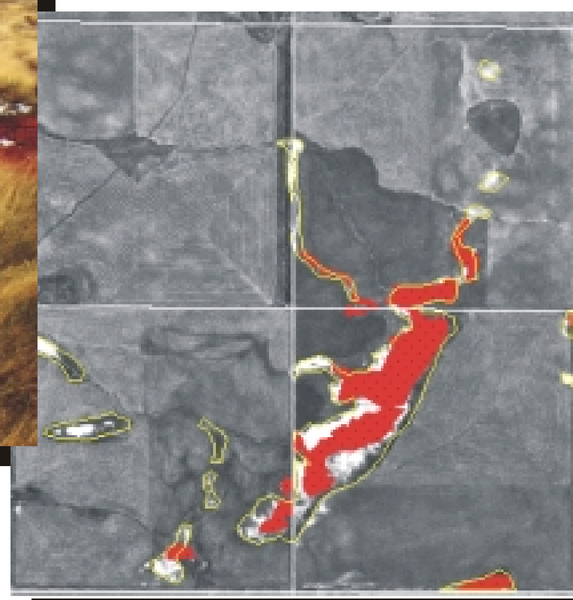
Procedures Manual for Watershed-Based Salinity Management

A comprehensive manual for assessing and addressing salinity on a watershed basis



AESA
Alberta Environmentally Sustainable Agriculture Program

Dryland Salinity Control Association

County of Warner

Alberta
AGRICULTURE, FOOD AND RURAL DEVELOPMENT

Procedures Manual for Watershed-Based Salinity Management

A comprehensive manual for assessing and addressing salinity on a watershed basis

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Acknowledgments

Alberta Agriculture, Food and Rural Development (AAFRD) initiated this project in 1996 in response to a request from the ***County of Warner No. 5*** and the ***Dryland Salinity Control Association (DSCA).*** The County of Warner and the DSCA were concerned about the extent of salinity in the County and the possibility that salinity might increase in extent. They requested assistance to develop and apply procedures for planning and implementing solutions to control and reduce visible dryland salinity.

Personnel from the County of Warner involved in initiating the request included ***Bob Forest*** and ***Keith Heggie***, the Agricultural and Assistant Agricultural Fieldmen at the time and ***Councilor Gordon Peterson,*** Chair of the Agricultural Service Board. Their interest in and enthusiasm for, a watershed based approach to assessment and control of soil salinity provided the initial impetus for the project and greatly influenced its conceptual design and organization. ***Vern McNeely*** and ***Kirt Thompson*** of the DSCA were also instrumental in recognizing the need for a formal set of procedures to assist municipalities to identify and control dryland salinity. They encouraged and supported the initial request for assistance and contributed their expertise to the project design and implementation.

Jane Holzer and her colleagues with the ***Montana Salinity Control Association*** were most gracious in sharing their experiences with addressing salinity on a watershed basis in Montana. The authors acknowledge the influence of their ideas on many of the technical and planning procedures adopted for the current project.

Several individuals associated with the ***University of Alberta, Department of Earth and Atmospheric Sciences*** assisted with technical aspects of the project***.*** ***Dan Hemenway***, unpacked and reformatted the DEM data used in the project and also provided a copy of his public domain software (DMMODEL) for creating 3D perspective views. ***Craig Coburn*** and ***Kai Bader*** were responsible for scanning and geo-registering the secondary source environmental maps used in the project. Kai also helped to produce a registered base map.

Significant contributions by colleagues at AAFRD are also acknowledged. ***Hank Vander Pluym*** reviewed and critiqued many of the initial concepts and proposed solutions. His insistence on a systematic appraisal of the environmental and topographical controls on the distribution of visible salinity was responsible for the new method of estimating potential salinity hazard (PSH) that was developed for this project. The project relied heavily on previously prepared digital data depicting the location and extent of visible salinity provided by ***Jan Kwiatkowski*** and others at AAFRD. ***Gerald Stark, Longin Pawlowski*** and ***Ron Blize*** provided the digital base map data. ***Don Wentz*** contributed numerous suggestions, ideas and encouragement as well as participating in most of the field trips and planning meetings. ***Don Wentz*** and ***Keith Heggie*** were responsible for collecting field data to verify the location and extent of each type of saline seep in the study area and provided a map of land use for the test sub-watershed. The initial manuscript was reviewed, edited and prepared for publication by ***Carolyn King***.

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Any deficiencies in this Manual are entirely the responsibility of the authors.

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Introduction

Purpose of the manual

This Manual describes procedures for identifying, evaluating and planning for the control and remediation of ***soil salinity*** in agricultural landscapes in Alberta.

The Manual emphasizes procedures that address salinity within the context of ***watersheds***. Watersheds are natural landscape features that control the flow of water both on the surface and, to a lesser extent, in the subsurface.

The overall objective of the Manual is to provide a set of clearly structured guidelines and procedures that will help municipalities to address soil salinity concerns. These concerns include how best to assess the degree to which salinity is a problem, how to set goals for addressing salinity, and how to develop programs, policies and site-specific technical procedures for controlling and reducing soil salinity.

The Manual was initially prepared to document procedures developed for a Pilot Project undertaken in the County of Warner in 1995/96.

What is soil salinity?

Soil salinity is a condition in which soluble salts occur within the rooting zones of non-alkali soils in quantities that interfere with the growth of most crops (Agriculture Canada 1976).

Why is soil salinity a concern?

Salinity can reduce crop yields significantly, depending on the salinity tolerance of the crop and the soil salinity levels to which the crop is exposed. In extreme cases, complete loss of plant cover can create bare spots, which increases the risk of wind and water erosion. Saline sites often develop trafficability problems that impede efficient cultivation. Saline sites are associated with decreasing the quality of surface water and groundwater supplies.

Why address soil salinity on a watershed basis?

There are several advantages to developing administrative programs and technical procedures for addressing salinity at a watershed level.

The first is that the water driving the salinity problem usually comes from a different location than where the salts accumulate. Investigations confined solely to saline seeps are often unable to determine the source of the excess water causing the salinity. Investigations that cover a broader areal extent defined by watershed boundaries are far more likely to successfully identify the source of the water.

Second, successful salinity control requires that the problem be attacked at its source, by reducing the flow of water from its source to the seep. This can only be done if the source area can be identified and mapped. A watershed approach ensures that each problem saline seep can be linked to the source area of the excess water carrying salts.

Third, a watershed represents a logical natural region within which to document soil salinity, identify its cause and, most importantly, to find and apply solutions. Since salinity is mainly a problem of excess water and since a watershed encompasses all of a given region draining to a given location, it is reasonable to assume that all or most of the water giving rise to soil salinity in a given watershed originates within the watershed.

