA
65	Svea-Barnes 0-2%	HIGH	INTERMED.	LOW	LOW
77	Vallers, saline	HIGH	HIGH	LOW	LOW
81B	Edgeley 2-6%	HIGH	HIGH	LOW	LOW
83F	Kloten-Buse 9-35%	HIGH	HIGH	HIGH	LOW
86	Overly-Nahon	HIGH	HIGH	LOW	LOW
87	Svea-Cavour 0-3%	HIGH	INTERMED.	LOW	LOW

Step 7

Determine the displacement potential of the pesticide-sediment interaction factor by applying the Goss-Wauchope matrix to the use of picloram.

By applying knowledge of picloram properties (Appendix I) to the algorithm in Table 6, a moderate influence on the displacement potential of the pesticide-sediment interaction factor was determined. The soil influence on the pesticide-sediment interaction factor was determined using knowledge of soil properties (Table II1) with the algorithm in Table 7. The influence of pesticide properties and soils is combined (Table 8) to determine the pesticide displacement potential for the pesticide-sediment interaction factor (Table II2) and is displayed schematically in Fig. II4.

Step 8

Determine land slope of soil mapping units.

The influence of slope on pesticide displacement potential is shown in Table 9. Average slope for each SMU (Table II1) is used for this determination, and the resulting displacement potential is presented in Table II2. Fig. II5 schematically displays the pesticide displacement potential for the slope factor.

Step 9

Determine the flooding frequency of soil mapping units.

The influence of flooding on pesticide displacement potential is shown in Table 10 and is found for each SMU in Table II1. The displacement potential for the flooding factor is presented Table II2 and shown schematically in Fig. II6.

Step 10

Determine the sensitivity of surface water resources to picloram use by combining the pesticide displacement potential for the six factors.

The pesticide displacement potential maps (Fig. II3-II6) can be overlaid on the displacement potential map for the proximity factor (Fig. II2). The result (Fig. II7) will show which areas meet the criteria of different surface water sensitivity categories (Tables 11-15) for picloram use. The results of the assessment show what is intuitively obvious, surface water resources closest to the point of pesticide application are the most sensitive.

Delineations of SMU 56 on either side of the Sheyenne River in Sec. 10 have the highest sensitivity and are categorized as High (formulation, solution). This means the pesticide displacement potential is high for the proximity, formulation-application, and pesticide-solution interaction factors.

Bordering the High Sensitivity area is a large area of Somewhat High Sensitivity in Sec. 9 and 10 that encompasses delineations of several SMUs. All of the subcategories of Somewhat High Sensitivity have an Intermediate pesticide displacement potential with respect to the proximity factor. The Somewhat High (formulation, solution-sediment, slope) subcategory has a high displacement potential for the formulation-application, pesticide-solution interaction, pesticide-sediment interaction, and slope factors. The Somewhat High (formulation, solution-sediment) subcategory has a high displacement potential for the formulation-application, pesticide-solution interaction, and pesticide sediment interaction factors. The Somewhat High (formulation, solution) subcategory has a high displacement potential for the formulation-application and pesticide-solution interaction factors.

Bordering the area of Somewhat High Sensitivity are areas of Intermediate Sensitivity that encompass delineations of several SMUs mostly in Sec. 8. The two subcategories of Intermediate Sensitivity have Low pesticide displacement potential for the proximity factor. The Intermediate (formulation, solution-sediment) category has a high displacement potential for the formulation-application, pesticide-solution interaction, and pesticide-sediment interaction factors. The Intermediate (formulation, solution) category has high displacement potential for the formulation-application and pesticide-solution interaction factors.

Step 11

Determine appropriate management recommendations that relate to the areas of different surface water sensitivity.

Management recommendations can begin to be formulated by studying the results of the Sensitivity assessment. Because proximity of water resources to the point of pesticide applications are so important, the first management strategy that should be considered is reduced applications of picloram in areas that have High and Somewhat High Sensitivity. Clearly, areas of High Sensitivity should receive greatest attention.

