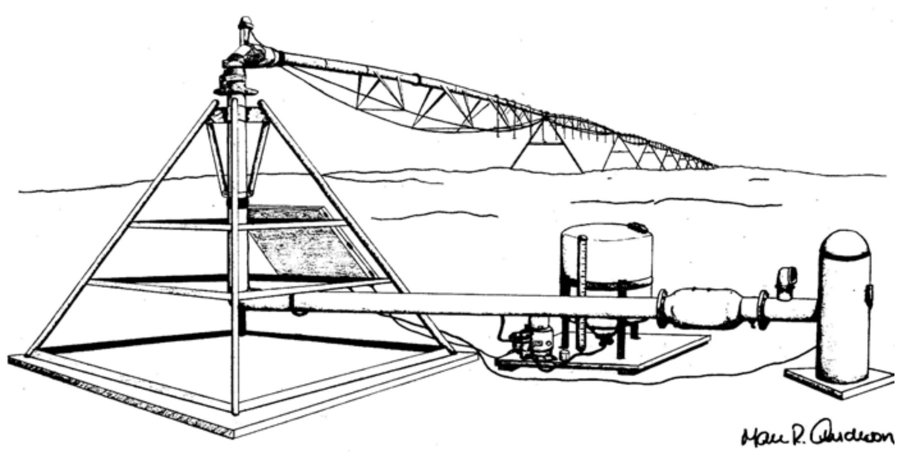
CSL-31A (09-07)

CHEMIGATION IN KANSAS

CERTIFIED CHEMIGATION EQUIPMENT OPERATOR EXAMINATION MANUAL



KANSAS DEPARTMENT OF AGRICULTURE
Pesticide and Fertilizer Program
Records Center, Chemigation Section
109 SW 9th Street
Topeka, Kansas 66612-1281

Acknowledgment

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I. INTRODUCTION

Many agricultural producers are using irrigation systems to apply both water and agricultural chemicals. This practice, commonly called chemigation, is defined by Kansas law as any process whereby pesticides, fertilizers, or animal wastes or other chemicals are added to irrigation water applied to land or crops, or both, through an irrigation distribution system.

Just as there are benefits and risks associated with applying agricultural chemicals using conventional ground or aerial methods, there are benefits and risks associated with chemigation. The most significant risk is potential contamination of the irrigation water supply. To minimize risks associated with chemigation, an irrigation system must be properly equipped, calibrated and operated. Anti-pollution equipment must be added to the system, and properly maintained. Procedures should be followed to ensure operator and environmental safety as well as efficacy of the chemical application.

The purpose of this manual is to provide guidelines for safe and effective chemigation. It is intended only to supplement operator's manuals for irrigation and chemical injection systems.

II. LAWS AND REGULATIONS

Both federal and state laws and regulations affect the practice of chemigation. Laws, regulations, court decisions and administrative rulings pertaining to the use of agricultural chemicals and chemigation are subject to change. To be certain that you are in full compliance, check periodically with the Kansas Department of Agriculture which regulates the practice of chemigation in Kansas.

A. Federal Laws and Regulations

1. Federal Insecticide, Fungicide and Rodenticide Act

All pesticide applications, including those made through an irrigation system, are subject to the provisions of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) as amended. FIFRA provisions that will affect an applicator include the requirements to: (1) use pesticides only as directed by the label; and (2) be a certified pesticide applicator or be supervised by a certified applicator if you plan to purchase or use any pesticide classified "For Restricted Use Only."

To become certified, a pesticide applicator must demonstrate his/her competence. For example, a private applicator (e.g., a farmer) is required to score 75 percent or better on an open book examination. Commercial (for-hire) applicators must score 75 percent or better on a closed book examination over the category(ies) in which they do business. The pesticide applicator training and certification program and chemigation certification are totally separate requirements. Being a certified pesticide applicator does not exempt a producer who plans to chemigate from the obligation to be certified as a Chemigation Equipment Operator. Similarly, the certification as a Chemigation Equipment Operator does not exempt a producer who plans to use "Restricted" pesticides from the need to complete a pesticide applicator training program.

2. Pesticide Labels

The label of a pesticide (i.e., the document affixed to the pesticide container along with any supplemental labeling that may be provided) constitutes a legal document. It has the same force as federal law. Using any pesticide in a manner inconsistent with its labeling is a violation of FIFRA and can result in legal actions being taken against you. Therefore, before buying or using any pesticide it is important that you first read completely and fully understand the product label.

In its efforts to ensure environmental safety, the U.S. Environmental Protection Agency (EPA) has adopted a policy of restricting the methods by which some pesticides can be applied. Pesticide products which can not legally be applied through the irrigation system will bear the statement "Do not apply this product through any type of irrigation system." Presently, pesticide products which can legally be applied through an irrigation system will have specific instructions pertaining to anti-pollution equipment, calibration, supervision and application rates. Look carefully for one of these statements before purchasing any pesticide for chemigation.

If a pesticide product may be applied by any type of chemigation system, several generic statements will appear on the product label pertaining to the type of irrigation system, the efficacy of the pesticide application, calibration of the injection system, public water supply safety and supervision.

In addition to the generic label statements, the labels of Toxicity Category I products (those with the signal word DANGER) which allow chemigation will include requirements for posting of areas to be chemigated. Posting of chemigated areas must conform to specific requirements addressed by the label. The posting required for chemigation does not replace other posting and re-entry interval requirements for farm worker safety.

Requirements for anti-pollution devices outlined by the label may vary depending upon the type of irrigation system or water supply, and may differ from local equipment regulations. Nonspecific label statements which may also be included may pertain to chemical agitation, chemical and water applications, and mixing.

Remember, the pesticide label is a legal document and carries with it the full force of federal law. If you have questions about a specific pesticide, contact your local Extension or regulatory personnel before applying the product through your irrigation system.

The site (crop) on which you wish to apply a pesticide must appear on the label. It is a violation of FIFRA to use a pesticide if the crop is not listed on the label. A pesticide may be applied against any pest occurring on the crop, animal or site specified on the label unless use of the pesticide is limited only to those pests specified on the labeling, or restricted by the Kansas Department of Agriculture.

Applying more pesticide than the label specifies also violates FIFRA. To be certain that you are using the proper rate, it will be necessary to calibrate your chemigation system. Procedures for doing this are described in Section VII. It is permissible, however, to apply a pesticide at a dosage, concentration or frequency less than that specified on the labeling. However, if less-than-labeled rates are used, the pesticide manufacturer is no longer liable for lack of effectiveness, environmental damage, or any other liabilities that may result when label directions are not followed.

3. Federal Water Pollution Control Act

Amendments to the Federal Water Pollution Control Act generally provide authority to the federal government only over surface waters. If surface waters (streams, rivers, lakes, etc.) are used as irrigation water sources, any pollutant discharge (e.g., pesticides or fertilizers) incident to chemigation operations may subject the violator to federal prosecution. In most states, regulation of pollutant discharges into ground water is provided through state programs approved under the Water Pollution Control Act.

4. Federal Safe Drinking Water Act

There may be cases in which an irrigation well is situated in close proximity to a municipal water well. Any back-flow of water and/or chemicals that enters an aquifer which is, or could be, used as a public drinking water source is a violation of the federal Safe Drinking Water Act. Laws in some states may prohibit chemical injections into irrigation systems if the irrigation water is drawn from a well within a given distance of a public drinking water source. If your irrigation system is connected to a public drinking water source, special equipment, such as a reduced pressure back-flow prevention valve, may be required.

5. Resource Conservation and Recovery Act (RCRA)

Disposal of pesticides or pesticide-contaminated materials, such as containers and rinsate, is subject, under some conditions, to the requirements of the Resource Conservation and Recovery Act. Be sure to follow label directions carefully in disposing of such materials.

It is vitally important that producers become familiar with the provisions of all applicable laws and regulations and local ordinances before chemigating.

B. Kansas Laws and Regulations

1. Kansas Chemigation Safety Law

Chemigation is defined by Kansas law as being "any process whereby pesticides, fertilizers or other chemicals or animal wastes are added to irrigation water applied to land or crops, or both, through an irrigation distribution system."

An "irrigation distribution system" is defined as "any device or combination of devices having a hose, pipe or other conduit which connects directly to any source of ground or surface water, through which water or a mixture of water and chemicals is drawn and applied to land. The term does not include any hand-held hose sprayer or other similar device that is constructed so that an interruption in water flow automatically prevents back-flow to the water source. For practical purposes, the law excludes greenhouse irrigation and residential yards.

The primary objective of the Kansas Chemigation Safety Law is to protect the environment, and more specifically, to protect our water resources, especially groundwater. The point at which water is withdrawn from a water source is termed a "point of diversion" and is defined as (1) The point where the longitudinal axis of the dam crosses the centerline of the stream in the case of a reservoir; or (2) the location of the headgate or intake in the case of a direct diversion from a river, stream or other watercourse; or (3) the location of a well in the case of a groundwater diversion. Animal waste lagoons are not considered to be water sources.

Any person who wishes to chemigate must fulfill several legal requirements. Persons who wish to chemigate must first install all of the required antipollution devices and injection equipment, pass a Chemigation Equipment Operator examination, pay the required fees, and obtain a Chemigation User's Permit from the Kansas Department of Agriculture.

Chemigation User's Permit. Applications of pesticides, fertilizers or other chemicals or animal waste through an irrigation system is regulated under the Kansas Chemigation Safety Law. Persons who wish to chemigate must first obtain a Chemigation User's Permit from the Kansas Department of Agriculture. The permit must be renewed each year, and expires on December 31 of the calendar year during which the permit was issued. In order to obtain a permit, applicants must:

1) Be 18 years of age or older by January 1 of the year of permit issue;
2) Submit a completed application for a Chemigation User's Permit and pay the prescribed fees;
3) Submit a plan for using required anti-pollution devices;
4) Submit a plan for handling tailwater or accumulations of water; and
5) Pass a Chemigation Equipment Operator Certification examination provided by the Secretary of Agriculture, or have one or more employees who are Certified Chemigation Equipment Operators.

Permits are only issued to persons who own or operate the land on which chemigation is to be used. A permit may be issued to a corporation or partnership provided that the application is accompanied by a list of the names and addresses of the officers or partners.

Anyone using the chemigation process must first install anti-pollution devices on the irrigation equipment being used. Anti-pollution devices are mechanical equipment used to reduce hazard to the environment in cases of malfunction of the equipment during chemigation. These devices are required by law and are designed to protect the water source, injection site, and operator from potential chemical contamination. These anti-pollution devices must be functional, and installed and used according to criteria described in Section VI.

Each person using the chemigation process must keep records regarding each application of any chemical other than water. The records must contain the following information:

1) the type of chemical used;
2) the amount of active ingredient used
3) the date of use;
4) the legal description of the water supply location or the point of water diversion;
5) the type of crop to which the chemical was applied;

AND, in the case of pesticides:

6) the EPA registration number of each pesticide applied;
7) the name of the target pest(s) identified by its common name (e.g., Southwestern corn borer, grassy weeds, etc.)

Persons who apply only animal wastes must keep records regarding each application through the irrigation system. The records must contain:

1) the date of use; and
2) the legal description of the water supply location or the point of water diversion;

These records must be retained by the holder of the Chemigation User's Permit for a period of not less than two years from the date of application. Each application for renewal of a Chemigation User's Permit must be accompanied by a copies of the chemical application records for the previous year.

Chemigation Equipment Operator Certification. A Chemigation User's Permit may not be issued to any person unless that person is a Certified Chemigation Equipment Operator or has in his or her employ at least one Certified Chemigation Equipment Operator. A Certified Chemigation Equipment Operator is an individual who has successfully completed an examination provided by the Kansas Department of Agriculture and has paid the prescribed fee. A Chemigation Equipment Operator Certificate is valid for four years after the year it is issued and may be renewed by passing an examination and paying a fee.

If the Chemigation User's Permit is issued to an individual, that individual must successfully complete the Chemigation Equipment Operator Certification examination.

The Chemigation Equipment Operator Certificate expires on December 31 of the fourth calendar year after the year of issue. Certification may then be renewed for a succeeding five year period by payment of the certification fee and by passing an examination.

The certification examination can be obtained from the Kansas Department of Agriculture. An applicant for Chemigation Equipment Operator Certification is required to correctly answer at least 75 percent of the questions to pass the examination.

A certificate and pocket card will be issued to each certified person upon his or her satisfactory completion of the requirements for certification. The Certified Chemigation Equipment Operator must supply this certificate or pocket card when requested to do so by any law enforcement official, the Secretary of Agriculture or any authorized representative of the Secretary of Agriculture.

Certified Chemigation Equipment Operators are responsible for the supervision of the chemigation equipment to ensure safe and accurate operation. "Supervision" is defined by Kansas law as : "the attention given to the chemigation system during its operation when chemicals are being applied." "Direct Supervision" is furthermore defined as "supervision with the ability to change procedures."

No Certified Chemigation Equipment Operator may supervise more than ten simultaneously operating chemigation units. If more than ten operating chemigation units are to be operated at the same time, additional Certified Chemigation Equipment Operators must be employed.

Violations of the Chemigation Safety Law are punishable by criminal fines of up to $5,000 per violation. In addition to any criminal penalties, violators may also be subject to civil penalties of up to $5,000 per violation or $5,000 per day for continuing violations.