Landowners in a watershed have a common interest in managing their shared water resource and in minimizing the adverse effects of management practices on the accumulation and flow of surface and subsurface water. Watersheds are therefore an ideal functional and administrative grouping to facilitate cooperation, planning and implementation of salinity control measures.

Role of municipalities

In Alberta, municipalities have the responsibility to determine what conservation issues may be problems and what should be done to address these problems. The municipal level is therefore the first scale at which to begin defining procedures for locally managed initiatives to document and address conservation issues such as soil salinity.

The process of creating conditions, structures and tools to ensure that farmers and landowners apply and maintain technical solutions is much more difficult than developing the technical solutions themselves.

Municipal councils and conservation agencies have a major leadership role to play in helping farmers address these institutional and planning issues. In particular, municipal and regional conservation agencies need to work with farmers and landowners to develop and implement farmer-controlled funding mechanisms, structures and planning procedures that will work effectively at a local or site level.

In some cases, watersheds cross municipal boundaries. Addressing salinity in these watersheds will require joint, coordinated efforts.

Introduction

How to use this manual

This Manual uses a multi-level, hierarchical approach which integrates technical activities with policy and planning activities and goals (Figure 1).

The ***multi-level approach*** involves identifying, describing and addressing salinity concerns at successively larger scales and greater detail. Three levels are identified: ***municipal***; ***major watershed*** within a municipality; and ***local watershed*** within a major watershed. A local watershed consists of parts of one or more individual farms or management units that all belong to a sub-watershed that contributes water flow to an individual saline site or group of saline sites.

The approach is ***hierarchical*** in that activities to address salinity proceed systematically from general considerations at the municipal level to implementation of specific salinity management plans at the local watershed level.

The approach is ***integrated*** in that technical activities are tightly linked to policy and planning activities and goals. Policy and planning goals defined by municipal councils and agricultural service boards are the driving forces that determine what technical activities are required and how they are implemented.

Technical activities are targeted to provide information based on science needed to make a decision or take an action to control or reduce salinity. The multi-level approach recognizes that there are different levels at which salinity can be assessed and addressed, and that different policies, plans and technical activities are required at each level.

The Manual's structure reflects this integrated, multi-level, hierarchical approach. Policy and planning objectives and activities are identified at each of the three levels (municipal, major watershed, local watershed). Each policy objective or activity is then linked to the technical activity required to support it.

Each of the three levels is addressed in a separate module. Each module is divided into two major sections. The first section describes the policy and planning objectives and appropriate activities. The second describes the technical activities required to support the policy and planning activities. Each technical activity is clearly linked to a policy or planning need.

The procedures documented in this Manual were developed, applied and tested in response to a request from the County of Warner. They reflect the need expressed by the County to develop technical procedures linked explicitly to policy and planning needs. Input from the County was critical when determining the need to identify and manage salinity at several levels.

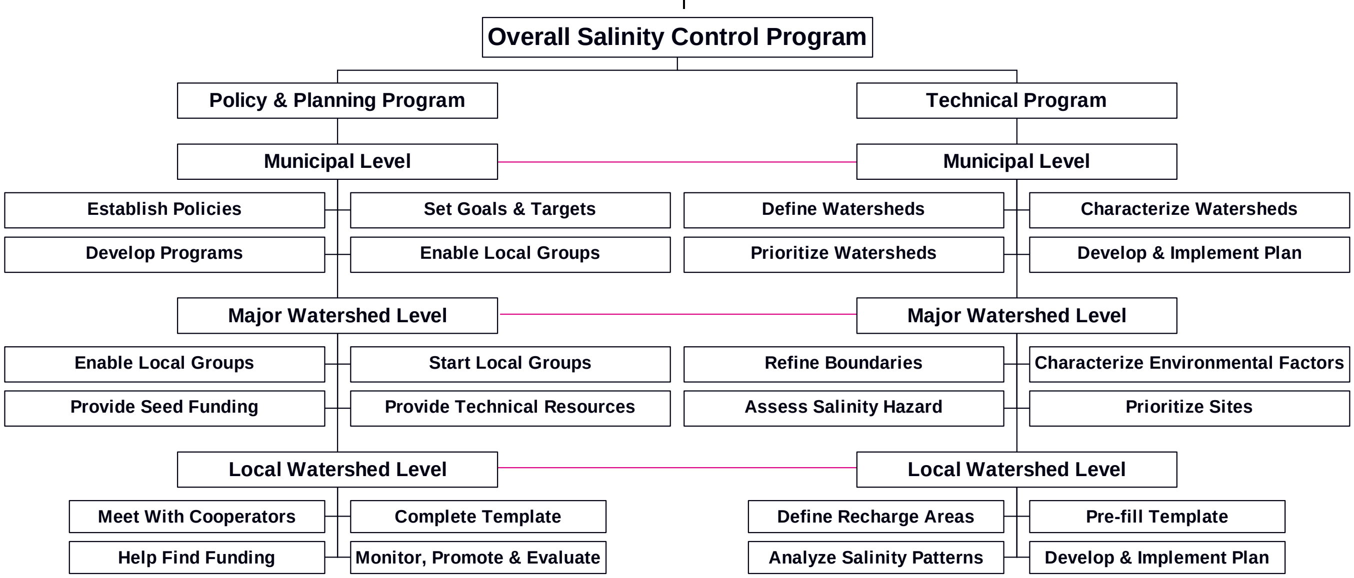
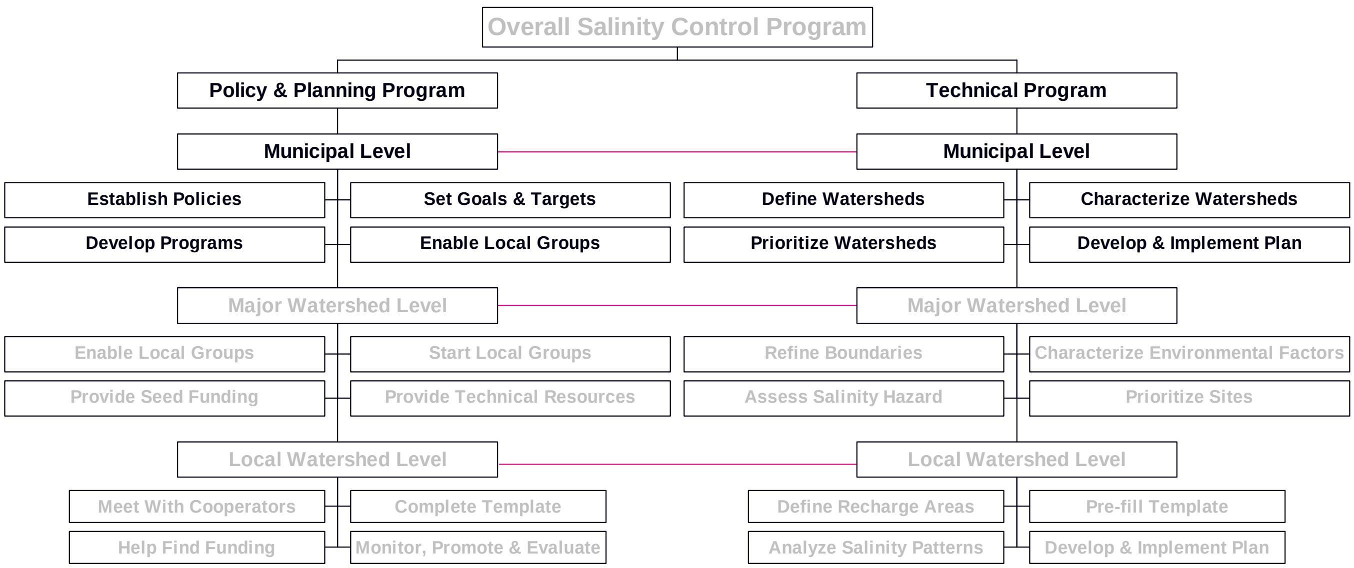