Complete elimination of picloram in High and Somewhat High Sensitivity areas would be most effective, but perhaps not practical. Utilization of improved application and IPM techniques would be particularly appropriate in these areas and should be implemented before soil and water conservation practices are considered.

Implementation of soil and water conservation practices (SWCP) in the High and Somewhat High Sensitivity areas will probably result in little protection. All of these areas have a high pesticide displacement potential with respect to the pesticide-solution interaction factor. SWCPs have not been demonstrated to be very effective in controlling movement of soluble chemicals. Of the SWCPs, vegetative buffer strips and settling basins are used specifically for water quality protection as opposed to erosion control. It is evident that vegetative filter strips have some capacity to remove soluble chemicals from runoff; however, results from field studies have been variable and are dependent on site specific conditions. Because SWCPs are generally most effective in controlling sediment losses and adsorbed chemicals, they are of greatest practical benefit in those areas that have High pesticide displacement potential with respect to the pesticide-sediment interaction factor. Implementation of SWCPs for pesticide control should receive emphasis in these areas.

The Intermediate Sensitivity areas also have high pesticide displacement potentials and should be addressed accordingly. However, because these areas have low displacement potential with respect to the proximity factor, they should only receive attention after the implementation of pesticide control practices is close to completion in the High and Somewhat High Sensitivity areas. When management practices are addressed in the Intermediate Sensitivity areas, emphasis should be placed on improved application and IPM practices, because SWCPs are not likely to provide much benefit in areas of high pesticide displacement potential for the pesticide-solution interaction factor.