2. Kansas Pesticide Law

All applications of pesticides (herbicides, insecticides, etc.) including those using the chemigation process, are subject to the requirements of the Kansas Pesticide Law. Like the Federal Insecticide, Fungicide and Rodenticide Act, our state law generally requires that pesticides be applied in accordance with their labeling and requires that persons who apply restricted use pesticides be certified or under the direct supervision of a certified applicator. To become certified, a private applicator (e.g., farmer) must pass an open-book examination provided by the Kansas Department of Agriculture and pay the prescribed fee. The examination is given at County Extension offices. Certification is good for four years after the year it is issued and may be renewed by passing an examination and paying a fee. This examination is separate and independent of the examination for Chemigation Equipment Operator Certification.

Violations of the Kansas Pesticide Law are Class A misdemeanors subject to criminal penalties of up to one year in jail and/or a $2,500 fine for each offense. In addition to any criminal penalties, violators may also be subject to civil penalties of up to $5,000 per offense.

Questions about the Kansas Chemigation Safety Law or the Kansas Pesticide Law should be directed to:

Kansas Department of Agriculture
Records Center, Chemigation Section
109 SW 9th St. Topeka, Kansas 66612-1281
Telephone: (785) 296-3786 FAX: (785) 296-0673

III. SAFETY

During any chemical application, monitor the irrigation system and chemical injection equipment at regular intervals to be certain that both are operating properly. To facilitate proper monitoring, the main control panel, water pump, chemical supply tank, chemical injection pump and the area around them must be kept free of chemical contamination. Plugging the sprinkler outlets in the immediate area of this equipment will significantly reduce the possibility of inadvertent exposure to chemical contamination.

Pesticides. Because of their toxicity, many agricultural chemicals, especially pesticides, are potentially dangerous to people. Pesticide product labels have "signal" words that clearly indicate the degree of toxicity - and the associated degree of risk to the user. Pesticides labeled CAUTION are slightly toxic; an ounce to more than a pint, if taken orally, would kill the average human adult. Those labeled WARNING are moderately toxic; a teaspoonful to a tablespoonful would be fatal to the average adult. Pesticides labeled DANGER include the skull and crossbones symbol and are highly toxic; a teaspoonful or less would be fatal.

A. Exposure Routes

There are three ways that chemicals can enter the human body:

(1) through the mouth (oral)
(2) by absorption through the skin (dermal)
(3) by breathing into the lungs (inhalation)

Along with the signal words, pesticide product labels also include "route of entry" statements and statements of specific actions a user should take to avoid exposure.

Route of entry statements also indicate the outcome from product exposure. For example, a pesticide label might read "Poisonous if swallowed, inhaled, or absorbed through the skin. Rapidly absorbed through the skin and eyes." This tells the user that this pesticide is a potential hazard through all three routes of entry, and that skin and eye contact are particularly hazardous.

The specific action statements normally follow the route of entry statements and indicate what must be done to prevent accidental poisonings. In the example of the pesticide mentioned above, the statement might read, "Do not get in eyes, on skin, or on clothing. Do not breathe spray mist or fumes."

B. Protective Clothing and Equipment

Regardless of their relative toxicity, all pesticides should be used carefully. Before handling, mixing, loading, or applying any pesticide, read label directions thoroughly. If the label calls for the use of protective clothing or equipment or both, comply fully with those directions.

The type of protective clothing and equipment needed depends on both the toxicity of the pesticide and the type of formulation. Some labels state that specific items of clothing, equipment and footwear must be used. In such instances, the applicator (Certified Chemigation Equipment Operator) is legally responsible for using the listed safety apparel. Others carry no statement at all. In general, the more toxic the pesticide, the greater the need to use protective clothing and/or equipment.

When a pesticide label does not give specific instructions regarding proper protective clothing, wear at least a long-sleeved shirt and long-legged trousers, or coveralls that fully cover your arms and legs. Disposable coveralls are available that provide adequate protection.

Shoes and socks also should be worn. Avoid sandals, thongs, and cloth or canvas shoes. Rubber boots are highly recommended and should be worn while working with highly toxic pesticides (signal word DANGER), when there will be prolonged exposure to pesticide spray, or when there is significant contaminated water or mud that might be absorbed by leather shoes or boots. Leather shoes or boots can not be effectively decontaminated, and once contaminated should be discarded.

When mixing and loading concentrates, especially those that are highly toxic, the appropriate safety equipment specified on the label should be used.

Protection for your head is also advisable, and in some cases specifically required. In general, a wide brimmed, easily cleaned hat that will keep pesticides away from the neck, eyes, mouth and face is adequate. Avoid hats with cloth or leather sweat bands as these will absorb pesticides. Labels that specify the use of headgear are usually found on highly toxic liquid concentrates and may require you to wear a waterproof hood or plastic hard hat with a plastic sweatband.

Pesticides can cause eye damage and may be readily absorbed through the eyes. Precautionary statements on liquid pesticide labels that have the signal words WARNING and DANGER generally specify the use of goggles or a face shield.

Gloves are also needed for handling pesticides. Unlined, liquid-proof neoprene or rubber gloves with tops that extend well up on the forearm are best. Avoid lined gloves because the linings can absorb the chemicals and are hard to clean. In most cases, wear gloves under shirt sleeves and pant legs outside of boot tops to prevent pesticide from leaking into the glove or boot.

C. Cleaning Protective Equipment

Protective equipment should be cleaned daily after use. Follow cleaning procedures specified on pesticide label.

To clean protective equipment (e.g., respirators, face shields, gloves, waterproof coats, pants, etc.) use warm soapy water. Do not use solvents such as alcohol, gasoline or diesel fuel.

Protective equipment should be stored in a clean, dry area away from the pesticide storage area. Protective equipment can become contaminated from fumes and/or dust if kept in the pesticide storage area while not in use.

D. Laundering Pesticide Contaminated Clothing

When laundering pesticide-contaminated clothing, the following procedures should be followed:

* Read the pesticide label for information.
* Disposable pesticide clothing provides extra protection.
* Use soil/water repellent finish for work clothing.
* Pre-rinse clothing by:
  - presoaking in a suitable container;
  - agitating in an automatic washing machine;
  - spraying/hosing the garment(s) outdoors.
* Always pretreat.
* Washing machine setting: Hot water temperature (140oF/60oC), full water level, normal (12 minutes) wash cycle.
* Rewash the contaminated clothing two or three times, if necessary.
* Use more liquid detergent than recommended by the product label.
* Wash a few contaminated garments at a time, using lots of water.
* Wash separately from family laundry.
* Discard (using directions for disposal on the pesticide container) clothing if thoroughly saturated or contaminated with highly toxic pesticides.
* Launder clothing daily when applying pesticides daily.
* Rinse machine thoroughly after laundering contaminated clothing.
* Be aware of when pesticides are being used so that clothing can be appropriately laundered.

For additional details concerning laundering pesticide-contaminated clothing, contact your County Extension agent.

E. Re-Entering Treated Areas

In general, fields that have been chemigated with pesticide should not be reentered until foliage has dried. A specific waiting period may be specified on the container label of some products.

In such cases, chemigators have a legal obligation to prevent unauthorized entry into treated areas. To discourage unauthorized entry, chemigators may be required to post treated fields. The EPA has revised pesticide label requirements to include more restrictive provisions for posting chemigated fields treated with Toxicity Category I products. Before chemigating, therefore, carefully read the product label and comply with all posting requirements. If fields must be re-entered before the end of the label-specified waiting period, use the protective equipment specified by the pesticide label.

F. Container Disposal

Refer to the label for specific instructions for the disposal of pesticide containers. In the absence of specific disposal instructions, the use of "triple-rinse" procedures will generally be adequate. Triple rinsing refers to a container which has been flushed three times, each time using a volume of diluent at least equal to 10 percent of the container's capacity. The rinsate should be used as a diluent for the same pesticide or injected directly into the irrigation system as rinsate.

Operate the irrigation system for at least 10 minutes to allow complete flushing of the rinsate from the system.

Triple rinsed containers and empty paper bags should be kept in an enclosed, locked and posted facility until sent to an approved landfill or offered for recycling. Non-returnable triple-rinsed containers should be crushed or punctured. Disposal should be done in a timely manner to avoid unnecessary and unsightly build-up.

G. Accidental Back-Siphoning and Spills

Recommendations for Notification and Corrective Actions for Groundwater Contamination due to Back-Siphoning.

1. Notification

The Chemigation User’s Permit holder must report immediately to the Secretary of Health and Environment and to the Secretary of Agriculture, all spills, accidents, system malfunctions, or other situations involving actual or potential contamination of either ground or surface water.

Who to Notify

(1) Notify the Secretary of Health and Environment.

Notification should first be made to the Secretary of Health and Environment at the following telephone number:

<u>Pesticides and Fertilizers</u>

KDHE 24-Hour Spill Line 785-296-1679

You may also call field personnel as they would probably be assigned to investigate spills, back-siphons, or other occurrences. A listing of field personnel, their addresses and phone numbers, and a map showing their respective regions is included on page 15.

(2) Notify the Secretary of Agriculture.

Notification must then be made to the Secretary of Agriculture at the following telephone number:

KS Dept. of Agriculture Spill Line (785) 296-3786 Mon-Fri 8A-5P

- Sat – Sun and after 5, leave a message, including your name and contact telephone number.
- Or call immediately at the beginning of the next weekday.

KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT
Division of Environment/Bureau of Remediation - DISTRICT STAFF
(As of October 2004; subject to change)

1 SOUTHWEST DISTRICT OFFICE –
302 W. McArtor Rd., Dodge City 67801 (620) 225-0596
Guernsey, Al Administrator FAX (620) 225-3731
Doubek, Doug Env. Geol.

2 SOUTH CENTRAL DISTRICT OFFICE –
130 S. Market, 6th Floor, Wichita 67202-3802 (316) 337-6020
Jones, Michael Administrator FAX (316) 337-6023
Parker, Kyle Env. Geol.
Husain, Meer Env. Geol.
Marcotte, Stanley Env. Scientist.

3 SOUTHEAST DISTRICT OFFICE –
1500 W. 7th, Chanute 66720 (620) 431-2390
Stutt, David Administrator FAX (620) 431-1211
Thornton, William Env. Geol.

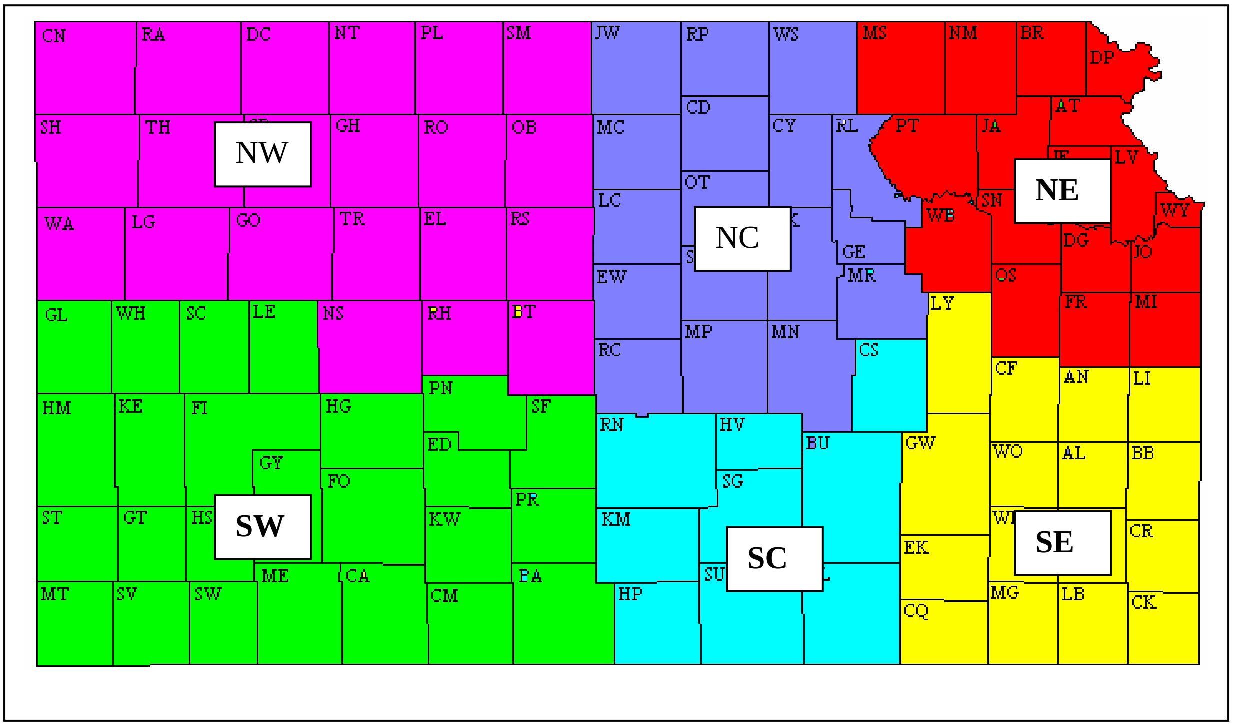
4 NORTHEAST DISTRICT OFFICE –
800 W. 24th St., Lawrence 66046 (785) 842-4600
Coleman, Julie Administrator FAX (785) 842-3537
Kellerman, Daniel Env. Geol.
Roth, Meredith Env. Tech.
Wells, Dan Env. Geol.

5 NORTH CENTRAL DISTRICT OFFICE -
2501 Market Place, Suite D&E, Salina 67401 (785) 827-9639
Brunetti, Rick Administrator FAX (785)827-1544
Lang, Scott Env. Geol.
DeBauche, Howard Env. Geol.