Figure 1. Manual organization integrating policy, planning and technical activities at three levels

Municipal Level Module



Municipal Level Policy and Planning

Policy and planning objective

The primary objective of programs to address soil salinity at the municipal level, is to safeguard the municipality's long-term agricultural productivity, environmental health and economic viability. This must be accomplished by minimizing the adverse impacts of actual or potential soil salinity on the soil and water resource base.

Policy and planning activities

The following activities are required to support the primary municipal policy and planning objective:

1. Determine if soil salinity is an actual or potential problem in the municipality.
2. Develop municipal policies, goals and targets for the control or reduction of soil salinity.
3. Identify and implement funding mechanisms to support salinity control measures.
4. Develop and implement specific watershed-based programs and municipal plans to address salinity.
5. Review and evaluate the goals and targets of the programs.

Determine if salinity is a problem

The first activity in support of the municipal level objectives is to determine if soil salinity is a current or potential problem. Deciding if salinity is a problem in a municipality and if policies and programs are needed to address salinity requires input in the form of both ***facts*** and ***opinions***.

Reviewing the facts

The main facts of interest are: the present extent of salinity in the municipality; the spatial distribution of that salinity; whether the salt-affected area is expanding or contracting; factors influencing salinity; location and extent of potential future salinity; and funding options to support salinity programs. These facts are addressed by technical activities that measure and map soil salinity.

Assessing public opinion

Public perception is an essential input to the development of salinity policies and plans. It is important to assess the degree to which rate payers and land managers consider salinity to be a problem on their own or neighboring parcels, and their willingness and ability to adopt measures to address salinity.

Public attitude is addressed by activities that inform the public and solicit their input. The two aspects are related. Awareness and concern about salinity can be stimulated by better information about salinity extent and trends in the growth or reduction of salinity. Similarly, increased awareness about salinity may lead to increased reporting of saline sites, thereby improving the factual database.

Municipal councils have a variety of mechanisms for obtaining public input including scheduled council or agricultural service board meetings, special public meetings, unsolicited letters of concern and custom-designed questionnaires. Questionnaires offer a systematic approach to acquiring comprehensive, consistent feedback on public opinion. An example of a questionnaire on opinions and attitudes about salinity is provided on page 9.

The role of agricultural fieldmen

Agricultural fieldmen or external technical consultants can assist councils and agricultural service boards by collecting and presenting data to support council decisions. The primary activities of agricultural fieldmen at this level are to:

1. Arrange for, collect and distribute to landowners factual information on the known extent, location and rate of change in salinity in the municipality.
2. Arrange for or conduct an assessment of the potential salinity hazard in the municipality under likely future conditions (change in rainfall, change in cropping systems or change in amount of fallow).
3. Collect, compile and distribute additional information relevant to understanding soil salinity in the municipality, including:
   a. the locations, boundaries and size of watersheds,
   b. the pattern and distribution of environmental and topographical factors that can affect the development or control of salinity,
   c. patterns of crop production, land use and farm management practices by watershed.

Municipal Level Policy and Planning

4. Develop and manage a process to obtain feedback from farmers and other landowners on:
    a. the degree to which they perceive soil salinity to be an actual or potential problem in the region,
    b. their willingness to participate in activities and programs to control or reduce salinity,
    c. their willingness to cooperate with neighboring landowners and to contribute to the costs associated with salinity control efforts.
5. Present to councils or agricultural service boards their findings and recommendations on:
    a. the extent of salinity and the need for measures to control salinity,
    b. the locations (watersheds) where salinity is both widespread and controllable,
    c. the priority locations (watersheds) where operator interest and willingness to participate in and fund salinity control efforts is high,
    d. mechanisms for implementing and funding salinity control action plans that have received significant landowner approval.

The technical activities needed to obtain the factual data are described later in this Manual. Fieldmen may choose to do much of the technical work themselves, or they may have it done by external agencies such as Alberta Agriculture, Food and Rural Development (AAFRD) staff or consultants.

Develop policies, goals and targets

Establishing policies

If soil salinity is deemed to be a problem, it is important to develop municipality-wide policies that reflect a general consensus among ratepayers, land managers and administrators regarding the severity of the salinity problem and how to address it.

A general policy might simply state that soil salinity is considered to be a problem within the municipality and that the municipality plans to minimize the adverse impacts of salinity on its soil and water resource base.

As an example, the County of Warner Agricultural Program Management Plan adopts the A.S.B. General Statement of Policy, which is:

1. To maintain agricultural production in the County of Warner No. 5.
2. To carry out the legislative responsibilities in accordance with the provision of the Agricultural Service Board Act.

Setting goals and targets

Setting specific goals and targets ensures that efforts to address soil salinity will be effective and that their degree of effectiveness can be measured.

Goals and targets need to reflect local opinions and decisions. Examples of possible salinity targets are:

1. To ensure that the current extent of observable salinity does not increase over the next five years.
2. To improve crop production in 20% of the currently saline and potentially saline areas over the next five years.
3. To reduce the extent of salinity affecting arable land by 30% over the next five years.
4. To remove all evidence of soil salinity affecting arable land over the next five years.

Clearly, the goals can range from very conservative (1) to very ambitious (4), depending on the degree to which salinity is deemed to be a problem and the degree to which local public opinion supports addressing salinity.

The important thing is to have formal recognition of a specific set of goals and targets for addressing salinity. These should be widely circulated, discussed and agreed to by affected ratepayers and land managers.

Specific goals and targets should reflect the intent of the general policy, but also need to be feasible and based on realistic assessments of known data on salinity type and extent. Goals should be measurable and provide a means of determining if policy objectives are being achieved.