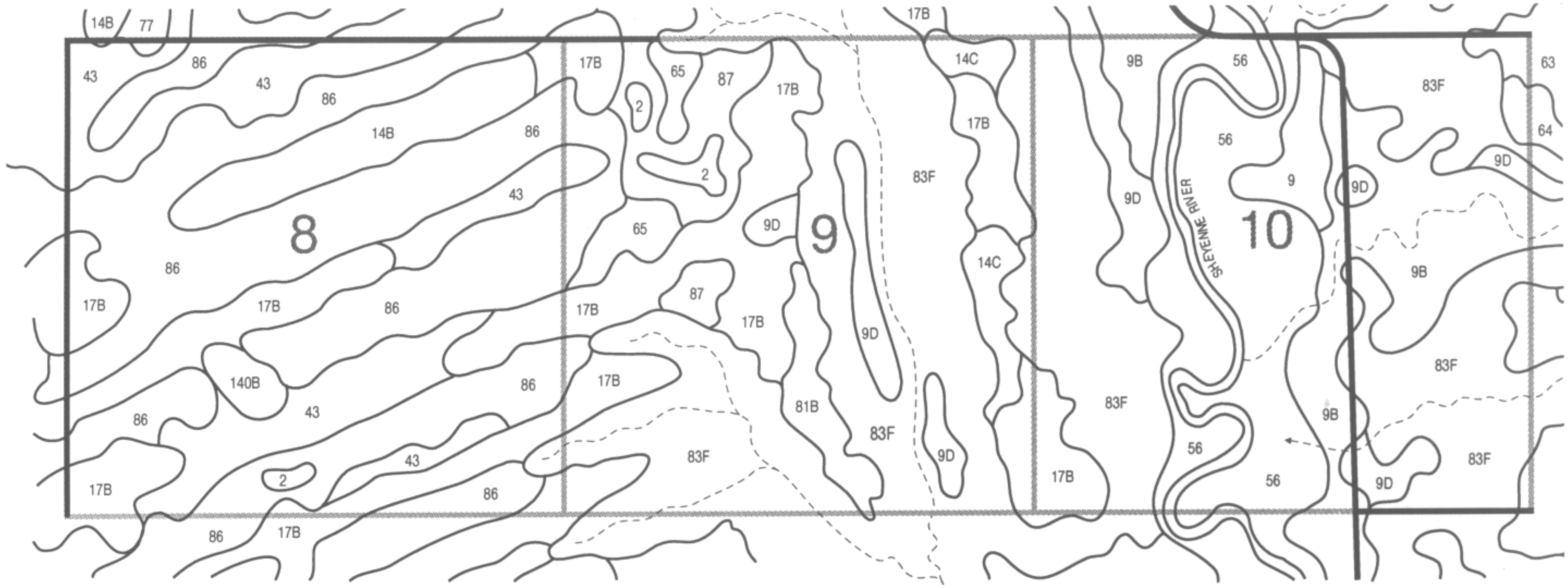


Figure II1. Soil map of Section 8, 9, 10, T. 138N., R.58W. Barnes County.

Legend

— road

- - - - - intermittent drain

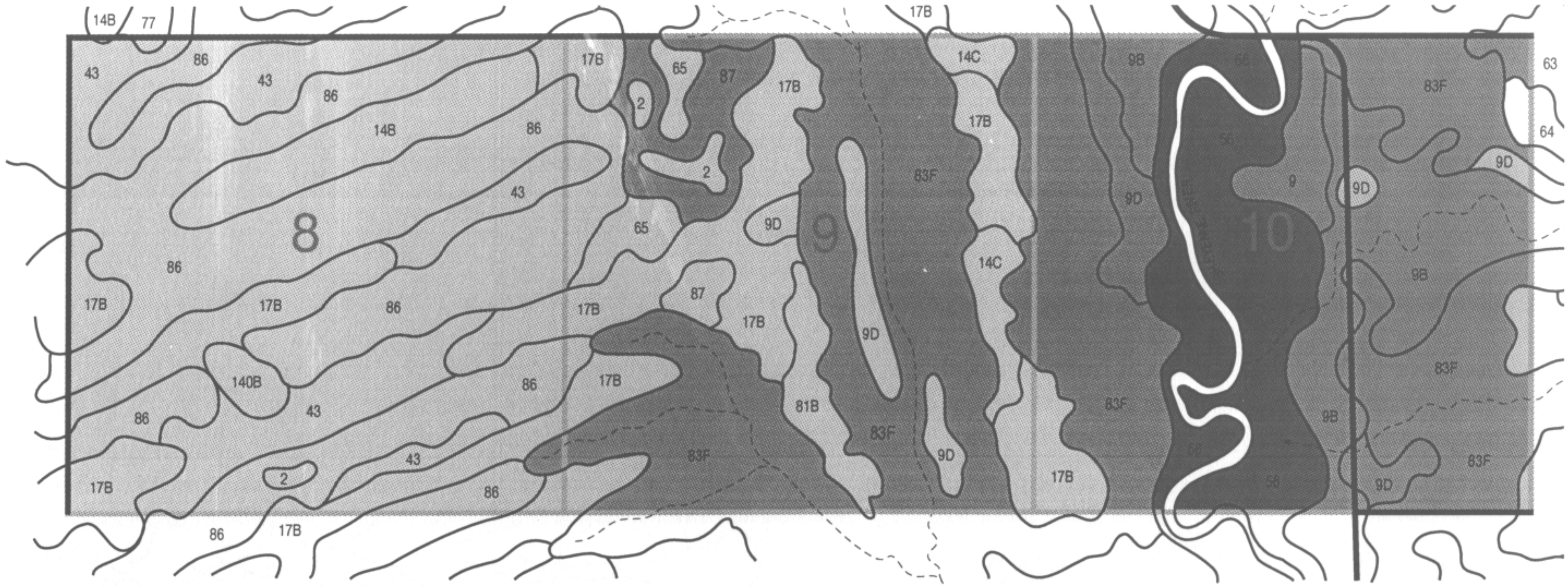


Figure II2. Proximity displacement factor; Section 8, 9, 10, T. 138N., R.58W. Barnes County.