6 NORTHWEST DISTRICT OFFICE –

2301 East 13th, Hays 67601 (785) 625-5663

Brooks, Ken	Administrator	FAX (785) 625-4005
Heimann, Bill	Env. Geol.	
Shippy, Darell	Env. Tech.	



Information to Report

The following information needs to be included in the reports made to both the Secretary of Health and Environment and the Secretary of Agriculture:

1) The location where the incident occurred.
2) The identity of the chemical or product lost or spilled.
3) The approximated quantity of the material involved.
4) The date when the event occurred.
5) The distance from any known domestic drinking water wells or public water supplies, and locations of these water sources.

Penalties for Failing to Report

Failure to notify the proper authorities in a timely fashion could result in the assessment of civil penalties of up to $5,000 per day.

2. Corrective Actions

BACK-SIPHONING. If back-siphoning into a well has occurred or is suspected, continue to pump water from the well at the normal rate of operation continuously until the proper authorities have been notified, or as otherwise instructed by Department of Health and Environment and/or Kansas Department of Agriculture personnel. Well water samples should be collected and analyzed as directed by official state personnel.

MINOR SPILLS. Generally speaking, a minor spill is one involving one quart or approximately two pounds or less of pesticide concentrate. However, common sense must be used in determining how much action you as an individual take regarding chemical spills; special consideration should be made of the toxicity of the spilled chemical.

If a MINOR chemical spill has occurred, keep people away from the spilled chemical. Rope off the area and flag it to warn people. Do not leave unless someone is there to confine the spill and warn of the danger. If the chemical was spilled on anyone, wash it off immediately with large quantities of water (or as otherwise directed by the product's label).

Confine the spill. If it starts to spread, dike it with sand or soil. Use absorbent material such as soil, sawdust, or an absorbent clay to soak up the spill. Shovel all contaminated material into a leak-proof container for disposal and dispose of it as you would a pesticide waste following all local, state or national pesticide disposal guidelines. Or, apply the spill material for its pesticidal benefit (through land-spreading or other acceptable method) without violating any of the pesticide product label or labeling. Do not hose down the area, because this spreads the chemical. Always work carefully and do not hurry.

Do not let anyone except properly trained persons enter the area until the spill is completely cleaned up.

Avoid letting chemical flow away from the spill site into any surface water source. If the chemical spill has occurred in the immediate vicinity of the well, the contaminated soil should be removed immediately to avoid possible contamination of the gravel pack and well. Do not attempt to flush chemical contaminants into the well so that they may be pumped out later. This will only contribute to the spread of contamination. Care should be taken to not disturb the gravel pack. Soil that cannot be removed should be allowed to recover naturally.

MAJOR SPILLS. The cleanup of a major spill may be too difficult for you to handle, or you may not be sure of what to do. In either case, keep people away, give first aid if needed, and confine the spill. Then call one or all of the following: Chemtrec, The National Spill Response Center, your local fire department, and/or other state pesticide authorities for help.

The National Spill Response Center (NRC) offices are in Washington, D.C. Release to the environment of a reportable quantity of a hazardous substance and any that threatens a waterway, a phone call to the National Spill Response Center 1-800-424-8802 must be made within 24 hours of the spill.

Chemtrec stands for the Chemical Transportation Emergency Center, a public service of the Chemicals Manufacturing Association. Its offices are located in Washington, D.C. Chemtrec provides immediate advice for those at the scene of emergencies. Chemtrec operates 24 hours a day, seven days a week, to receive calls for emergency assistance. For help in chemical emergencies involving spills, leaks, fires, or explosions, call toll-free 1-800-424-9300, day or night. This number is for emergencies only.

The following are additional telephone numbers that may be needed in the event of accidents involving chemigation (as of October 2006; subject to change):

(1) Kansas Division of Emergency Management (Adjutant General) Hazardous Materials, should be notified any time there is a spill of materials that may result in water or soil contamination. They will notify the Kansas Department of Agriculture Pesticide Spill Response Team. The Pesticide Spill Response Team is not a first responder, but will provide technical information and resources in the case of significant spills.

24-Hour Spill Number **(785)296-8013**
or 1-800-275-0297

24-Hour Natural Disaster **(785) 269-3176**
or 1-800-905-7521

For Non-Emergencies Only:
Jennifer Clark, Technical Hazards (785) 274-1394

For Non-Emergencies Only:
Emergency Communications Center (785) 274-1422

For Non-Emergencies Only:
Bill Chornyak, Administrator (785)274-1401

Or contact your local county environmental planning group (LEPC) coordinator or local emergency management coordinator in your county.

(2) U.S. Environmental Protection Agency (EPA) Kansas City Office:

24-Hour Spill Number (913) 281-0991

SUMMARY. As with any method of application (e.g., ground or aerial), chemigation introduces pesticides and/or fertilizers into the environment. To minimize risks to the environment and applicator:

* Read and comply with the product label.
* Monitor the injection system.
* Plug the first few interior nozzles on center pivots to keep the pivot point dry.
* If an accidental spill occurs, avoid personal contamination and minimize potential spill damage.
* Notify the proper authorities.
* Avoid non-target application.
* Avoid application to surface water.
* Avoid deep percolation.
* Flush irrigation and injection systems adequately.
* The label is the law; read it every time the product is used.

IV. IRRIGATION SYSTEMS

The three basic types of irrigation systems are: (1) sprinkler; (2) surface; and (3) drip or trickle. Differences in these systems have important consequences for chemigation.

A. Sprinkler Systems

In Kansas, chemigation is most common with center pivot sprinkler systems, for which they are well suited. Other sprinkler systems include:

* Self-propelled linear or lateral move.
* Solid set.
* Hand move lateral.
* Side roll lateral.
* Tow-line lateral.
* Traveling big gun.

This manual will focus primarily on procedures for center pivot sprinkler systems.

Center pivot and self-propelled linear systems are the most popular for chemigation. Properly designed, calibrated and operated, they provide a high degree of uniformity in water and chemical application. Water-powered center pivot systems that discharge water directly into the wheel track are not recommended for chemigation with pesticides, but may be used in applying fertilizers. However, some water-powered systems have emitters that uniformly distribute water, and may be acceptable for chemigation.

Center pivots frequently have a high instantaneous rate of water application near the outer portions of the circle. End guns and low pressure spray nozzles, particularly those on drop tubes, have the highest application rates and have the greatest runoff problems. The center pivot sprinkler package should be selected to minimize runoff potential. The irrigation system dealer, Soil Conservation Service, and Cooperative Extension Service personnel can all help to select a sprinkler package that matches field conditions. In many situations, the quantity of irrigation water applied can be controlled to prevent runoff. The amount of water applied by a center pivot during an irrigation cycle is determined by the pumping rate and the time of rotation. The minimum amount will be applied when the system is operated at maximum speed. A practical minimum application rate for a typical center pivot system is about 0.1 inch, which is approximately 2700 gallons per acre.

Traveling gun systems may be acceptable for chemigating in low wind conditions. Characteristically, large guns have poor application uniformity and are susceptible to wind drift of major proportions.

Solid set, hand move, and side roll lines are examples of stationary systems. These systems differ from self-propelled types in that they are stationary and do not move during irrigation. The greatest limitation with stationary systems is distortion of the sprinkler pattern by wind.

B. Surface Systems

Surface or gravity flow (furrow and flood) irrigation systems have limited potential for chemigation. They cannot be used for foliar applications and frequently provide poor distribution uniformity. The tops of ridges or beds are poorly wetted, which may be important for soil-applied chemicals. If a surface system is used for chemigation, attention to detail can be very important. The forming of the furrow or bed is important because it influences the rate of flow, the amount of water applied, and uniformity. Furrow slicking or packing devices and bed forming machines produce a smooth, firm, clod-free surface that aids water application during the first irrigation.

Surge valves or surge irrigation are also a help in obtaining improved uniformity and reducing deep seepage and runoff. Chemigation probably should not be considered until the second or third irrigation of the season. The first few irrigations have the poorest uniformity and the greatest deep-seepage losses. Water application of 2 to 2.5 inches is a practical minimum for most furrow or flood systems, and a reuse pit to collect tailwater is required. Tailwater must be collected and reapplied on the same field or other crops for which the chemical is appropriate.

C. Drip or Trickle Systems

Drip or trickle irrigation is the slow application of water to soils through emitters, orifices or micro-sprinklers located at selected points along the crop row or under the plant canopy. The water may be applied to the surface or within the root zone. Only a portion of the soil is wetted, which reduces surface evaporation and encourages root growth in a limited area. Point source emitters usually deliver 1 to 2 gallons per hour at each point. Line emitters, which are perforated tubes, deliver 0.15 to 2 gallons per hour per foot of length. The micro-sprays or sprinklers have higher discharge rates but spread the water over a much larger area to reduce the application per square foot of soil surface.

Fertilizers and herbicides that need to be applied to the soil surface or incorporated into the soil are commonly applied through drip irrigation systems, but relatively little data has been compiled on the effectiveness of applying other pesticides in this manner.

V. CHEMIGATION MANAGEMENT

Most chemical accidents result from careless practices or lack of knowledge about safe handling of chemicals. Time spent taking precautionary safety measures is an investment in protecting the health and safety of people and the environment while helping to achieve the desired results. Selecting a pesticide with a label that allows application through an irrigation system is the first and most critical consideration in making a decision to chemigate. All irrigation and injection equipment must be kept in good working order. Be sure to consider all factors: What materials do you wish to apply? Does the label allow use through an irrigation system of the type you intend to use? What will it cost to provide all of the necessary equipment? How frequently will you chemigate? In addition, instructions on chemical labels must be followed precisely. Additional factors also should be considered to evaluate equipment, management, or safety requirements.

A. Irrigation System Location

The degree of isolation of the irrigation system that will be used for chemigation is important. Complete control of any chemical application cannot be guaranteed, so the farther the system is from sites of potential harm, the less trouble that may occur. Wells used for chemigation should not be in close proximity to municipal water supply wells. Chemigation to sites located immediately adjacent to residential areas should be avoided. Any water supply should not be jeopardized by chemigation activities. Nearby water supply wells, if properly constructed, are probably at the least risk. Open water in drainage channels, rivers, streams, ponds or lakes are the most susceptible.

Chemigation on fields with permanent or semi-permanent surface water areas is not recommended. Such application may adversely affect wildlife, non-target plants and animals, or groundwater quality.

B. Soil Type

Soils can differ considerably over relatively short distances. It is not uncommon to find different types of soils within a single field. The rate at which water and/or agricultural chemicals enter the soil (infiltration rate) differs by soil type. It follows that variations in soil type will influence irrigation system management and chemigation operations.

Coarse-textured sandy soils have high infiltration rates. Assuming that other factors are equal (e.g., slope, compaction), there is less potential for runoff on coarse-textured soils than on fine-textured soils. On the other hand, chemigating with excessive amounts of irrigation water could result in leaching of chemical(s) below the crop-root zone. Where fine-textured soils (those with high clay content) are to be chemigated, the situation is reversed: the potential for deep percolation of water and/or chemical(s) is decreased, but the potential for runoff is increased.

Consult soil survey maps published by the Soil Conservation Service for specific soil characteristics. Soil Conservation Service and Cooperative Extension Service personnel can provide assistance with irrigation management. Evaluation of potential non-point pollution of ground and surface water should be completed prior to making the decision to chemigate.

C. Irrigation System Characteristics

Physical characteristics of an irrigation system can affect the capacity for applying agricultural chemicals. Many irrigation systems can be used to apply fertilizers or pesticides that must be incorporated into soil. However, only a sprinkler system can be used for foliar application. System characteristics have a direct effect on the overall efficiency of the chemical application. Any system used to chemigate must have the appropriate injection equipment and anti-pollution safety devices installed, and the entire system must be in good working order. Applied agrichemicals should vary no more than 5 percent in deposit uniformity along the application system.

D. Irrigation System Uniformity

Any irrigation system has chemigation potential. However, many types of irrigation systems have inherent limitations that prevent them from being efficient chemigation systems. Center pivot systems are one type of irrigation system that can be used efficiently and effectively for chemigation, provided they are properly designed, properly maintained, and are at locations where environmental and human exposure risks are acceptable.

Uniformity of irrigation water application is an important criteria for deciding whether an irrigation system has chemigation potential. The uniformity of any chemigation procedure is limited by the uniformity of the irrigation system. The condition of the center pivot also effects uniformity.

Application uniformity is generally a strong point of center pivot irrigation systems, but is not guaranteed. Numerous design, installation and maintenance factors have a significant effect on uniformity. Perfect uniformity means each point along the distribution lateral receives an identical amount of water. Poor uniformity results in large deviations from the desired average application with some areas receiving excess water while other areas receive too little. If water distribution is poor, chemicals carried in the water will be poorly distributed as well.

When selecting sprinkler packages for a new system or when refitting an old system, operators have a wide variety of sprinkler types and configurations from which to select. In addition, pressure and discharge rate are important considerations. The irrigator should select a sprinkler package that can adequately meet his/her irrigation management requirements while achieving high uniformity and minimal runoff. Factors such as soil texture, infiltration rate, water application rate, field elevation change, irrigation system size, water supply and tillage practices play important roles. If chemigation is planned, these needs should be considered as well.