Identify funding mechanisms

Mechanisms for funding municipal or watershed level salinity programs and individual site salinity control activities are a key concern of any municipality. Municipal councils may wish to develop proposals for funding from both government and non-governmental sources. Beever (1998) contains a list of conservation program funding agencies.

Municipal Level Policy and Planning

Municipal salinity control efforts will likely have to rely at least in part on local funding. One approach that has met with some success in other jurisdictions is a locally funded and managed salinity association. Holzer (1996) outlines what has been done in Montana. These landowners formed a voluntary group and assessed themselves a fee based on owned or arable acres within the watershed boundaries. Fees ranging from 10 cents to five dollars per acre were reported.

The pool of money is mainly used to provide incentives. Farmers who replace fallow with forages or continuous cropping can withdraw money from the fund either to compensate for the costs incurred in changing or to compensate for the difference in return from the lower value forage crops. Landowners who expect to benefit from reductions in salinity that increase yields or at least maintain the ability to crop land that had been threatened by salinity are expected to be net contributors to the fund.

Another option could be a municipality-wide conservation tax. Assessments of five to 10 cents per acre would likely be sufficient to fund an ongoing program for a municipality. Other funding options include tax relief in the form of unchanged assessments for land reclaimed from salinity or tax penalties for recharge areas left fallow.

Develop watershed-based programs

The fourth municipal level activity identified above is to develop specific programs to address salinity. This Manual recommends and describes a watershed-based approach. A watershed approach is effective both for technical reasons and for awareness and extension purposes.

Watersheds are the most technically appropriate hydrological sub-divisions of municipalities. It may be assumed that most of the excess water responsible for salinity within any given watershed originates within the watershed. Thus each watershed is likely to contain not only the saline seeps that are the expression of the problem but also the associated recharge areas that are the source of the problem. It makes sense to ensure that salinity programs are applied to areas that contain both the source and the expression of the problem.

Watersheds are conveniently sized sub-sets of a municipality within which to promote awareness about salinity and foster cooperation among landowners to control salinity. Watersheds are an appropriate maximum scale at which to convince land managers that changes in farm management practices can affect soil salinity. It is easy to observe a local reduction in salinity within a small watershed and to accept that the reduction can be attributed to local efforts to replace fallow with high-water-use crops. It is much more difficult to relate changes in practices implemented 10 to 50 km away to local reductions in salinity.

Watershed-based salinity control programs allow municipal technical resources to be focused where they will have the most immediate benefit. Mobilizing a small group of motivated landowners who recognize that they have a salinity problem and are interested in addressing it, is easier and more effective than trying to get everyone in a municipality involved, including those who have no salinity problems or perceive none.

Successful reduction of salinity within an initial watershed area is probably the best advertisement for later efforts to convince landowners in other watersheds of the benefits of adopting salinity control measures.

Organizing & funding watershed-based programs

Municipal councils need to establish a framework for watershed-based salinity programs. This framework might take the form of approval of a municipal policy or bylaw that recognizes and encourages the formation of landowner-controlled groups to control salinity in local watersheds. The decisions a council takes will depend on the degree to which soil salinity is perceived to be a problem locally and the local will to address it. Councils may decide to develop and fund a municipality-wide program to stimulate the formation of watershed-based groups and to provide technical assistance and data to such associations. It may be necessary to find and allocate funds to enable municipal staff to help organize these groups and help obtain, collate and distribute information on soil salinity and its control.

Neighboring municipalities may need to enter into cooperative agreements in cases where watersheds overlap municipal boundaries.

Councils may wish to enact bylaws or statutes that encourage management practices that reduce salinity or penalize those that increase salinity. It may be possible to modify assessment procedures to provide tax relief or bonuses to those who adopt conservation measures or penalties for those who do not.

Municipal Level Policy and Planning

Develop a municipal level plan

The success of municipal salinity control efforts depends, to a great extent, on development and application of a feasible and widely supported plan. A good plan ensures that the activities to address soil salinity will be effective and that their degree of effectiveness can be demonstrated.

No plan is ever perfect and none is ever implemented exactly as first conceived. However, a good plan provides a useful framework for implementing effective actions and evaluating the success of those actions. A good plan should also be flexible enough to permit modification as experience is gained during its implementation.

The plan need not be exhaustive. In most cases, a complete plan is no longer than two to three pages.

Preparing the plan

A municipal level salinity control plan should be prepared by the agricultural fieldman after all relevant technical data and ratepayer input have been obtained and analyzed. The plan should be discussed, reviewed, revised and approved by ratepayers, the agricultural service board and council.

Components of the plan

A municipal level plan for salinity control may include all or some of the following components:

Objectives:

Clearly specified and attainable objectives are essential for a successful plan. Councils, agricultural service boards, fieldmen and ratepayers need to consider all available information about salinity in their area to arrive at realistic goals and targets for addressing salinity.

The objective may be to reduce salinity in the municipality by a specified amount or, if current conditions are acceptable, to simply to prevent expansion of salinity. Objectives could also take into account that certain types of salinity are more or less permanent and are not likely to respond to most control efforts. It may be preferable to set targets for controlling or reducing specific types of salinity in specific landscape settings.

Objectives must be specific and measurable. If they are not, it will be impossible to determine whether the actions undertaken to address salinity have had any beneficial impact. They should therefore state explicitly if, where, when, and by how much, salinity is to be reduced.

Methods:

A methods section can simply list the methods to be used and reference these to published manuals. It may simply list a number of steps as in the following example:

1. Collect all relevant data and input into a GIS.
2. Define major watersheds.
3. Characterize major watersheds in terms of:
    a. extent of salinity by type,
    b. extent of land use by type,
    c. extent of soils by agricultural capability.
4. Prioritize major watersheds in order of their need for salinity control measures and likely success in response to control measures.
5. Organize watershed-based salinity control groups in the highest priority watersheds representing ***X*** acres.
6. Develop and implement local watershed plans for salinity control, at ***N*** of the highest priority sites in each of the major watersheds.
7. Summarize and report the results of the individual site plans on both a municipal and a watershed basis.

Work plan:

The work plan simply summarizes who will do what and when. It is often developed as a table or chart with a list of tasks down the left-most column and a list of work days, weeks or months across the top row. Time lines are drawn in to show the start and finish times for each task. One or more individuals are assigned responsibility for each task and an estimate is included for the number of days, weeks or months needed to complete each task. The individuals' names and number of days for completion of each task may be entered into separate columns at the end of each task row.

Municipal Level Policy and Planning

Budget:

A detailed work plan is the basis for creating a budget. The personnel costs associated with each task are calculated by multiplying the total number of hours or days that each individual is required by an hourly or daily rate for each individual. Non-personnel costs are usually broken down into operating costs (supplies and services) and capital costs (major purchases). Both of these sets of expenditures should be directly linked to tasks in the work plan.