Pesticide displacement potential

- High
- Intermediate
- Low
- No rating

Legend

- road
- intermittent drain

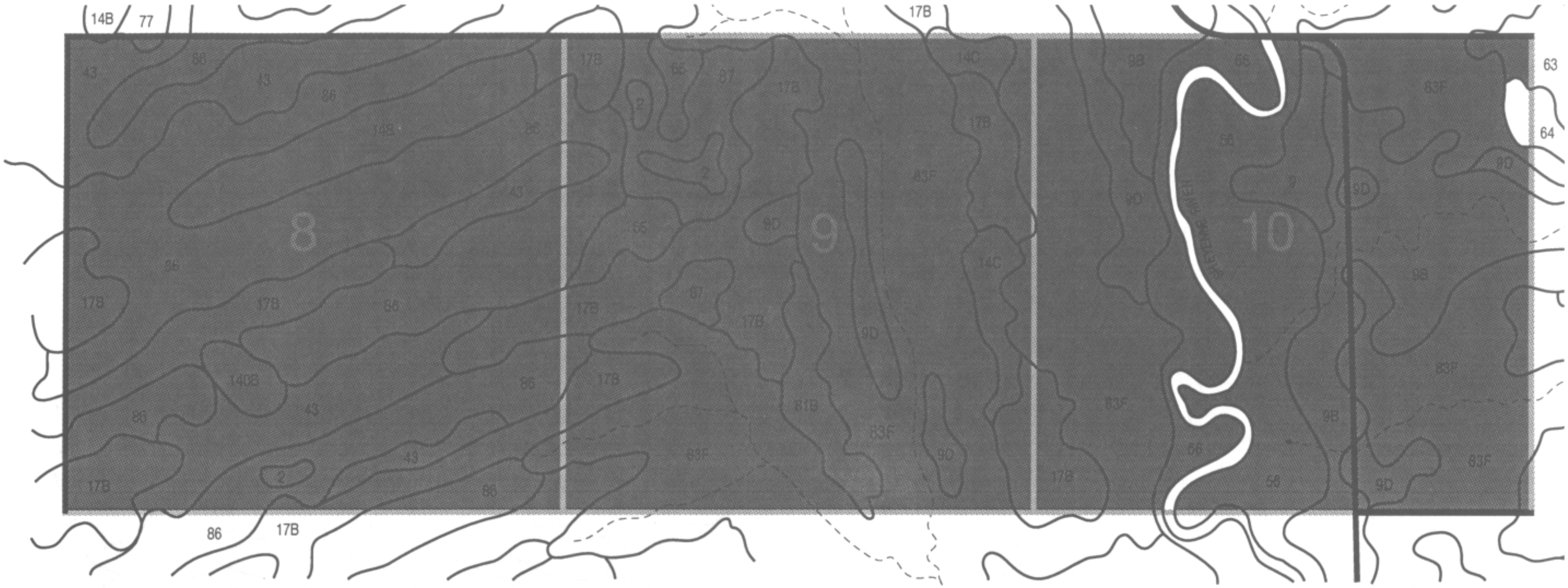


Figure II3. Pesticide/solution interaction displacement factor; Section 8, 9, 10, T. 138N., R.58W. Barnes County.