High pressure systems generally have good application uniformity because of the large overlapping of the individual sprinkler patterns. Low pressure systems have closer spacing due to reduced radius of throw of the individual sprinklers, resulting in less overlap of the wetting pattern of the individual heads. This can result in lower uniformity.

Another consideration is the driving mechanism. Electrically driven machines move in a series of stops and starts. The amount of water and chemical applied increases during a stop. This may be important in systems with very low pressure sprinklers or with spray nozzles with small wetted radii. Uniformity favors the shortest stop periods, which normally occur at the fastest speed.

E. Topography

The topography of a field can affect the application uniformity of an irrigation system. Variations in slope or elevation may seriously affect how evenly the irrigation water and chemicals are distributed, especially for low pressure systems. In general, the flow from an individual sprinkler head should not vary by more than 10 percent. Pressure regulators or higher operating pressure may be required if field elevation changes exceed specific guidelines (See Table 1).

Table 1. Operating pressures and corresponding elevation differences which will cause a 10 percent variation in sprinkler flow rate.

Operating Pressure (PSI)	15	25	35	45	55	65	75	85
Elevation Difference (Feet)	7	11	15	20	24	29	33	37

Surface irrigation systems on irregular topography may not be suitable for chemigation.

F. Non-Point Pollution Potential

Drift, runoff and deep percolation are the leading causes of inadvertent losses from chemigation applications. Environmental conditions during application, type of sprinklers, type and formulation of chemical being applied and climatic conditions during and after irrigation affect the magnitude of chemical losses.

1. Drift

When water emerges as spray from a sprinkler nozzle, part of it may evaporate, part may be intercepted by vegetation or soil, and part may be carried by wind outside the treated area where it may be deposited on a variety of non-target sites (vegetation, soil, water, structures, etc.). Wind can quickly create a potentially hazardous drift problem. A producer is responsible for monitoring the weather when chemigating. If the wind is strong enough to cause any off-target movement, the system should be shut down.

The potential for drift will also be greatly affected by the volatility of the chemical that is being applied. Chemicals with high volatilities have significantly greater potentials for drift than less volatile materials.

Sprinkler-package selection for center pivots plays a key role in controlling drift as well. Water droplet size is an important consideration. Spray nozzles generally have smaller droplet sizes than impact sprinklers, making them more susceptible to wind. This susceptibility is often partially offset by lower placement, which reduces the exposure to wind.

To minimize problems associated with wind drift, these steps can be taken:
* Avoid use when winds are great enough to cause significant drift.
* Space the sprinklers and lines more closely together.
* Operate at night when winds are relatively calm.

2. End Guns and Corner Systems

End guns and corner systems are popular options for many center pivot systems. In general, however, these options are not recommended for chemigation because of uncertain conditions of uniformity created by their use. End guns have high drift potential and notoriously poor distribution patterns. End guns that operate at all times cause the least problem. However, most end guns operate on only part of the circle, which may create uniformity problems. Overall system uniformity will be best when the irrigation system is operated with the end gun either on or off during the entire application. Booster pumps and automatic speed controls which slow the center pivot while the end gun is in operation are a definite help, but should be checked by the operator to determine how well they work to produce a uniform application. Corner or swing systems do essentially the same thing as an end gun when used intermittently, but on a larger scale. Intermittent use also disturbs the pressure pattern in the remainder of the system, which may reduce uniformity and necessitate recalibration when these systems are functioning.

End gun shutoffs that fail to function and unfavorable weather conditions are among the common sources of nontarget or off-target applications using an end gun. In situations where end gun or corner swing systems are required to secure much of the normal irrigation, a careful evaluation of operating parameters should be made prior to deciding to chemigate.

3. Runoff

Runoff can potentially occur whenever the irrigation system is applying water at a rate greater than the soil infiltration rate. The occurrence of runoff depends on the application rate, soil intake rate, field slope, soil surface roughness, crop canopy, and the amount of residue. Chemigation runoff water that leaves the field is a potential hazard and must be prevented.

The irrigation system should be managed to prevent runoff of the water/chemical mixture. If runoff does occur within the field, precautions to prevent runoff water from leaving the field when the chemical is being applied are essential. The initial design of the center pivot greatly affects runoff potential.

Tillage practices greatly affect surface storage and runoff potential. Center pivots with high runoff potential may be suitable for chemigation if proper residue management or surface treatments (such as furrow damming or pitting in crop rows) are used. Runoff potential is also reduced by using a faster speed of revolution. The peak application rate is not changed by increasing the speed, but the total volume of water applied per acre is reduced and so is runoff potential. Making chemigation a separate event, independent of normal irrigation, can greatly reduce runoff by applying less water during the treatment. Even pesticides that require soil incorporation frequently benefit from a reduced application. The amount of water required to incorporate a pesticide into 2.5 inches of soil is only about 0.5 inches for sandy soils and 0.75 inches for a fine-textured soil. Applying more water may actually reduce the effectiveness of the application.

Field borders can be planted to vegetated cover to act as a buffer strip. Buffer strips slow runoff and allow potential contaminates more time to be degraded by bacteria and sunlight. Buffers also trap sediments that may be pesticide carriers. Impoundment structures can also be used to capture any runoff, further aiding the breakdown of chemicals.

Relatively high application rates are characteristic of the outer portions of center pivot systems, particularly those operating at low pressures. In general, sprinkler systems that do not cause runoff during normal operation will be satisfactory, but the amount of water being applied may have to be adjusted to meet pesticide (or other chemical) label requirements.

4. Deep Percolation

The irrigation system should be managed so that deep percolation of the water/chemical mixture does not occur. Reducing the application size by making a faster revolution will reduce the potential for runoff and deep percolation. Good irrigation management practices must be used throughout the season to limit movement of water below the crop root zone and to reduce the potential for chemical leaching.

Proper irrigation scheduling procedures will help keep well water levels within optimum ranges. However, it is recommended that only an amount necessary to uniformly distribute the chemical should be applied. Do not plan to irrigate and chemigate at the same time. Take care not to apply a heavy irrigation treatment immediately following a chemigation treatment, particularly if the upper portion of the soil profile is very wet. This may cause either runoff or deep percolation of the chemical below the target zone.

G. Calibration

Calibration of the chemigation system is critical. Without an accurate calibration, there is no way to determine whether the amount of chemical applied is correct. Over-application may cause more harm than good and the chemigator is liable for any resultant damage. Under-application is frequently ineffective and over-application may be needlessly expensive. See Section VII on Calibration Procedures for additional information.

H. Equipment Maintenance and Inspection

Proper equipment maintenance is necessary to ensure safe distribution of chemicals. All hoses, clamps, fittings, etc., must be in good repair. Inspect them before each chemigation operation. All components that are in contact with chemicals, from the supply tank to the point of injection on the irrigation pipeline, should be constructed of chemically resistant materials.

Periodically monitor the irrigation system and chemical injection equipment to ensure proper operation. Before chemigating, inspect your equipment to be certain that the following items are functioning properly:

* the irrigation system main pipeline check valve, vacuum relief and low pressure drain;
* the chemical injection line check valve;

* the irrigation system and pumping plant main control panel and the chemical injection pump safety interlock;
* the injection system including the in-line strainer, manual valve and chemical storage tank;
* the irrigation pump, injection pump, and power source.

These and other anti-pollution devices are discussed in Section VI.

I. Flushing Chemigation and Irrigation Systems

After an injection is completed, operate the irrigation system for at least 10 minutes to flush any remaining chemicals from the irrigation system. Some systems, especially drip systems, may take longer than 10 minutes to completely flush. If the irrigation system was shut down automatically, flush the system as soon as possible after the shutdown is discovered, and extend the flushing period to a minimum of 30 minutes.

To prevent accumulation of precipitates in the injection equipment, flush the injection system with clean water after each use. It is best to flush the injection system while the irrigation system is operating so that the water used for cleaning can be applied to the field where the chemigation application was made.

A fresh water faucet is not required but convenient. Install the faucet between the check valve and the irrigation pump for freshwater purposes. Use this valve only as a source of water for clean up. Do not use this valve as a water supply for diluting the chemical in the supply tank, or rinsing chemical containers as a back-siphon could develop in the event of equipment failure or shutdown and a valve located at this location would effectively by-pass back-flow prevention. A water faucet located downstream from the irrigation line check valve would be more appropriate for mixing chemicals in the field. This faucet should not be used for drinking water purposes.

J. Plug First Nozzles on Center Pivots

To facilitate monitoring of the chemigation operation, the main control panel, water pump, chemical supply tank, chemical injection pump and the area around them must be kept free of chemical contamination. Plugging the nozzle outlets in the immediate area of this equipment will significantly reduce the possibility of inadvertent exposure to chemical contamination.

VI. EQUIPMENT

Anyone using the chemigation process must first install anti-pollution devices on the irrigation equipment being used. "Anti-pollution devices" are mechanical equipment used to reduce hazard to the environment in cases of malfunction of the equipment during chemigation.

Without proper safety and anti-pollution devices installed, there is the potential for groundwater and surface water contamination. Anti-pollution and safety devices installed on the irrigation and injection system are designed to prevent the following:

1) The possibility of a back-siphon of concentrated chemical or chemically treated water into the water source;
2) The potential for chemical to be siphoned from the supply tank into the irrigation system during times of system malfunction or shutdown;

3) The potential for water to flow back through the chemical injection system into the chemical supply tank, which could cause the supply tank to overflow, creating a spill.

Equipment required for all chemigation systems includes: (1) an interlock system; (2) a main water-line check valve; (3) a chemical injection line check valve; (4) a vacuum relief device; and (5) an automatic low pressure drain.

Additional equipment required for chemigation systems injecting chemicals other than animal wastes include: (6) manually operated valve on the chemical supply tank; (7) a strainer located on the suction side of the chemical injection pump; and (8) a calibration device of sufficient volume to accurately calibrate the injection pump.

Additional injection equipment required for the injection of PESTICIDES (insecticides, herbicides, fungicides, etc.) or other chemicals includes: (9) an air bleeder valve for the injection pump and high pressure injection line; (10) a positive displacement injection pump (such as a diaphragm pump); and (11) any other equipment required by the pesticide's label or labeling.

All of the above-listed anti-pollution devices are discussed in more detail.

A. All Chemigation Systems

1. One-Way Interlock

A one-way interlock must be installed between the irrigation pump and chemical injection pump to ensure that if the irrigation pump stops, the chemical injection pump will also stop. This prevents the injection of chemical into the irrigation pipeline when there is no flow to distribute the chemical.

On engine-driven irrigation pumps, where the injection pump is driven directly off the engine, the drive shaft, or auxiliary equipment driven by the engine, nothing needs to be done. When the engine stops, the injection pump also stops.

On electric motor-driven irrigation pumps, a separate small electric motor is usually used to drive the injection pump. The electrical controls for the two electric motors must be interlocked so that both motors will stop when the electric motor on the irrigation pump stops.

Injection pumps that are driven directly by the drive shaft on the irrigation engine will meet the minimum requirement for a one-way interlock. When the irrigation engine stops, the injection pump will also stop.

An additional interlock is recommended to shut off the irrigation system and pumping plant if the injection unit stops or malfunctions. This allows the operator to know where chemicals were applied when the chemical injection stopped. The interlock can be done electrically or with the use of a flow sensor on the discharge side of the chemical injection device. When there is no flow in the injection line, the irrigation system or pumping unit would be shut down.

2. Irrigation Water-Line Check Valve

An automatic, quick-closing check valve must be installed in the irrigation water line between the point of introduction of chemicals and the water supply. The valve must be capable of preventing back-flow of the water/chemical mixture into the water source in case of equipment or power failure. This valve must have positive closing action and should provide for a watertight seal. Ease of inspection, maintenance, and repair should be considered when selecting a check valve for chemigation. An easily-accessible inspection port must be located between the pump discharge and the check valve, and situated so the automatic low pressure drain can be observed through the port and the flapper can be physically manipulated. The check valve and associated devices should be inspected prior to every chemical injection. The check valve must meet specifications (K.A.R. 5-3-5c) adopted by the Kansas Department of Agriculture, Division of Water Resources, and must be maintained in proper operating condition. The Division of Water Resources maintains a list of approved check valves. The chemigation permit holder is responsible for maintaining the functional effectiveness of the equipment.

3. Chemical Injection Line Check Valve

A spring-loaded check valve in the chemical injection line is required. The only exception to this requirement is where only animal waste is injected. This valve should prevent the flow of water from the irrigation system into the chemical supply tank. If this check valve were omitted and the injection pump stopped, irrigation water could flow back through the chemical line into the chemical supply tank, overflowing the tank and causing a spill around the irrigation well. This check valve should have a minimum opening (cracking) pressure of 10 psi and should be constructed of chemically resistant materials.

With a minimum 10 psi opening pressure, the valve should also prevent gravity flow from the chemical supply tank into the irrigation pipeline after an unexpected shutdown. This valve should be inspected annually and overhauled or replaced to ensure safety.

4. Vacuum Relief Device

A vacuum relief device must be installed between the water-line check valve and the water supply to allow air into the water line, preventing a vacuum that could lead to siphoning. This valve, when installed and maintained properly, prevents pressure within the pipeline from falling below atmospheric pressure. The valve must be installed in such a position and in such a manner that insects, animals, floodwater or other pollutants cannot enter the well through the vacuum relief device. The vacuum relief valve may be mounted on the inspection port as long as it does not interfere with the inspection of other anti-pollution devices.