Reporting, review and evaluation:

This section should clearly state what types of reports or other deliverables will be produced, by whom and when. It should identify who reviews the project, how reviews will be made and when. It must include specific procedures for measuring success.

Models for implementing salinity control plans

In Montana, individual salinity control projects have been organized and managed on a watershed basis, in which watersheds typically contain about 50 sections or 32,000 acres (12,950 ha). Actions at individual sites within a watershed require from one to several (5 to 10) neighboring landowners to cooperate in selecting and implementing measures to control salinity. This model of local, farm-scale control is recommended as the most likely to result in adoption and maintenance of effective salinity control measures by farmers in Alberta.

Enabling salinity control groups

At a policy level, it is recommended that municipal councils design and put in place appropriate bylaws or ordinances to provide a legal basis for recognizing and devolving authority to local salinity control groups at the scale of a watershed or group of sub-watersheds. Fieldmen may need to stimulate and assist in initial organization of the first few watershed level associations.

Holzer (1996) prepared a fact sheet about the procedures used in Montana to set up a watershed-scale salinity control association. It describes some options for defining the purpose, role, organizational structure, decision making process and funding mechanisms for one possible model. Any functioning watershed-scale salinity control association will ultimately have to define its own unique mandate and organization. The fact sheet is simply a starting point for discussion and an initial model that can be adopted or modified as desired.

Alberta Environmentally Sustainable Agriculture (AESA) Program soil conservation coordinators, AAFRD regional development specialists and agricultural fieldmen can develop a team to facilitate the formation of local watershed-based groups.

Sample Questionnaire: Salinity Awareness and Concern

Please take a few minutes to complete this short questionnaire. The results will be used by Agricultural Service Board staff to assess the level of awareness and concern about soil salinity in <Print name of municipality here >.

This questionnaire will help to identify and prioritize areas in which salinity management programs are needed, wanted by most landowners, and can expect to receive the level of landowner support required to be successful.

	Landowner/Operator Name					
	Home Quarter Section					
		QTR	SEC	TWP	RNG	MER
	Telephone Number:					
	No. Acres Farmed					
No.	**Questionnaire on Attitudes and Concerns about Soil Salinity**	**None**	**Low**	**Moderate**	**High**	**Very High**
	(Please circle one number on the scale from 1 to 5 for each question)	**1**	**2**	**3**	**4**	**5**
1	How much soil salinity occurs on lands that you manage?	1	2	3	4	5
2	How much salinity do you observe on nearby lands managed by your neighbors?	1	2	3	4	5
3	How would you rate your level of concern with salinity as an agricultural management problem in your area?	1	2	3	4	5
4	Would you be willing to join with your immediate neighbors to form a cooperative association to address salinity jointly in your area?	1	2	3	4	5
5	How likely would you be to adopt practices such as continuous cropping or growing forages if these practices reduced salinity on your own land?	1	2	3	4	5
6	How likely would you be to adopt practices such as continuous cropping or growing forages if these practices reduced salinity on your neighbor's land?	1	2	3	4	5
7	In your opinion, to what degree does your present farm management (crop selection, machinery complement, field arrangement) limit your ability to adopt practices for controlling salinity?	1	2	3	4	5
8	In your opinion, to what degree do financial considerations limit your ability to adopt practices for controlling salinity?	1	2	3	4	5
9	How willing would you likely to be to accept some form of self-imposed and self-managed assessment to help fund the adoption of practices in your immediate area?	1	2	3	4	5

The personal information (information that will identify you) being requested on this form is being collected for the development of salinity control programs by <municipality name>. It is being collected under the authority of the Freedom of Information and Protection of Privacy (FOIP) Act and is subject to the FOIP Act. If you have any questions about the collection, contact: <municipality name, address, phone>.

Municipal Level Technical Activities

Technical objective

The primary objective of technical activities at the municipal level is to provide necessary input data and support for decisions or actions undertaken to establish policies or develop and implement municipal level plans.

Technical activities

The following technical activities are required to support municipal level policy and planning activities:

1. Acquire and input into a geographic information system (GIS) the necessary widely available background data, specifically:
    a. a digital base map,
    b. a digital municipal scale salinity map,
    c. a digital elevation model (DEM),
    d. secondary source environmental data.
2. Establish the boundaries of natural watershed units within the municipality.
3. Characterize the defined watersheds in terms of:
    a. their extent of salinity by type,
    b. their extent of land use by type,
    c. their extent of soil by agricultural capability class,
    d. their other environmental conditions,
    e. their potential for developing expanded salinity (potential salinity hazard).
4. Prioritize the defined watersheds in terms of:
    a. their need for salinity control measures,
    b. their likelihood of responding positively to salinity control measures.

Who should compile the data?

Compilation and analysis of the municipal level digital data is a one-time activity that requires technical expertise in both GIS and environmental analysis. Therefore, it is recommended that the databases be compiled and analyzed by trained technical personnel.

For some municipalities, it may be convenient to have AAFRD staff conduct, or arrange for, compilation and initial analysis of the municipal scale digital databases.

Municipal Level Technical Activities

Acquire the GIS digital database

Most of the data for supporting policy decisions or creating and implementing plans at a municipal scale requires a computer for data gathering and analysis. This Manual; therefore, assumes that computer capabilities exist and will be used to implement planning activities.

The GIS analyses needed to produce the technical data required for input into policy and planning decisions could be accomplished using any number of available GIS packages. For this reason, the following documentation is as generic as possible and makes few assumptions about which GIS software packages will be used to accomplish the tasks.

In practice, the Pilot exercise made use of two raster GIS packages, namely ***Idrisi*** (Eastman 1993) and ***PC-Raster*** (van Deursen and Wesseling 1992) as well as several custom written programs. Since the Pilot was completed, ***Arc/Info*** and ***ArcView Spatial Analyst*** have become widely adopted by AAFRD and most rural municipalities. Any of these packages can be adapted to support the GIS processing described in this Manual.

Trained technical personnel should do the compilation and initial analysis of the municipal scale GIS databases.

Selecting and acquiring a base map

The first technical requirement is to select and acquire a digital base map covering the entire municipality. Figure 2 shows an example. The base map provides the framework on which all other data will be referenced and displayed.

Several digital base maps are available for use in Alberta. At present, these include:

1. A very simple 1:1 million scale base map which covers the entire province in a single file.
2. A somewhat more detailed and accurate series of 1:250,000 scale digital base maps by NTS sheet.
3. A very detailed series of 1:20,000 scale digital base maps (each file covers about 1.5 townships).