Pesticide displacement potential

■	**High**
□	**No rating**

Legend

▬ road

- - - - - - intermittent drain

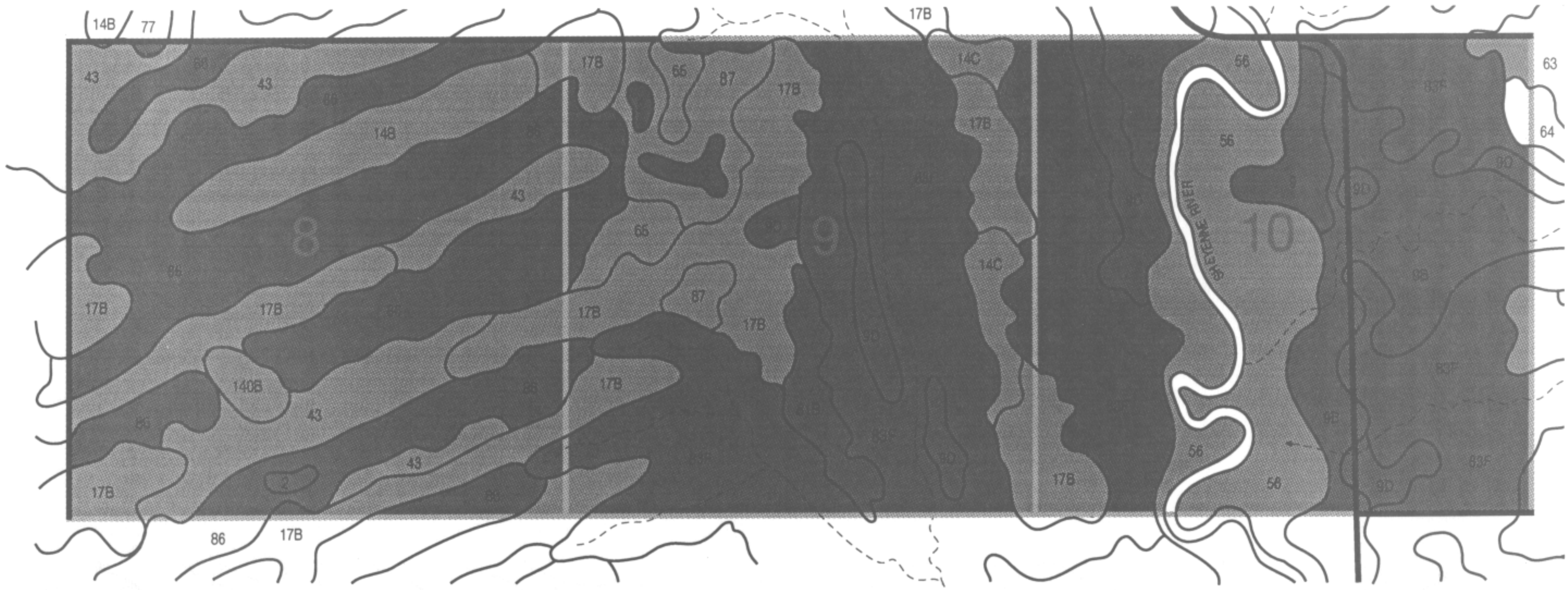


Figure II4. Pesticide/sediment interaction displacement factor; Section 8, 9, 10, T. 138N., R.58W. Barnes County.