Allowing air into the line also reduces the differential pressure on the water-line check valve and reduces the potential for check valve leakage.

Inspection ports must be at least 4 inches in diameter. When possible, inspection ports should be installed immediately above the automatic low pressure drain to allow for easy inspection and maintenance. By removing the vacuum relief, the low pressure drain may be seen directly below and a hand may be inserted into the opening to inspect whether the closure on the water-line check valve is operating properly.

5. Automatic Low Pressure Drain

An automatic low pressure drain valve must be installed on the bottom of the horizontal pipeline between the water-line check valve and the water source. In the event that the water-line check valve leaks, the automatic low pressure drain allows the water/chemical mixture to be drained away from the water source rather than into it.

The drain must be installed in such a way that any fluid that may seep toward the well around the check valve will automatically drain out of the pipe. The drain must be at least 3/4 inches in diameter and must be located on the bottom of the horizontal pipe, between the pump discharge and the check valve. It must be level and must not extend beyond the inside surface of the bottom of the pipe. If the low pressure drain is not flush with the irrigation pipe, a "dam" is required upstream of the drain to prevent flow past the drain. The outside opening of the drain must be at least two inches above the grade.

Check valves manufactured specifically for chemigation will generally meet these requirements. The water-line check valve, vacuum relief valve, and low pressure drain are usually assembled into a single unit and sold as a package.

All check valves must be installed in accordance with the manufacturer's specifications and maintained in working condition whenever fertilizer, pesticide, animal waste or other chemical or foreign substance is injected into the irrigation system. The check valve construction should allow easy access for inspection and maintenance of all devices in the check valve assembly.

B. Chemigation Systems Used to Inject Fertilizers

The five anti-pollution devices listed above are required for all chemigation systems (with the single exception that the chemical injection line check valve is not required if only animal waste is applied). The following three additional devices are also required on all chemigation systems used to inject fertilizers:

1. Chemical Supply Tank With Manually-Operated Valve

A manually operated valve must be installed on the chemical supply tank to close the chemical supply line during times of emergency or equipment failure or shut down. This valve must provide for a positive shutoff of chemical flow to the injection pump.

The tank should be constructed of noncorrosive materials, such as stainless steel, fiberglass, or polyethylene. Iron, steel, copper, aluminum and brass should be avoided. Agitation in the chemical tank must be provided as required by the product label. Hydraulic agitation may be sufficient for some chemicals, but mechanical agitation is required for others. Refer to product labels for specific instructions.

Some flammable chemicals require explosion-proof electric motors and wiring, a separation distance maintained, or chemical dilution. Wiring must conform with the National Electrical Code for hazardous area applications. Check chemical labels for specific requirements.

More than one type of tank may be necessary. For example, a large-capacity tank may be required for fertilizers and a smaller tank(s) for pesticides.

2. Chemical Suction Line Strainer

A strainer on the inlet end of the chemical injection line is required to prevent clogging of the injection pump, check valve, or other equipment. The mesh size of this strainer will depend on the type of chemical being injected. For most chemicals, a 50-mesh screen will be appropriate.

3. Calibration Device

A calibration device or procedure is required on most systems. A calibration tube in the suction line of the injection pump is normally provided for this purpose. The operator should be able to measure the output of the injection pump during normal operation of the system and a graduated tube can provide this capability. The tube should be clear, resistant to breakage, and graduated in units of volume (pints, ounces, milliliters, etc.). Proper calibration may require that chemical injection be monitored for at least five minutes. The calibration tubes must, therefore, be large enough to hold enough chemical to inject for this time period.

Flow meters, volume measures of the pump discharge, and weight measurements may all work, but are not normally provided. Whatever type of system or procedure that is used, it should be accurate to within one percent and should not create a potential hazard to either the operator or the environment. A calibration device does not have to be permanently attached to the injection system, but must be equipped to allow for quick and easy connection to the suction line while the pump is running so that the injection rate may be checked periodically. Calibration procedures are described in Section VII. If the irrigation system is a continuously moving system like a center pivot, some type of injector will be needed. However, a simple venturi, water-driven pump, or even a centrifugal pump with an appropriate flow control can work (Note: Only positive displacement pumps may be used for pesticide injection). The burden of proof is on the chemigator to demonstrate that the injection system is safe and maintains an acceptable degree of chemical control. A check valve on the injection line to prevent back-flow of water into the chemical storage tank and a positive closure on the supply line from the chemical supply tank, if any, are required. Chemigation through a solid set sprinkler system may require even less equipment. A given amount of chemical per set may be introduced into a tank and fed into the irrigation stream by a variety of methods. In some cases, a pressure tank is used and the solution is forced into the system by excess air or water pressure. In other cases it may be drawn into the irrigation supply by differential pressure in the supply pipe. A restriction or pipe elbow can be used to create the necessary differential. Finally, with a surface system, the chemical may be fed directly into the water. Dry powders or liquids could be gravity fed and gases controlled with a flow regulator. As stated previously, the chemigator will be required to demonstrate the safety and degree of control if these other methods are used.

C. Chemigation Systems Injecting Pesticides or Other Chemicals

The eight anti-pollution devices described above (A-B) are required for all chemigation systems used for the injection of animal waste and fertilizers. These eight devices are also required for chemigation systems used to inject pesticides or other chemicals. Additional equipment is also required for chemigation systems used to inject pesticides or other chemicals. This equipment is described below. These additional antipollution devices are required when either restricted-use

(RUP) or general-use pesticides are injected.

1. Air Bleeder Valve

For pesticide injection, an air bleeder valve must be installed on the output side of the injection pump on the high pressure injection line. This valve helps to remove air trapped on the intake side or within the injection pump which could otherwise affect the rate of chemical injection.

2. Positive Displacement Injection Pump

A positive displacement injection pump is required for the chemigation of pesticides. A positive displacement pump is sometimes defined as a pump whose output cannot be throttled or whose volumetric displacement correlates with RPM or speed and not with output pressure. A delivery accuracy of plus or minus one percent is desirable, and adjusting the rate should be easy to do. The pump should be mechanically sound with noncorrosive internal and external components. A variety of injection pumps is available. The main types, based on operating principle, are diaphragm and piston pumps.

The injection pump capacity should be consistent with the rates of application needed for the chemicals that are to be used. The rates can vary dramatically and no single pump is best for all rates. As a consequence, potential rates should be determined prior to selection of an injection pump. Diaphragm pumps are normally the easiest to adjust, but have more restricted capacities than piston pumps. In some cases, two or more pumps, or a combination diaphragm-piston pump, may be needed to cover the range in rates desired.

Injection pumps do best in the mid-range of capacity. Operating near the lowest flow possible (lowest 10 percent of range) or near the maximum capacity is not recommended. It is better to have two pumps with overlapping capacity ranges than to operate one pump at either end of its range.

Most injection pumps have graduations on an adjustment device to regulate the rate. The values may be in units of volume, a percentage of full capacity, or merely index marks for reference. No matter what the units are, they should not be trusted until verified by calibration procedures for the particular materials being applied.

Diaphragm Pumps. Diaphragm pumps have been used in the chemical industry for many years, but have only been actively marketed for chemigation since the mid 1980's. Although most diaphragm pumps are more expensive than piston pumps, they have several distinct advantages.

* A very limited area is exposed to chemicals, which greatly reduces the potential for corrosion, wear, leakage, maintenance costs and risks caused by leaks.
* Diaphragm pumps are easy to adjust. Most diaphragm pumps can be adjusted while running by simply turning a knob. In general, diaphragm pumps are the most convenient pumps to use for pesticide applications.

Piston Pumps. Piston Pumps were the first pumps available for injecting agricultural chemicals. Both single and dual piston units are available in a wide range of capacities. The major advantage is relatively large capacities. However, piston pumps have two major weaknesses: (1) seals tend to wear rapidly, allowing leakage around the pistons; and (2) rate adjustments tend to be difficult to use.

Some newer piston pumps can be adjusted while operating. Piston pumps are most commonly used to apply fertilizers where relatively high injection rates are needed.

3. Equipment Required by Pesticide Label

Chemigation systems used to inject pesticides or other chemicals must also be equipped with any other equipment required by the pesticide's label or labeling. On June 5, 1980, the Environmental Protection Agency announced the establishment of a Label Improvement Program under which the labels of pesticide products were to be upgraded, improved or revised to meet current labeling standards. A PR Notice 87-1 issued March 11, 1987, required that all labeling of agricultural pesticides intended for application through irrigation systems must include the use of certain types of safety devices to protect groundwater from pesticide contamination. As a result of comments and new information received subsequent to issuance, a list of alternative devices to those included in PR Notice 87-1 has been considered and approved for use. In some cases these alternative devices may be less expensive, more reliable, or more available than originally required.

Persons using the chemigation process should be advised that all of the devices originally included in PR Notice 87-1 are still acceptable and that the PR Notice 87-1 is, in its entirety, still in effect. Devices required in PR Notice 87-1 which have no listed alternatives are still required components of all chemigation systems. The original devices as required in PR Notice 87-1 and their corresponding alternatives are listed below:

Original Device. Functional normally closed, solenoid-operated valve located on the intake side of the injection pump.

Alternative Device 1. Functional spring-loaded check valve with a minimum of 10 psi cracking pressure. The valve must prevent irrigation water under operating pressure from entering the pesticide injection line and must prevent leakage from the pesticide supply tank on system shutdown. This valve must be constructed of pesticidally resistant materials. (Note: This single device can substitute for both the solenoid-operated valve and the functional, automatic, quick-closing check valve in the pesticide injection line.)

Alternative Device 2. Functional normally closed hydraulically operated check valve. The control line must be connected to the main water line such that the valve opens only when the main water line is adequately pressurized. This valve must prevent leakage from the pesticide supply tank on system shutdown. The valve must be constructed of pesticidally resistant materials.

Alternative Device 3. Functional vacuum relief valve located in the pesticide injection line between the positive displacement pesticide injection pump and the check valve. This alternative is appropriate only for those chemigation systems using a positive displacement pesticide injection pump and is not for use with venturi injection systems. This valve must be elevated at least 12 inches above the highest fluid level in the pesticide supply tank and must be the highest point in the injection line. The valve must open at 6 inches water vacuum or less and must be spring loaded or otherwise constructed such that it does not leak on closing. It must prevent leakage from the pesticide supply tank on system shutdown. The valve must be constructed of pesticidally resistant materials.

Original Device. Functional main water-line check valve and main water-line low pressure drain.

Alternative Device 1. Gooseneck pipe loop located in the main water line immediately downstream of the irrigation water pump. The bottom side of the pipe at the loop apex must be at least 24 inches above the highest sprinkler or other type of water emitting device. The loop must contain either a vacuum relief or combination air and vacuum relief valve at the apex of the pipe loop. The pesticide injection port must be located downstream of the apex of the pipe loop and at least 6 inches below the bottom side of the pipe at the loop apex.

Original Device. Positive displacement pesticide injection pump.

Alternative Device 1. Venturi systems including those inserted directly into the main water line, those installed in a bypass system, and those bypass systems boosted with an auxiliary water pump. Booster or auxiliary water pumps must be connected with the system interlock such that they are automatically shut off when the main line irrigation pump stops, or in cases where there is no main line irrigation pump, when the water pressure decreases to the point where pesticide distribution is adversely affected. Venturis must be constructed of pesticidally resistant materials. The line from the pesticide supply tank to the venturi must contain a functional, automatic, quick-closing check valve to prevent the flow of liquid back toward the pesticide supply tank. This valve must be located immediately adjacent to the venturi pesticide inlet. This same supply line must also contain either a functional normally closed solenoid-operated valve connected to the system interlock or a functional normally closed hydraulically operated valve which opens only when the main water line is adequately pressurized. In bypass systems as an option to placing both valves in the line from the pesticide supply tank, the check valve may be installed in the bypass immediately upstream of the venturi water inlet and either the normally closed solenoid or hydraulically operated valve may be installed immediately downstream of the venturi water outlet.

Original Device. Vacuum relief valve.

Alternative Device 1. Combination air and vacuum relief valve.

For further information regarding pesticide label requirements for chemigation and the use of alternative devices, please contact the Kansas Department of Agriculture, Pesticide Program.

D. Other Safety/Anti-Pollution Equipment

Several other safety/anti-pollution devices are not specifically required by law, but are recommended in some instances to ensure safe operation and efficient applications.

Suction Line Solenoid Valve. A normally closed solenoid valve electrically interlocked with the engine or motor that drives the injection pump is desirable. Consult label requirements. If a normally closed solenoid valve is not mentioned, the use of such a device is optional. The manually-operated valve, however, is required on all chemical supply tanks to provide a positive shutoff of chemical flow to the injection pump. The intent of the normally closed solenoid valve is to prevent chemical flow into the irrigation system in case of injection pump failure.

Because of the relatively limited use of normally closed solenoid valves on agricultural chemical injection systems, they may not be readily available. Pesticides labeled for chemigation may require the use of a solenoid valve, but suitable alternatives may be allowed. Consult label requirements or contact Extension or Kansas Department of Agriculture personnel for up-to-date information.

Vacuum Relief Valve on Chemical Injection Line. A vacuum relief device on the high pressure chemical injection line could also be used to prevent chemical from being siphoned into the irrigation pipeline. This valve should be installed at a level which exceeds the highest point on the chemical supply tank.