The 1:1 million digital base map used for the pilot project on which this Manual is based was the only digital base map that was affordable and available at the time. Since that time, AAFRD has acquired and simplified the 1:20,000 series of digital base maps for the entire agricultural portion of the province. The result is a

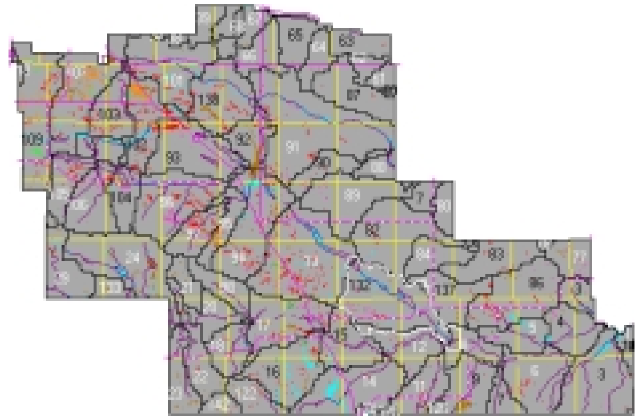


Figure 2. Example of a digital base map for a municipality

product which facilitates combining the many individual 1:20,000 data files into a single digital file for any municipality or area of interest.

It is recommended that the AAFRD digital base map be acquired and used for building the municipal scale digital databases.

The AAFRD data set organizes information into layers by theme (i.e. roads, rivers, etc.) and has also simplified the data in some layers. Only those layers that are essential to analyzing and portraying salinity data need be acquired. The following layers of vector data were found to be useful in the pilot exercise:

1. Political and administrative boundaries (i.e. the municipality's outline, irrigation district boundaries).
2. Section and quarter section lines.
3. Land ownership parcels.
4. Hydrography (rivers, streams and lakes).
5. Irrigation canals and drainage ditches.
6. Primary and secondary highways.
7. Outlines of cities, towns and villages.

Selection of an appropriate map projection is a critical aspect of constructing a digital base map. Municipal base maps produced by combining the AAFRD 1:20,000 digital data sets should adopt the appropriate UTM reference system for all areas that do not straddle the 5th meridian. The Alberta 10TM projection is required for any areas that straddle the 5th Meridian since it is the boundary between the two major UTM zones in Alberta.

Municipal Level Technical Activities

Acquiring a municipal scale salinity map

Many policy decisions and planning activities are based on analysis of the location, extent and pattern of distribution of soil salinity by type.

The municipal salinity maps prepared by AAFRD (e.g. Kwiatkowski et al. 1995) represent the best digital information on salinity by type currently available and should be acquired and registered to the selected base map. If a municipal scale salinity map is not available, arrangements should be made to produce one.

Acquiring a DEM

Digital elevation models (DEMs) are used to define the extent and boundaries of major watersheds and sub-watersheds. They are also used to compute terrain derivatives used to assess potential salinity hazard and to define recharge areas for individual saline seeps.

DEMs of a scale suitable for municipality-sized areas are available for Alberta from the following two sources:

1. The U.S. Geological Survey's Digital Topographic Elevation Data (DTED) 3 arc-second DEM with a variable resolution approximating 90 to 100 m.
2. The Alberta provincial 1:20,000 digital base map DEM with fixed grid resolutions of 25 or 100 m.

Both DEMs may be obtained from AAFRD.

AAFRD has obtained the 1:20,000 DEM data for the entire agricultural area of Alberta. The data have been unpacked from their original format and are available as raw X,Y,Z data stored in DBF type database files and as a regular 100 m grid stored in ArcView 3 Spatial Analyst grid files.

The raw X, Y, Z files need to be interpolated to a regular raster grid in order to be used for the procedures outlined in this Manual. The DEM data were originally collected in the UTM reference system using the NAD27 datum. They may require conversion to the updated NAD83 datum prior to use. The raw DEM contain areas for which elevation data are missing or in error so users will frequently need to locate and fix problems with the 1:20,000 DEM data prior to using it for the purposes described in this Manual.

It is recommended that rural municipalities interested in obtaining a DEM for their area contact AAFRD's Conservation and Development Branch for assistance to identify their needs and to obtain the most recent DEM data for their area of interest. AAFRD can advise them on any measures required to reformat, resurface or clean up the available 1:20,000 DEM data.

Acquiring environmental data

Other environmental data are both highly relevant to understanding soil salinity and widely available for most areas of Alberta.

These data (Table 1) include type and depth to bedrock, surficial geology, hydrogeology and hydro-chemistry, and soils. Most of these data sets are currently available only as hard copy maps and require digital conversion. Other useful data, such as land use and land management, are currently not widely available in any form.

Table 1. Environmental and topographical data sets

Variable	Data Source	Reference
Bedrock Type	Bedrock Geology of Alberta	Green, 1972; contact Alberta Geological Survey (AGS)
Bedrock Depth	Soil reports or hydro-geology maps	various; contact AGS or AAFRD
Groundwater Flow Rates	Hydrogeology maps	various; contact AGS
Groundwater Chemistry	Hydrogeology maps	various; contact AGS
Surficial Geology	Quaternary Geology of Southern Alberta	Shetsen, 1987; contact AGS
Soils	Agricultural Region of Alberta Soil Inventory Database	CAESA Soil Inventory Working Group, 1998
Land Use	Not available	need to collect
Topographical Indices	Compute from DEM	as per this Manual

These data sets need to be acquired, converted into digital form (if not already digital) and registered to the digital base map. Options for conversion include digitizing into a vector GIS or scanning into a raster GIS followed by registration and, optionally, by raster-to-vector conversion.

Most of the data sets of interest were not available in digital form at the time of the initial pilot project. Many have since been converted to digital form or are in the process of being converted. Contact AAFRD for up-to-date information on the availability and status of the required environmental data.

Municipal Level Technical Activities

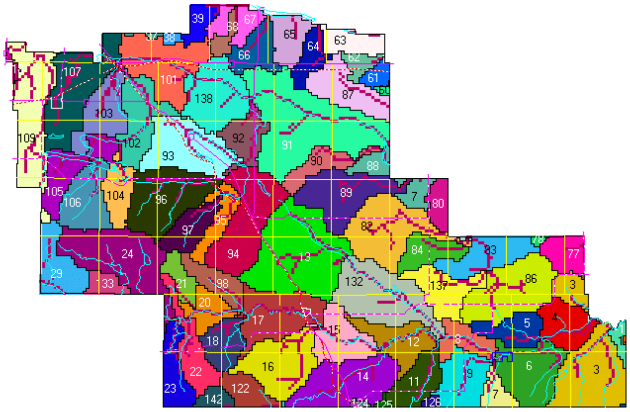


Figure 3. 2D illustration of major watersheds within a municipality

Establish boundaries of natural watershed units

Since watersheds form the basic units for many of the discussions and planning procedures, it is necessary to define the location and extent of all major watersheds within the municipality (Figure 3). Many GIS packages provide routines for computing watersheds from digital elevation data. Arc/Info and ArcView 3, Spatial Analyst are widely used by AAFRD and many rural municipalities for this purpose.