Pesticide displacement potential

- **High**
- **Intermediate**
- **No rating**

Legend

- road
- intermittent drain

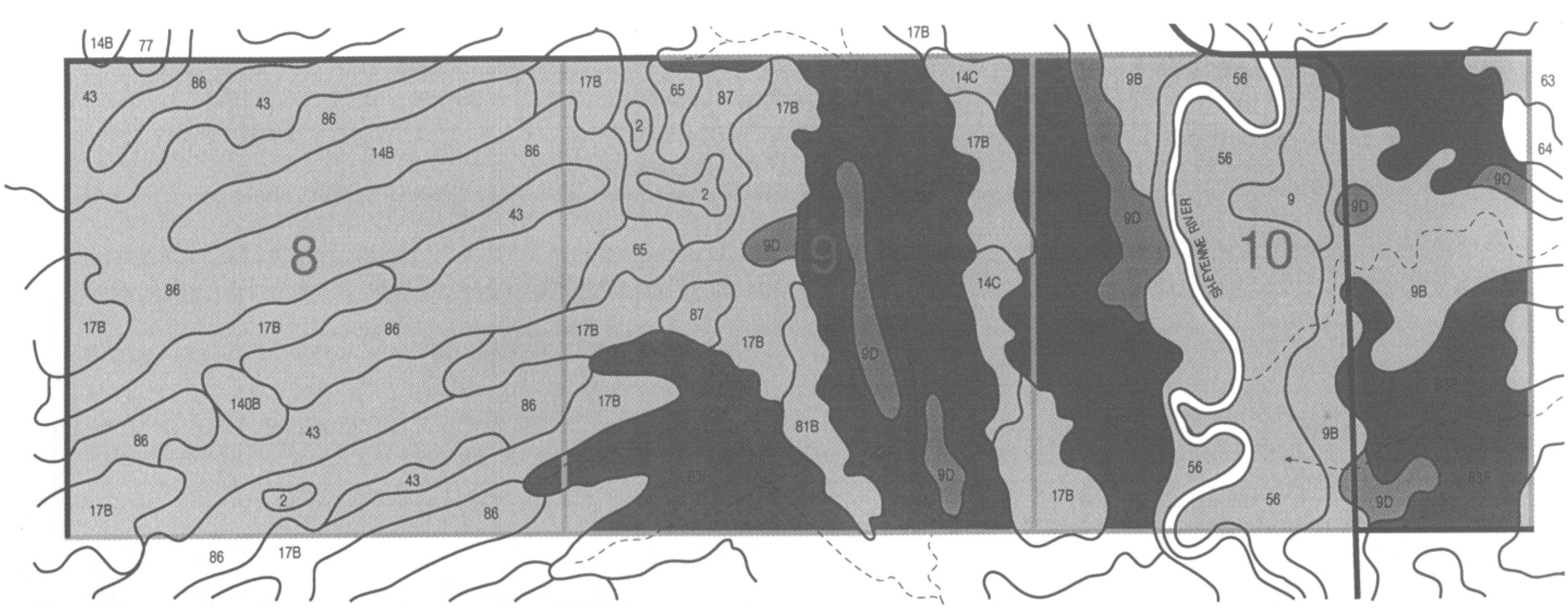


Figure II5. Slope displacement factor; Section 8, 9, 10, T. 138N., R.58W. Barnes County.