E. Chemigation Systems Used to Apply Animal Waste

The distribution of manure or other waste material through an irrigation system is chemigation under the law. If the system includes a water supply from a well, stream or other freshwater source without an air gap, the same rules for anti-pollution equipment apply. Water sources must be protected from back-flow. Injection control (as described above) is generally not the problem. Rather, dilution and total application rates are the problem. Manure and other wastes are most often pumped from a holding tank or pond and the percentage of solids that may be moved is quite restricted. Water is frequently needed to dilute the material so they may be pumped. A water jet is frequently used for agitation to help mix the solids with the liquid portion. How this is done and the degree of protection provided to water sources are the most important issues.

Manure and other wastes have poorly defined characteristics compared to other chemigated materials. Application rates are not clearly defined, but over-application has been documented. A chemigator who applies manure or other waste materials is advised to consult the Midwest Plan Service Handbook - 18 "Livestock Waste Materials Handbook" available through county Cooperative Extension agents. Rates should be adjusted using soil tests on the site and analysis of the particular waste material as guidelines. In addition, soil types, crop type, site drainage and the level of soil microbiological activity can all play a part in rate recommendations.

The chemigator applying waste is advised to start with moderate rates of application. Experience will indicate whether rates can be increased or reduced. Obviously, runoff must be avoided or controlled.

F. Runoff or Tailwater Control

The equipment for runoff or tailwater control consists of a storage tank, pit or pond, pumps and the necessary piping and controls. The size of the storage is a function of the rate and amount of runoff and the rate and timing of reuse pumping. A small storage will do if reuse is nearly instantaneous and at a rate equal to runoff. Such a system normally requires automation and, in the case of chemigation, additional controls. A larger storage capacity provides for additional flexibility in the management of tailwater, but increases the risk of environmental contamination. Ideally, a pump is used in a larger storage. The normal operation would be the speedy return of runoff from the sump with an automatic control on the pump but, in case of trouble, the large storage would provide storage space for tailwater until pumping could be accommodated.

Runoff containing pesticides is critical. The severity of the problem depends on the potential harm the particular chemicals may cause. Fertilizer or animal waste runoff is less serious but still represents a potential threat to ground or surface water. Automated pumping normally requires electrical service and permanently installed pipes. If runoff water must be reintroduced into a sprinkler system, the pressure must be greater than the normal irrigation line pressure, or an arrangement must be made to create a low pressure zone to allow tailwater into the pipe. An interlock will also be required to prevent pumping tailwater into the system in case of accidental shutdown of the water supply, injection pump or irrigation system. The problems are so great that systems with known runoff problems should not be considered for chemigation with pesticides.

Help with designing a tailwater return system may be obtained from Soil Conservation Service or Cooperative Extension Service personnel. It is important to indicate to these persons what you wish to do and how you wish to manage. The system is dependent on management, and site conditions may preclude some alternatives.

G. General Comments

All anti-pollution devices must be maintained in a functional state for any irrigation system used in the chemigation process. Injection equipment must be constructed and maintained in a manner that ensures applications of pesticides within label recommendations, and application of fertilizers at planned application rates. Injection equipment must be calibrated before each chemical application.

All equipment and accessories that come into contact with the materials being applied, including hoses, seals, gaskets, pipes, valves, etc., should be resistant to such materials. The chemigator must remember that some pesticides are a mixture of various materials, emulsifiers, solvents, etc., and not all formulations of the same active ingredient act the same. Diluted solutions are normally less aggressive than more concentrated ones, but not always. Be sure to consult the label, other users, and chemical suppliers for information about potential problems.

The equipment described above will provide acceptable levels of protection against contamination of the environment when used properly. The concern primarily has been addressed to dedicated water supplies (wells). If the water source is a public water system, different anti-pollution equipment will be required. The Kansas Department of Health and Environment should be consulted before using a public water supply when chemigating.

H. Possible Protection Alternatives

Although the information presented above outlines equipment and procedures that can be used to provide protection against possible pollution, there are other procedures that could also be used. One method of preventing direct contamination of the water supply is to use a two-pump system, with an air gap between the discharge of one pump and the intake of the second pump. In this situation, one pump would discharge the water into a reservoir, and the second pump would draw from this reservoir. The chemical injection would be made after the second pump. Thus, there would be no direct connection of the chemical and the water source. Most irrigation installations would require considerable modification to use this procedure.

Another method that could be used to eliminate any direct connection between the chemical and the water source is to use a separate pipeline on a center pivot for the chemical. This would involve the addition of a second, smaller diameter pipeline and a spray nozzle system to the center pivot system. The two pipeline systems would eliminate the mixing of chemical with the water supply. However, considerable modification of the existing system would be needed.

One method of eliminating gravity flow of chemicals from the supply tank into the irrigation system and hence into the water source is to locate the injection point higher than the chemical supply tank. This will not always be possible, but should be considered where feasible.

VII. CALIBRATION PROCEDURES

Calibration of chemigation equipment is extremely important. Without accurate measurements, it is impossible to know what is being applied. Calibration is a standardization process so that deviations from a standard can be identified and proper correction factors can be determined. This requires measurements which must be carefully done in a way that produces accurate results.

Chemicals applied below recommended rates may provide unsatisfactory results, such as reduced yield and reduced profits. On the other hand, applying too much chemical may be illegal under federal and/or state laws. Too much chemical is also costly, may cause crop damage, or contaminate ground or surface waters. Your own personal safety may also be at stake.

Proper calibration takes time, particularly at first. The process should not be rushed. The dealers who sell injection equipment can help with the calibration procedure for their equipment, but it is the responsibility of chemigators to ensure that the entire system functions properly. The procedure must be done correctly. Poor calibration leads to a false sense of security.

Calibration is a process that ensures the proper amount of material is delivered to the area being treated. This requires measures of the treated area and the rate at which this area is treated. Desired application rates are determined from label limits and research results. Other factors, such as total amount to apply and rate at which the material should be injected, are calculated based on these measurements and the chosen application rate.

A. System Uniformity

In Kansas, chemigation takes place most commonly through a center pivot irrigation system. Chemical application through a center pivot can only be as uniform as the water distribution. Therefore, it is important to make sure that your irrigation systems are in good condition and operating properly.

Before chemigating, it is essential to check the irrigation system's uniformity of distribution. One way to check the uniformity of the spray pattern is to place catch containers (such as equally-sized, empty coffee cans) at equal intervals along the full length of the irrigation system. It is essential that the catch containers are straight-sided and of equal diameter. The catch containers should be spaced approximately 10 feet apart in an open area, such as the pivot road, rather than under the canopy of the growing crop. The irrigation system should be operated at the same speed and pressure to be used when chemical is applied. However, a 1/2 inch application of water is recommended to assure accuracy during the uniformity check.

Once the system has passed completely over the catch containers, the quantity of water in each container and its location are recorded. The average amount of water in all containers is then compared to the quantity of water in each individual container. A significant deviation from the average at any particular point may indicate a problem with the distribution at that point. Nozzles or sprinklers at that point should be checked for damage or wear and replaced if necessary.

Several factors should be considered when selecting the water volume to be used while chemigating:

1) System capacity and speed;
2) Type of chemical to be applied;
3) The degree of incorporation that may be required;
4) The infiltration rate.

B. Measurements

Calculations will depend in part on the type of irrigation system you are using. Assuming a full-circle center pivot with the end gun either on or off for the entire circle, there are two measurements which need to be taken in order to calibrate: (1) the acreage treated; and (2) the rate of coverage by the pivot. If your center pivot does not make a full circle, you can still use the following procedure, with some adjustments:43

First, you must determine the area (acreage) to be treated. With the end gun on or off, the total wetted area is easily determined based on the straight-line distance from the center of the pivot to the edge of the area covered by the irrigation water (the wetted radius).

1. Center Pivots

The dealer usually knows the nominal lengths of spans that went into the system, but it is always wise to check. These distances would be straight-line measurements on level ground, and recorded to the nearest inch. The tape should be straight and held with some tension while the end points are being marked. A limp tape follows the contour of the surface and is not a straight line. Small errors have a way of adding up to larger ones. Care in measuring lengths will reduce this source of error to within acceptable limits. A tape of at least 100 feet in length is recommended. The measurement should start at the center of the pivot and extend on a straight line outward.

The limit of wetting under non-windy conditions is usually easy to locate when the machine is running. However, this may not necessarily indicate the boundary beyond which water application is diminished. Some estimates of a point where a nearly normal amount to water is being applied should be sought. If little is known about the distribution of water at the end of the system, an assumption that adequate irrigation occurs at one half to two thirds of the radius of throw of the end sprinkler is reasonable. If the end sprinkler is a volume sprinkler or end gun, the measurement should be taken with this sprinkler shut off. Large sprinklers are particularly susceptible to wind drift and frequently have poor water distribution patterns. As a consequence, the normal recommendation is not to use them during chemigation with pesticides or fertilizers. They should, therefore, not be included in the radius of coverage measurements.

Acreage to be treated is calculated by the following:

EXAMPLE: If the wetted radius of the circle is 1320 feet, then:

a) Area Treated = 3.14 x 1320 x 1320 = 5,471,136 ft^2

Convert this to acreage by dividing the area treated by 43,560.

b) Acreage Treated = 5,471,136 ft^2 / 43,560 = 125.6 acres

Area Treated (in square feet) = 3.14 x R2

Where R is the distance from the pivot point to the edge of the field, or dry soil. This is the wetted area in square feet. Next, convert this to acreage by dividing by 43,560 (the number of square feet in an acre).

In some cases, only part of the circular area that could be covered by the pivot system will be chemigated. Estimating the area to be treated becomes increasingly complex with partial circles, circles with intermittent end guns and other configurations. Calculations for determining the area of some irregular field configurations appear in Appendix A.

The total amount of chemical required can be calculated from the estimate made of the acreage treated. This is done simply by multiplying the acreage to be treated by the desired amount (volume) of chemical per acre.

EXAMPLE: If the acreage treated is 125.6 acres, and the desired chemical application rate is 0.25 gallons per acres, then:
Amount of chemical = 125.6 x 0.25 = 31.4 gallons

After you have estimated the total acreage to be treated, you must determine the <u>rate of coverage</u> (the number of acres covered per hour). In order to do this, you must determine the distance traveled by the outside tower, and then estimate the speed at which this distance is covered.

The distance traveled by the outside tower while making a complete circle is the <u>circumference</u> and is calculated by:

Circumference = 6.28 x D

Where D is the distance from the pivot point to the wheel track of the outside tower.

EXAMPLE: If the distance from the pivot center to the wheel track of the last tower is 1250 feet, then:
Circumference = 6.28 x 1250 ft = 7850 ft

You must then measure the rate of movement of the center pivot; that is, you must estimate what fraction of the circumference the pivot will cover in a given amount of time. Measurement of the rate of movement is a critical step in the calibration procedure. When measuring the rate of movement, the irrigation system should be operating at the same speed and water pressure that will be used when the chemical is applied.

A full quarter section center pivot with the normal 6-5/8 inch diameter pipe contains more than 2000 gallons of water which exerts a load of up to 3000 pounds per tower. Thus, operating on wet soil contributes to wheel slippage. Speed control settings are only approximate. They may be adequate for control of water application rates, but are not sufficient for chemigation operations. The rate of movement should be measured for the intended application amount. If a quick circle applying less than the normal irrigation amount is to be used, calibrate using this setting.

Center pivots have two common drive modes: continuous and intermittent. Hydraulic driven pivots move at a constant speed with all tower motors running at all times. Electrically driven pivots move in a start/stop fashion. At the highest speed setting, the outermost tower normally moves continuously with only the inner tower drives starting and stopping to keep pace with the outer tower. At slower speeds, all towers start and stop.

An excellent procedure with electric drive machines is to time how long it takes for a given number of run periods (e.g., 10) to occur and measure the distance traveled. This eliminates error due to starting and stopping. A marker is set at the center of an axle at the start of a run period and timing begins. When the 10th run period begins, another marker is set at the center of the same axle and the time recorded. The distance between the marks is measured and the rate determined by dividing the distance by the time. This is the best procedure when the machine is operating in the start/stop mode, but the advantage is small if the on/off cycle is short. A measurement of rate on a dry run or making one full speed wet run and proportioning the speed of travel using the control settings are only approximations. At slower speeds, the field is wetter, the ruts deeper and conditions are not the same.

Variations in soils and topography can also cause problems. If several quite different soils are present in the path of the end tower, this may cause differences in tractive properties, and several measurements of speed should be made. A measurement should be made in the best and the worst case soils. The same is true of topography. The rate of movement both up hill and down should be determined. If large differences are found, the measurements should be repeated and the consequences evaluated. Over- or under-application may be unavoidable under such conditions. Finally, a center pivot that has had the end tower stuck in a soft spot should not be used for chemigation unless the problem has been solved. Controls can be installed to shut down an electric drive center pivot if the end tower gets stuck, or the soil conditions in the troublesome spot can be corrected.

Calculate the travel speed of the pivot by measuring the distance the outside tower travels in a given period of time (at least 10 minutes). First, flag the position of either wheel on the outer tower when it begins to move. As the flag is set, start the stopwatch. After 10 minutes, flag the location of the same wheel. If the system moves intermittently, make sure the beginning and end measurements are taken at the same points in the move/stop cycle. Then measure the distance between the two flags.

The straight-line distance between the two flags represents an approximation of the actual length of the curved path followed by the wheel. However, the difference between the straight-line approximation and the true curved-path distance will be negligible as long as (1) the distance from the center pivot point to the outside tower is greater than 300 ft and (2) the observed straight-line distance between the two flags is 100 feet or less.