What is a natural watershed unit?

A watershed is an area in which all water flow (surface or subsurface) originating within the area eventually arrives at or passes through a single point, called the watershed outlet.

Manual definition of watersheds

Watershed boundaries were previously delineated manually by locating high points or watershed divides on topographic maps and drawing a line to connect a series of divide points.

All water within the boundary of the watershed is expected to flow within the watershed and to arrive at the watershed outlet prior to leaving the watershed and flowing downstream.

Computerized definition of watersheds

The most common computerized approach to defining watershed boundaries uses gridded sets of elevation data (DEMs). In these programs, the elevation data are organized as a regular grid of rows and columns.

The grid-oriented watershed programs link each cell to one of its neighbors by directing all water flow from each cell into its steepest downslope neighbor. Flow paths are then computed that trace water flow from each grid cell through all of the downslope cells to which it is connected.

Watersheds are computed by identifying all grid cells that contribute water flow to a specified target grid cell. Grid cells selected as target cells may represent locations where water flow terminates as in a depression or undrained lake. Alternatively, for areas with completely integrated stream networks, target cells may be selected just upstream of the junction of two tributary streams in a stream network (as in Figure 3). In either case, all cells that contribute flow to the target cell are considered to belong to the target watershed.

Computer programs for defining watersheds

A number of commercial and public domain computer programs are available to define watershed boundaries by processing digital elevation data.

Programs for computing watersheds from DEM data have become more widely available and easier to use since the pilot project was completed. AAFRD has access to the required capabilities through its Arc/Info, ArcView 3 Spatial Analyst and GRASS GIS programs. Considerable expertise is still required, however, to recognize and deal with problems with DEM data and to obtain the necessary output from the available commercial programs.

It is therefore recommended that trained AAFRD or contract personnel process DEM data to define watersheds.

Municipal Level Technical Activities

Generic description of procedures for defining watersheds

The following steps are typically followed to process a DEM to compute both watersheds and stream network maps for a county-sized area:

Computing initial flow directions and watersheds:

The initial step in processing DEM data to define watersheds is to compute initial flow directions and initial watersheds.

Flow directions are based on the premise that water flows downhill and that water from any given grid cell will flow into the lowest of its eight possible neighbor cells (Figure 4). A 3x3 window is moved over the data set and all neighbors are checked to determine which of eight possible neighbors is lowest in comparison to the center cell of the 3x3 window. A numeric value is recorded for each cell to represent the computed direction of flow.

In the software used for the Pilot, drainage directions were recorded as integer values between 1 and 9. A value of 5 was recorded for cells that had no possibility of flow to cells at the same elevation or lower. Such cells were considered to be pit cells and to represent depressions from which no outward flow was possible.

Initial watersheds were computed by first locating pit cells and then identifying all grid cells that flowed into a pit cell or into a cell previously determined to flow into a pit cell (Figure 5). All cells that were part of flow paths leading to a given pit cell were labeled with a unique number for that cell. All cells with the same label number belonged to the same watershed.

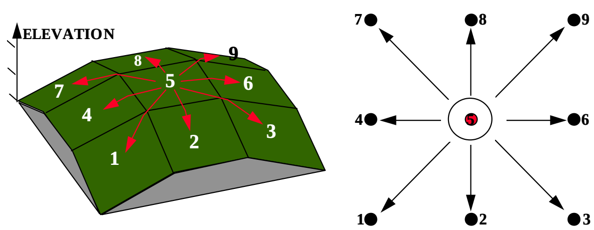


Figure 4. Illustration of numbers assigned to flow directions

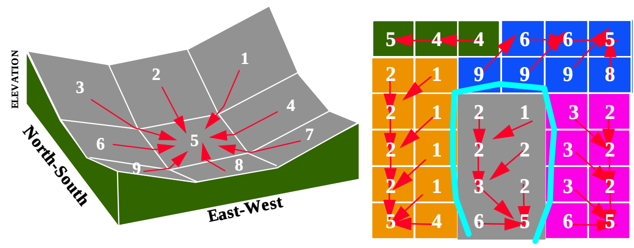


Figure 5. Illustration of pit cells and watersheds

Removing pits to integrate drainage:

Many pits in a DEM are artificial relicts arising from the discrete nature of grid cell sampling schemes. The dimensions of the grid cells (up to 500 m) are often too coarse to capture many of the narrow streams that channel flow from one cell to another. It is therefore often necessary to remove all depressions smaller than a given size to produce an integrated flow regime.

In the Pilot exercise, this was done using a "Pit Removal" option. This option worked by locating pour points where pits over spilled into the lowest downslope watershed (Figure 6). The flow path was then followed from the pour point to the pit center and all flow directions along the path were reversed to point back up toward the pour point. The new flow directions produced an effect like a pond filling up until it overflows at its outlet or pour point.

While pits still may actually exist in a DEM data set, it is necessary to remove all pits in order to simulate a completely integrated drainage network. For other uses (e.g. computing landscape position) a second DEM with not all pits removed may be required.

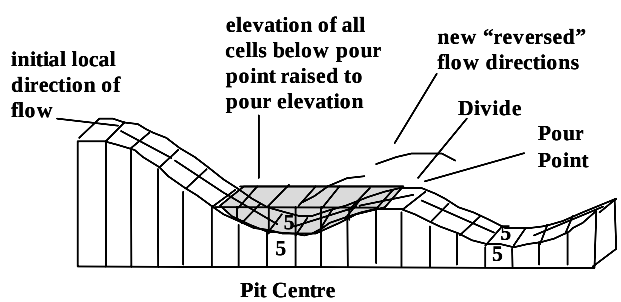


Figure 6. Illustration of pit removal mechanism

Municipal Level Technical Activities

Manually selecting sub-watershed seed points:

Once all pits are removed and flow paths are made continuous, automatic calculation of watersheds starting from watershed outlet seed points produces only a very few large watersheds. This is because drainage is completely integrated and flow paths now all connect to the edge of the DEM.

Typically, it is desirable to sub-divide large continuous watersheds into smaller components more properly called ***sub-watersheds*** (Figure 7). The smaller sub-watersheds are a more convenient size for planning and managing salinity control and other watershed-based programs. The usual case is to define sub-watersheds as the entire drainage area above a specified point, where the specified point is usually located just above a major junction in a stream network (Figure 7). Each tributary in the stream network is therefore assigned to a unique sub-watershed.