Pesticide displacement potential

- High
- Intermediate
- Low
- No rating

Legend

- road
- intermittent drain

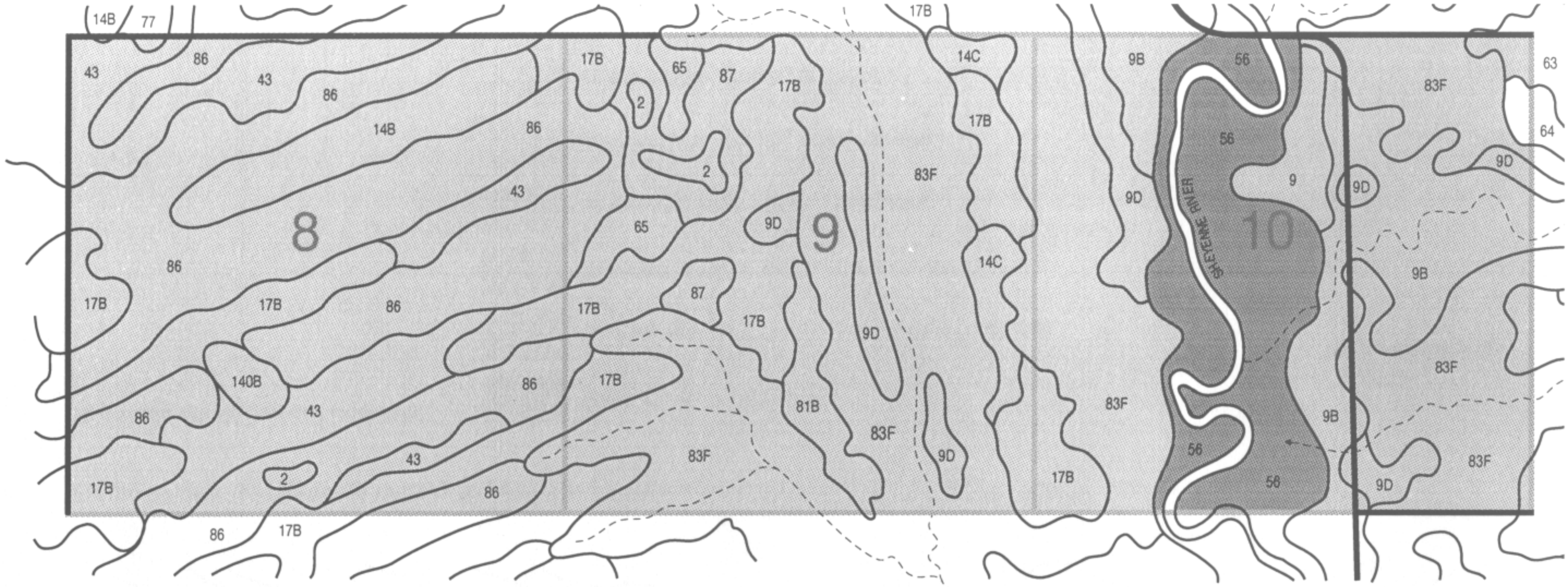


Figure II6. Flooding displacement factor; Section 8, 9, 10, T. 138N., R.58W. Barnes County.