If the field is hilly or rolling, repeat this procedure in several different locations and use the average speed in your calculations. Soil type, soil compaction, slope and track depth are among the factors which affect travel speed. It is a good idea, therefore, to verify travel speed several times throughout the growing season.

EXAMPLE:	If the outside tower travels 65 ft in 10 minutes, then: travel speed (at outside tower) Travel speed = 65 ft/10 min = 6.5 ft/min

The next step is to calculate the rate of coverage based on the measurements that you have made. This is calculated by the following two steps:

1) Multiply the speed (in feet per min.) of the outside tower by the total acreage treated;

2) Divide the product resulting from step 1 by the circumference (the length traveled by the outside tower).

The result of these two steps will yield the rate of coverage in acres per min.

EXAMPLE:	If the speed of the outside tower is 6.5 ft/min, the acreage treated is 125.6 acres, and the circumference is 7850 ft, then the rate of coverage would be: 1) 6.5 (ft/min) x 125.6 acres = 816.4 2) 816.4 / 7850 = 0.104 acres per min

Next, the rate of coverage can be converted from acres per min. to acres per hours by multiplying by 60.

EXAMPLE:	If rate of coverage is 0.104 acres per min, then: Rate of coverage = 0.104 x 60 = 6.24 acres/hour

Now that the above calculations have been performed, several other factors can be determined. The water (in inches) applied per acre can be calculated by (1) dividing the pump capacity (in gallons per minute) by the acres treated per minute, and then (2) dividing the result by 27,154 gallons per acre-inch.

EXAMPLE:	If the pump capacity is 900 gal/min and the rate of coverage is 0.104 acres per minute, then: (1) gal per acre = 900 / 0.104 = 8654 (2) inches per acre = 8654 / 27,154 = 0.32

At this point, you may need to readjust the speed of the irrigation system to apply either more or less water per acre, depending on the chemical label.

The next step is to determine the chemical application rate or injection rate, measured in gallons per hour. This is calculated by multiplying the rate of coverage (acres per hour) by the desired number of gallons per acre.

EXAMPLE:	If the rate of coverage of the system is 6.24 acres per hour, and you wish to apply 0.25 gallons per acre, then: Injection Rate = 6.24 x 0.25 = 1.56 gallons per hour

Knowing the chemical application rate in gallons per hour is helpful because most chemical injection devices are rated in gallons per hour. Your chemigation system should have a chemical metering device that can be easily and accurately adjusted.

2. Other Systems

Other types of irrigation systems can be handled in a very similar manner. Most other systems cover rectangular areas that are easy to evaluate. The systems that move while they apply water will need to be evaluated for the speed of movement similar to that explained for center pivots. If the movement is intermittent, that fact should be considered. Some systems may cast water beyond the path of the machine or water pipes while others cover only that area internal to the water distribution systems. The principles are the same. If the system moves, the area covered per hour is needed. If the system is stationary, that portion which is in operation at any one time and the period of operation provide the necessary data.

The measurements in the preceding sections are easiest to do when the crop is small or there is no crop present. Taping in a crop canopy is no fun, even under the best of conditions, and there is no reason why the chemigator must wait until chemigation treatment is needed to make most or all of the measurements. Pre-or early-season measurements for machine speeds would be the most suspect, but if the machine has been run enough to establish firm wheel paths, these measurements should be sufficient. Care must be taken to set the speed control precisely in the same locations as they were when measurements were made. Slack in the controls can be avoided by always setting the speed while turning the control knob in the same direction.

3. Injection Pumps

The injection system should be calibrated with a calibration device located in-line on the suction side of the injection pump. Commonly, a graduated cylinder is used for calibrating smaller volumes required for pesticides.

The cylinder is filled with liquid and the time required to withdraw a known amount of liquid is measured. The pump is started according to instructions and the liquid level observed. When the level reaches a distinctive point, such as an even ounce line, a stopwatch is started or the time observed. When the liquid level reaches the chosen volume below the starting point, the time is again observed to the nearest second or the stopwatch is stopped. The actual pumping rate is then computed by dividing the volume of liquid removed from the cylinder by the time (in minutes). The observed injection rate is then compared with the desired rate, and the pump adjusted accordingly.

The desired injection rate that was estimated in gallons per hour can be converted to measurement units that are appropriate for the chemical being injected and for the calibration tube. This conversion is done by multiplying the number of gallons per hour by the appropriate conversion factor:

1 gal/hr = 128 fl oz/hr = 3,789 ml/hr
1 gal/hr = 0.0167 gal/min = 2.13 fl oz/min = 63.14 ml/min

EXAMPLE: If the desired injection rate is 1.56 gallons per hour, and the calibration tube is marked in ounces, then:

Injection rate = 1.56 x 2.13 = 3.32 oz per min

If you run the system for 10 minutes, then the amount that should be drained from the calibration cylinder is:

3.32 x 10 = 33.2 oz

This method usually involves a high degree of trial and error. Manufacturers normally indicate pumping rates for various settings on the pump control, but these are seldom precise enough to use directly.

Rough adjustments may be made by observing the amount of chemical drained during one minute intervals. Make a final check over an extended period of at least five minutes. It is a good idea to observe the amount of chemical being used over longer periods, such as an hour, or even half a day. This can help you find calibration errors or equipment malfunctions.

Water may be used for preliminary trials, or the injection line can be removed from the irrigation supply pipe and injected material collected in a container. The operator needs to exercise care, particularly when pumping rates are high. The materials may emerge from the line with considerable force and splash out of the container. To prevent this, a cover may be used or liquid may be added to the container and the release made below the liquid surface, which should reduce splashing. The chemical line should also be secure. A high pressure stream may push the injection line out of the container causing a local spill. All containers, submerged hoses and other equipment used in calibration should be thoroughly cleaned after use.

Most positive displacement injection pumps are affected by back pressure. Therefore, do not rely on measurement of non-pressurized flow from the discharge side of the pump. The injection device must be adjusted to deliver a specific amount of material during a given period of time. To achieve accurate calibration, adjustments must be made while the injection device is delivering chemical against a pressure equal to the water pressure at the chemical injection point when the irrigation system is operating. This back pressure can be created by using a back-pressure device or by operating the irrigation system during calibration.

The initial calibration can be made more realistic by keeping the spring-loaded check valve and injection point attached to the injection line during calibration. An even more realistic condition can be established by attaching the injection line to a pressure relief valve that has been set the system pressure. Such a valve may be installed in a branch line which leads back to the chemical supply tank, or may be attached to the injection line discharging into a container. If a branch line is used, a diverted valve should be installed in the injection line so that all of the material is either diverted back to the chemical supply tank or into the irrigation system. Such a system increases safety but creates new problems. The valve used for the diversion should be one made for the purpose. The flow should go to either the injection point or out the branch line. There should not be an off position which prevents flow from occurring. Flow stoppage could result in a burst injection line and a spill of materials. Second, the branch line should be rinsed at the conclusion of chemigation, which creates an extra operation. Also, there is usually no easy way to safely drain this line. Finally, the diverter valve must be set to the injection position when chemigation is started.

The initial run should be done using the best estimate of where the rate adjustment on the pump should be set. The marks on the pump adjustment may be in a variety of units. Some manufacturers mark the adjustment in gallons per hour, others in percentage of the full flow, while others merely have a scale from 0 to 10 or 0 to 100 graduations. They all, however, indicate at least approximate settings to obtain various pumping rates.

If the adjustment for the pumping rate is convenient, easy to use and stable, the trial and error procedure will quickly converge to the proper setting. If the first setting does not provide the rate desired, additional settings must be tested until the pump is properly set. The operator should take note of each setting and record the results of the test. This will allow the operator to make better approximations for the next trial and will indicate how sensitive the adjustments are for a given increment of change. Much time can be saved if good calibration records are kept for future reference. A chemigator must keep records of what has been applied to the land for an annual report to the Kansas Department of Agriculture, so keeping calibration data is recommended.

The pump should be primed according to instructions and allowed to run long enough to stabilize before measurements are taken. This usually takes only a few moments, but if the pumping rate is low, several more minutes may be required to fill the injection line and start injecting chemicals into the irrigation line, catch container or chemical supply tank. Until the injection line is full, there is little back pressure on the injection pump and the pumping rate may not be stable. Measurements should be taken only after pumping has stabilized.

Some chemicals must be diluted and others may be diluted without loss of efficacy. To calibrate, the injection rate must be set using the amount of active ingredient in the dilute solution. Pre-mixing, if required, should be done according to label instructions. Keep track of the amount of dilution. Large chemical storage tanks should be level and carefully calibrated to indicate the amount of liquid contained. If the tank does not have a good set of calibration marks, the operator needs to calibrate the tank or purchase a flow meter to measure the amount of water added. One cubic foot of water contains 7.48

gallons. The operator can measure the size of the tank and determine the capacity. However, this is difficult with circular tanks that are positioned horizontally. A vertical tank can be calibrated by calculating the full capacity and proportioning the remainder, but a horizontal tank capacity is not directly proportional (See Table 2).

Table 2. Estimation of the volume of liquid in a horizontally-placed cylinder based on the percentage of diameter.

Percent Diameter	Percent Capacity	Percent Diameter	Percent Capacity
5	1.87	55	56.35
10	5.21	60	62.64
15	9.41	65	68.81
20	14.23	70	74.76
25	19.54	75	80.46
30	25.24	80	85.77
35	31.19	85	90.59
40	37.36	90	94.79
45	43.65	95	98.13
50	50.00	100	100.00

If the injection pump is within one percent of the correct value, the accuracy of dilution should match. Some tank calibration scales are too poor to come close to this requirement. Therefore, they should be checked. Plastic scales cemented to the tank are particularly troublesome. Dilution is also a handy way to extend the range of some large volume injection pumps. A large volume piston pump made for fertilizer injection may not be easily adjusted to the low volume rates needed for a concentrated pesticide, but with dilution can be made to work. The chemical supply tank must be large enough to work with the management system employed, but should not require any other modification.

Make sure of the units on the graduated cylinder. If there is any doubt about the values, they may be checked by measuring the inside diameter of the cylinder and measuring the distance between graduating marks. Some graduated cylinders have plastic scales cemented to the side of the tube. Sometimes these tend to shrink or come loose. Observe water levels in the graduated cylinder while viewing the cylinder at a right angle. Graduations that completely encircle the cylinder are the best indicator marks. When the graduation on the back side of the cylinder is hidden by the line on the front, the eye is at a right angle to the mark. Observe the lower edge of the liquid surface at the center. Most common liquids form a U-shaped surface. The lowest point on this surface is the best position to read. Finally, the graduated cylinder need not be left on the equipment. Several manufacturers make quick couplings for the graduated cylinder so that it may be easily removed for cleaning and safe storage. This also makes it possible to use several cylinder sizes to cover a wider range of pumping rates.

Two other factors are extremely important. First, read the chemical label thoroughly. Use the proper safety precautions and protective clothing while you are chemigating. Second, the density and viscosity of agricultural chemicals varies widely. Therefore, the final calibration must be performed while using the chemical to be applied.

Determining the correct setting for your chemical injection system is essential for safe, legal, economical and effective chemigation. Regardless of the type of system you use, calibration is essential. Since wear and tear on the equipment, viscosity, etc., all affect the rate of injection, it is necessary to recalibrate every time you chemigate.

C. Other Methods

Positive displacement injector pumps are required for chemigation with pesticides in Kansas, but if the operator only wishes to apply fertilizer or animal waste, a positive displacement injector pump is not required. The only requirement is that the operator control the application within reasonable limits. Large size diaphragm pumps and most piston pumps will handle fertilizer solutions as well as pesticides. If both are to be applied, there is little advantage in using other methods.

Other methods include pressure tanks, centrifugal and other non-positive displacement pumps, venturi devices and, in limited cases, gravity feed. Few of these methods are good with moving irrigation systems: center pivots, linear move, or traveling guns. Most of these devices are used with solid set sprinkler systems on golf courses and nursery stock irrigation. The area to be irrigated is fixed at any one time and the operator knows the amount of fertilizer to be applied to the area. The fertilizer can be measured into a tank and injected into the irrigation stream by any of the above methods. A few precautions, however, should be observed. The injection should be gradual to avoid poor distribution. If the distance from the injection point to the first outlet is very short, mixing in the pipe may not be complete before the fertilizer is discharged and may result in a greater or lesser application rate than was intended. A more significant problem, however, is a long length of pipe before the sprinklers. The volume of water in a long pipe is much larger than most persons realize, and the time required before the injected materials reach the last discharge point is great. If only a small amount of material is injected, the entire amount can still be in the pipe when the operator shuts down the system. On many center pivots and golf courses, there may be one quarter to half mile of pipe between the injection point and the first point of discharge. The operator needs to recognize this and allow for the travel time. A quarter mile of 4 inch pipe contains 862 gallons of water. If the pumping rate is 200 gallons per minute, it takes more than 4-1/2 minutes to displace that amount of water from the pipe. Obviously, this is also important when rinsing materials from the system.

Travel time in the pipe is even more complicated when consideration is given to lateral pipes or pipes from which flow is distributed. The entire flow does not travel the entire length. Each time a part of the flow is diverted, the remaining flow rate is slower. Near the outer end of the pipe there is usually only one or a few sprinklers, and velocity can be very low. For example, water and chemicals may require 5 minutes to reach a center pivot a quarter mile away and 7 more minutes to travel the length of the pivot. Solid set systems are even worse. In a center pivot, most of the flow is transferred to the outer end because this is where the large area is watered. However, with a solid set or linear system, the flow from each sprinkler is nearly equal. The travel time in a uniformly sized pipe with uniformly spaced sprinklers slows dramatically as the water approaches the end. The travel time in a given length of pipe is doubled with as few as four equally spaced sprinklers and nearly tripled when there are 10 sprinklers. This value can be calculated, but an easier method is to inject a dye into the system and measure the time required, or consult Table 3. Travel time in a pipe with evenly spaced outlets is found by multiplying the nearest coefficient for the number of outlets by the time required for uniform pipe flow.

Another occasion when travel time is important is during the rinse cycle. At the conclusion of any chemigation the system should be rinsed with clean water. A rinse does at least two things: (1) it clears all the chemicals or waste material from the system so it is less likely to react with the pipes or settle out in the system; and (2) it dilutes the concentration of chemicals in the drainage water. A normal recommendation is to rinse the system 1.5 to 2 times the estimated transit time for the system.

Table 3

Flow Travel Time in 1000 ft. of
Uniform Diameter Pipe with Uniform Flow

Flow	Pipe Size (inches)					
gpm	3	4	6	8	10	12
50	7.3	13.1	29.4	52.2	81.6	117.5
100	3.7	6.5	14.7	26.1	40.8	58.8
200	1.8	3.3	7.3	13.1	20.4	29.4
300		2.2	4.9	8.7	13.6	19.6
400		1.6	3.7	6.5	10.2	14.7
500			2.9	5.2	8.2	11.8
600			2.4	4.4	6.8	9.8
700			2.1	3.7	5.8	8.4
800			1.8	3.3	5.1	7.3
900				2.9	4.5	6.5
1000				2.6	4.1	5.9
1200				2.2	3.4	4.9
1500				1.7	2.7	3.9

$$T = 40.8\ D^2/Q$$

Where:
- T = time in minutes
- D = diameter in inches
- Q = flow in gpm

Coefficients for Travel Time

A. Uniformly spaced outlets with equal flow from each.

Number	Coef.	Number	Coef.
1	1.00	8	2.72
2	1.50	9	2.83
3	1.83	10	2.93
4	2.08	20	3.60
5	2.28	30	4.00
6	2.45	40	4.28
7	2.59	50	4.50

B. Center pivot with uniformly spaced outlets.

Number	No end gun* Coef.	End Gun 10%* Coef.
10	1.89	1.65
20	2.19	1.77
30	2.38	1.83
40	2.53	1.86
50	2.62	1.88

For example, if a center pivot with a long service line requires 12 minutes to reach the end sprinkler, then the rinse should last 18-24 minutes. An exception would be if the rinse water would wash materials from the surface of crops or the soil before they had time to react properly. Under this circumstance, the chemicals might be left in the system. The drains from most systems open in response to low pressure so they start to drain as soon as the pump is stopped. Stopping drainage from occurring may not be practical.

The operator must ensure the safety of any system. If fertilizer is injected or drawn into the system, there must be a check valve to prevent back-flow into the storage tank and a valve on the supply line from the storage to the injection device to shut off the flow in a positive manner. Calibration may be as simple as measuring or weighing the material into a tank or observing the rate of removal from the storage.

Chemigation with animal and other approved waste materials will usually be done from a holding pond or large tank. Dilution can be accomplished by providing an air gap between the water source and the waste holding facility of at least one foot above the highest possible liquid level. Doing this prevents any possibility of back-flow into the water source. Wastes are normally diluted to a consistency that is compatible with the pumping and irrigation system while in the tank or pond, and continuous stirring may be required. The temptation to provide stirring with the water used for dilution should be avoided if it does not include a permanent air gap. Stirring with a jet of liquid should be done using waste water from the tank or pond, or stirring may be done mechanically.

DETERMINE IRRIGATED ACREAGE

Formulas for calculating acreages in fields and segments are shown below:

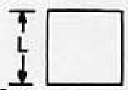
1. Area of a square = L^2
   "L" is the length in feet of one side of the square.

if L = 2640'

L^2 = 2600 x 2640

Area = 6,969,600 sq. ft.

Acres = $\frac{6{,}969{,}600\ ft^2}{*43{,}560\ ft.\ sq.}$ = 160 acres



*One (1) Acre = 43,560 ft^2

Acres = $\frac{ft.^2}{43{,}560\ ft.\ sq.}$

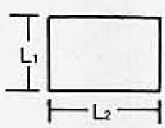
2. Area of a rectangular field. (A)

Area = $L_1 \times L_2$

Area = 2640' x 5280

= 13,939,200

Acres = $\frac{13{,}939{,}200\ sq.\ ft.}{43{,}560'}$ = 320 acres



3. Area of a circle

Area = $R^2 \times \pi$

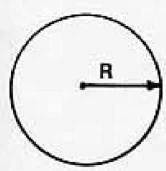
if R = 1300

A = 1300^2 x 3.14

= 5,309,291

Acres = $\frac{5{,}309{,}291\ sq.\ ft.}{43{,}560\ sq.\ ft.}$ = 121.88 acres

(ii = 3.1416)



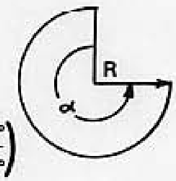
4. Area of a part circle

Area = $(R^2 \times \pi) \times \frac{\alpha}{(360)^\circ}$

if R = 1300 & α 270°

Area = $(1300^2 \times 3.14) \times \left(\frac{270^\circ}{360^\circ}\right)$

= 3,981,968 ft^2

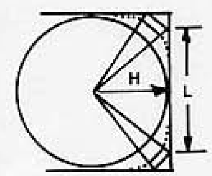


Acres = $\frac{3{,}981{,}968\ ft^2}{43{,}560\ ft^2}$ = 91.41 acres

α = number of degrees, measured with a protractor

5. Area of a triangle

Area = $\frac{H \times L}{2}$



if H = 1300 ft.

& L = 1900 ft.

Area = $\frac{(1300)\ (1900)}{2}$ = 1,235,000 ft^2

= 1,235,000 ft^2

Acres = $\frac{1{,}235{,}000}{43560}$ = 28.4

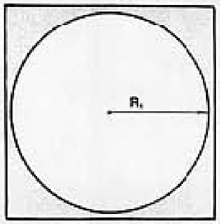
"H" is the same as system length and is equal to the "radius"

"L" is length of the base in the triangle

NOTE: To calculate (estimate) the **acreage** included in a very irregularly shaped area irrigated by a corner system, draw a straight line or a circular arc that will most nearly provide an "average" boundary.

On the following page you will find several typical examples incorporating the above segment formulas into whole field average calculations.

STANDARD ELEC/WATER DRIVE

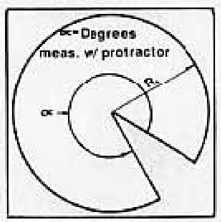


FULL CIRCLE W/O E.G.

$$\text{Area} = \frac{R^2 \pi}{43560}$$

$$= \frac{1294 \times 1294 \times 3.1416}{43560}$$

= 120.7 Acres

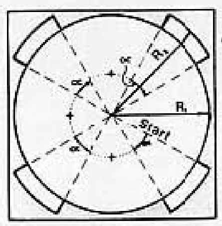


PART CIRCLE W/O E.G.

$$\text{Area} = \left(\frac{R^2 \pi}{43560}\right) \times \left(\frac{\alpha}{360}\right)$$

$$= \frac{1294 \times 1294 \times 3.1416}{43560} \times \frac{330}{360}$$

= 110.7 Acres

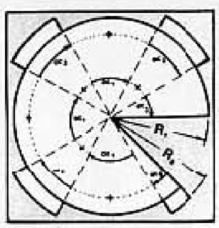


FULL CIRCLE WITH E.G.

$$\text{Area} = \left[\left(\frac{R_1^2 \pi}{43560}\right) \times \left(\frac{360 - 4\alpha}{360}\right)\right] + 4x \left[\left(\frac{R_2^2 \pi}{43560}\right) \times \left(\frac{\alpha}{360}\right)\right]$$

$$= \left[\frac{1294 \times 1294 \times 3.1416}{43560} \times \left(\frac{360 - 4 \times 30}{360}\right)\right] + 4x \left[\frac{1364 \times 1364 \times 3.1416}{43560} \times \frac{30}{360}\right]$$

= 125.2 Acres



PART CIRCLE WITH E.G.

$$\text{Area} = 3x\left[\left(\frac{R_1^2 \pi}{43560}\right) \times \left(\frac{\alpha_1}{360}\right)\right] + 3x\left[\left(\frac{R_2^2 \pi}{43560}\right) \times \left(\frac{\alpha_2}{360}\right)\right] + \left[\frac{R_1^2 \pi}{43560} \times \frac{\alpha_3}{360}\right] + \left[\frac{R_2^2 \pi}{43560} \times \frac{\alpha_4}{360}\right]$$

$$3x\left[\frac{1294 \times 1294 \times 3.1416}{43560} \times \frac{60}{360}\right] + 3x\left[\frac{1364 \times 1364 \times 3.1416}{43560} \times \frac{30}{360}\right] + \left[\frac{1294 \times 1294 \times 3.1416}{43560} \times \frac{30}{360}\right] +$$

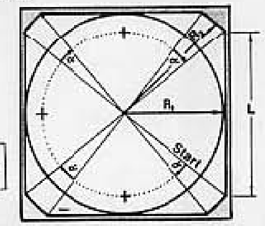
$$\left[\frac{1364 \times 1364 \times 3.1416}{43560} \times \frac{15}{360}\right]$$

= 109.58 Acres

NOTE: Lengths & Angles must be measured in the field or from maps, etc./The above dimensions & angles are only typical examples.

CORNER SYSTEMS

FULL CIRCLE - 4 CORNERS

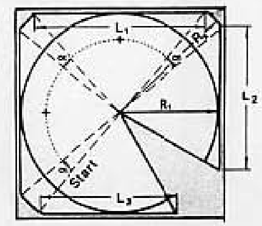


$$\text{Area} = 4x\left[\frac{\left(\frac{R_1 L}{2}\right)}{43560}\right] + 4x\left[\frac{R_2^2 \pi}{43560} \times \frac{\alpha}{360}\right]$$

$$= 4x\left[\frac{\left(\frac{1268 \times 2100}{2}\right)}{43560}\right] + 4x\left[\frac{1581 \times 1581 \times 3.1416}{43560} \times \frac{14}{360}\right]$$

= 150.3 Acres

PART CIRCLE



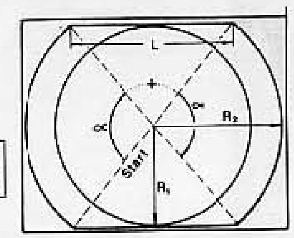
$$\text{Area} = \left[\frac{2\left(\frac{R_1 L_1}{2}\right) + \left(\frac{R_1 L_2}{2}\right) + \left(\frac{R_1 L_3}{2}\right)}{43560}\right] + 3x\left[\frac{R_2^2 \pi}{43560} \times \frac{\alpha}{360}\right]$$

$$= \left[\frac{2\left(\frac{1268 \times 2100}{2}\right) + \left(\frac{1268 \times 1800}{2}\right) + \left(\frac{1268 \times 1500}{2}\right)}{43560}\right] +$$

$$3x\left[\frac{1581 \times 1581 \times 3.1416}{43560} \times \frac{16}{360}\right]$$

= 139 Acres

RECTANGULAR FIELD

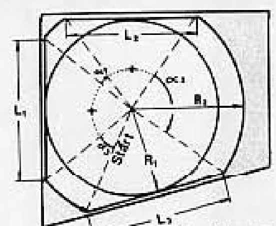


$$\text{Area} = \left[\frac{2\left(\frac{R_1 L}{2}\right)}{43560}\right] + 2x\left(\frac{R_2^2 \pi}{43560} \times \frac{\alpha}{360}\right)$$

$$= \left[\frac{2\left(\frac{1268 \times 2050}{2}\right)}{43560}\right] + 2x\left[\left(\frac{1581 \times 1581 \times 3.1416}{43560}\right) \times \left(\frac{110}{360}\right)\right]$$

= 169.8 Acres

ODD SHAPE FIELD



$$\text{Area} = \left[\frac{\left(\frac{R_1 L_1}{2}\right) + \left(\frac{R_1 L_2}{2}\right) + \left(\frac{R_1 L_3}{2}\right)}{43560}\right] + \left[\frac{R_2^2 \pi}{43560} \times \frac{\alpha_2}{360}\right] +$$

$$\left[\frac{R_2^2 \pi}{43560} \times \frac{\alpha_1}{360}\right] + \left[\frac{R_2^2 \pi}{43560} \times \frac{\alpha_3}{360}\right]$$

$$= \left[\frac{\left(\frac{1268 \times 1650}{2}\right) + \left(\frac{1268 \times 1700}{2}\right) + \left(\frac{1268 \times 1600}{2}\right)}{43560}\right] +$$

$$\left[\frac{1581 \times 1581 \times 3.1416}{43560} \times \frac{90}{360}\right] + \left[\frac{1581 \times 1581 \times 3.1416}{43560} \times \frac{15}{360}\right] +$$

$$\left[\frac{1581 \times 1581 \times 3.1416}{43560} \times \frac{26}{360}\right]$$

= 137.64 acres