Pesticide displacement potential

- **Intermediate**
- **Low**
- **No rating**

Legend

- road
- intermittent drain

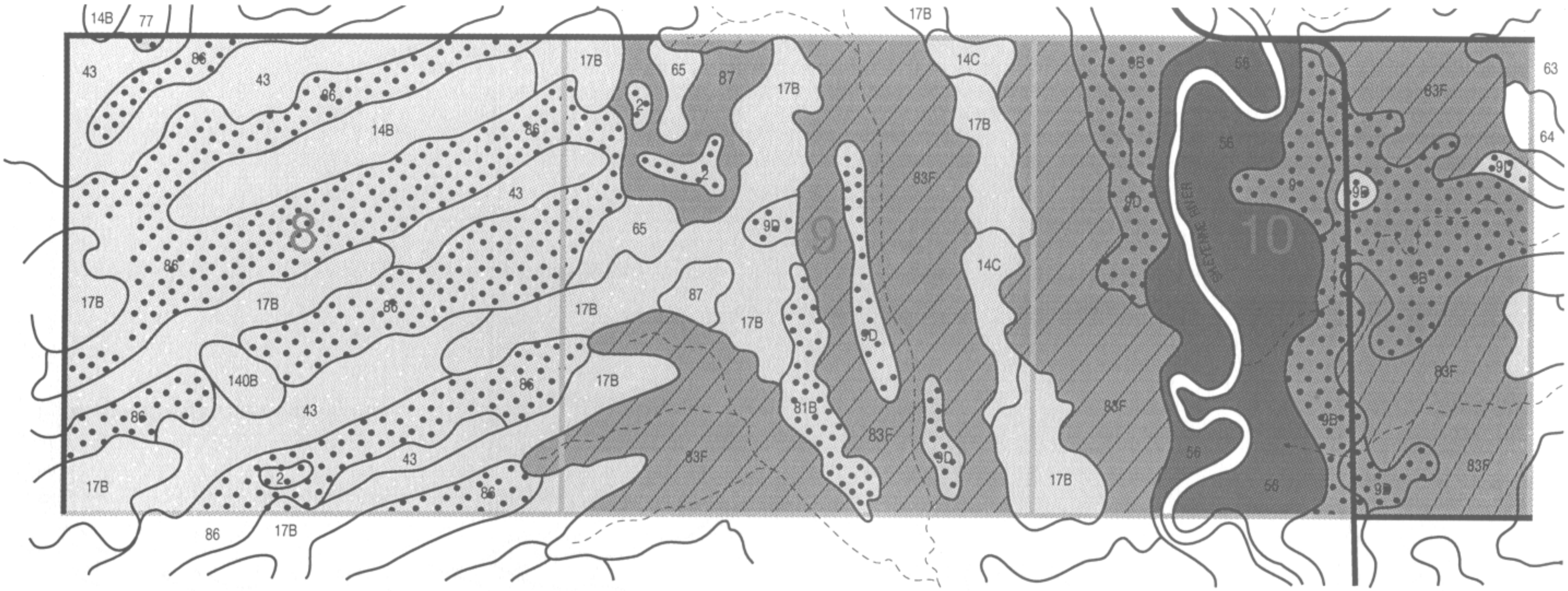


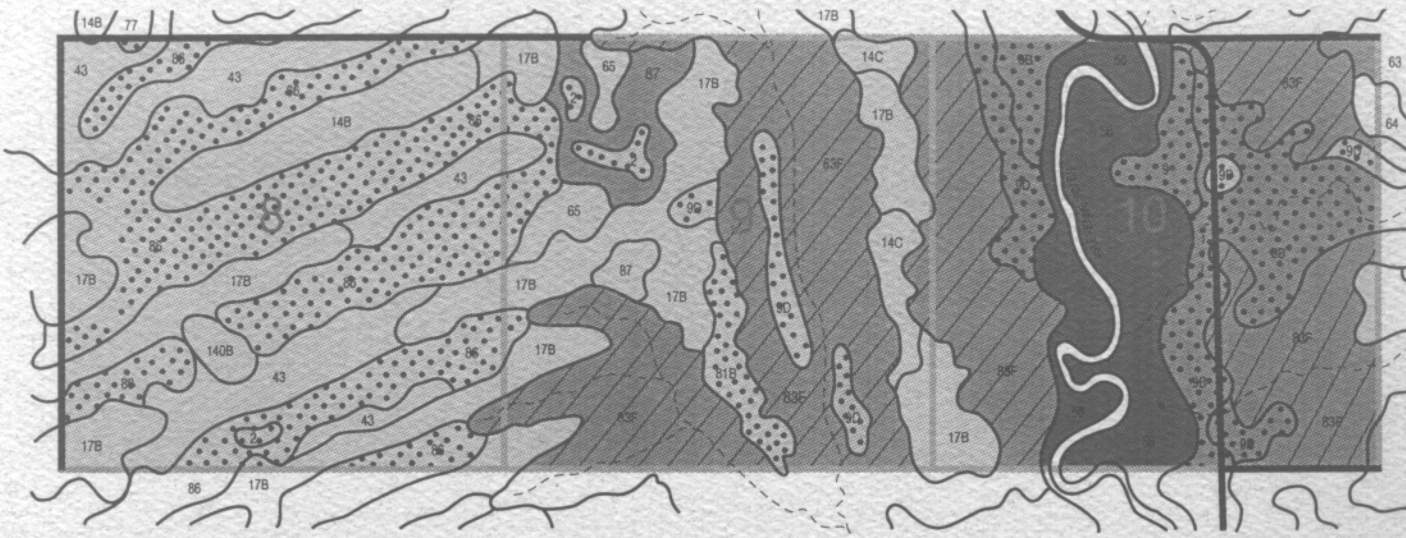
Figure II7. Surface water sensitivity to pesticide contamination; Section 8, 9, 10, T. 138N., R.58W. Barnes County.

Pesticide displacement potential

- **High** (form., solution)
- **Somewhat High** (form., solut.-sedim., slope)
- **Somewhat High** (form., solut.-sedim.)
- **Somewhat High** (form., solution)
- **Intermediate** (form., solut.-sedim.)
- **Intermediate** (form., solution)
- **No rating**

Legend

- road
- intermittent drain



Surface water sensitivity to picloram contamination; Section 8, 9, 10, T. 138N., R.58W. Barnes County

Pesticide displacement potential

- **High (form., solution)**
- **Somewhat High (form., solut.-sedim., slope)**
- **Somewhat High (form., solut.-sedim.)**
- **Somewhat High (form., solution)**
- **Intermediate (form., solut.-sedim.)**
- **Intermediate (form., solution)**
- **No rating**

Legend

- road
- intermittent drain

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