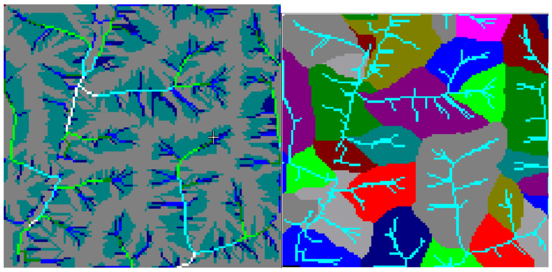


Figure 7. Illustration of flow networks and watersheds

Computing integrated sub-watersheds:

New integrated sub-watersheds are computed based on the list of manually selected seed points. The row and column locations of seed points and their order in the control file both affect the final definition of sub-watershed extent and boundaries.

It is important to select sub-watershed seed points that are on a major flow path and that are upstream from any stream junction of interest. It is also important that the seed points be ordered from lowest to highest elevation along each stream network. This is required to prevent incorporation of sub-watersheds higher in the stream network into those that are lower in the network, which will occur if lower sub-watersheds are computed after higher ones.

Saving watershed and network maps:

Final versions of both the sub-watershed and stream network maps should be saved for use in several analyses related to organizing and presenting salinity data by natural watershed unit (Figure 8).

The stream network map is complementary to the sub-watershed map. It permits comparison of the simulated stream network and the actual network on the base map.

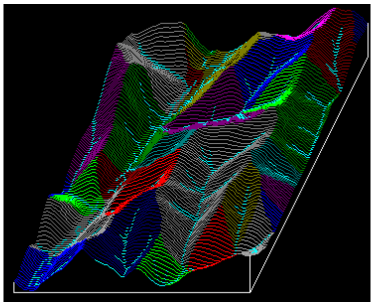


Figure 8. 3D illustration of automatically computed watersheds

Overlaying watershed & network maps:

This final operation uses a transparent overlay function available in most GISs to produce composite illustrations (Figures 7 and 8).

These maps and figures help in visualizing the location and extent of watershed areas and understanding how topography affects the flow of surface runoff. Farmers and landowners can readily see how water flow within a single defined watershed is part of a larger inter-connected system. From this understanding, they can appreciate how everyone in a watershed shares a common interest in managing the quality and quantity of water, and of soils affected by the movement of water, within the watershed.

Municipal Level Technical Activities

Characterize watersheds

Digital data sets of soil, salinity, land use and other environmental and topographical data can be analyzed by watershed. This analysis provides the statistical data required to decide which watersheds most need salinity control measures.

Determining the extent of salinity in a municipality

Factual data on the location and extent of different types of soil salinity are obtained by conducting a ***municipal level salinity survey***.

AAFRD's Conservation and Development Branch (C&D) has developed a methodology for conducting and reporting surveys (Kwiatkowski et al. 1995). If possible, the municipality should arrange to have a municipal level salinity survey carried out by C&D staff.

The municipal salinity map provides a database of the location and extent of eight different salinity types. Such data are fundamental for making decisions about the extent of salinity in an area and whether or not it should be considered a problem.

Analyzing salinity by watershed:

A watershed or sub-watershed is a convenient and logical natural unit within which to analyze and address soil salinity. Surface and sub-surface water flow is influenced by watershed boundaries. Any salinity control efforts within a watershed should have a measurable impact within the watershed and a limited impact outside the watershed. Also, the variety of environmental influences and agricultural practices is less diverse within individual watersheds than within a whole municipality. This facilitates meaningful analysis.

Concentrating efforts within watersheds is desirable for both technical and organizational reasons. From a technical perspective, programs to address soil salinity are most effective when they focus on those areas most affected by soil salinity of a type that can be controlled. From an organizational perspective, concentrating municipal staff time and the commitment of land managers maximizes the effectiveness of salinity programs.

Technical procedures:

Determination of the extent of soil salinity by type by defined watershed requires the following actions:

1. Acquire a municipal-scale soil salinity map in digital format.
2. Acquire a digital elevation model covering the entire extent of the municipality. Options include:
    a. USGS 3 arc-second DTED with a grid spacing of approximately 90 to 100 m,
    b. Alberta 1:20,000 digital base map DEM with a grid resolution of 25 or 100 m.
3. Register both of the above digital data sets to a common projection and reference map.
4. Compute watershed boundaries as per methods described elsewhere in this Manual.
5. Use a grid-based GIS such as Arc/Info GRID, ArcView3 Spatial Analyst, GRASS or Idrisi to:
    a. rasterize the vector soil salinity map to a grid of the same extent and dimensions as the watersheds computed from the DEM (suggested grid size is 25 m),
    b. run a cross-tabulation program to generate statistics on the extent of each type of salinity within each defined watershed area.
6. Import the statistics on the extent of each salinity type in each watershed into a relational database management system (DBMS).

Municipal Level Technical Activities

Determining the extent of land use by type within a municipality

Factual data on the location and extent of different types of land use and land management in a municipality are not generally available. New data can be obtained, if desired, by conducting a ***municipal level land use survey***.

A method for classifying and mapping agricultural land use was developed for the Pilot Project by County of Warner Agricultural Service Board staff in collaboration with C&D (Wentz and Heggie 1995). It considers agricultural land use in terms of soil moisture consumption characteristics (Table 2). The method was applied in a single test watershed (Figure 9) and has not yet been extrapolated to a county-sized area.

Table 2. Provisional legend for mapping land use

Land Use Class	Assumed Water Consumption Behavior Relative to Lowering the Water Table
Perennial Forage	Most efficient consumer of moisture. Roots extend 5 to 6 m deep. Active consumer of soil moisture from early spring to late fall. Can extract water from the top 1 m and from the deeper water tables.
Continuous Crop	Not as effective as perennial forage but the most effective of all annual cropping methods. Compared to perennial forage, season for water extraction is shorter (because crops do not become effective water consumers until well established), and depth of rooting is less than 1 m.
25% Fallow	The greater the extent of fallow, the greater the assumed increase in moisture storage and associated rise in water table levels.
33% Fallow	The greater the extent of fallow, the greater the assumed increase in moisture storage and associated rise in water table levels.
50% Fallow	The greater the extent of fallow, the greater the assumed increase in moisture storage and associated rise in water table levels.
100% Fallow	The greater the extent of fallow, the greater the assumed increase in moisture storage and associated rise in water table levels.
Saline Field	Fields mapped as mostly saline offer little scope for lowering water tables due to difficulties in seeding and establishing crop cover that will consume moisture and lower water tables.
Irrigated Field	Reducing irrigation or more efficient use of irrigation water may reduce groundwater recharge.
Water Body	Planting water-loving vegetation, like willow trees, around the water body may lower the water table.

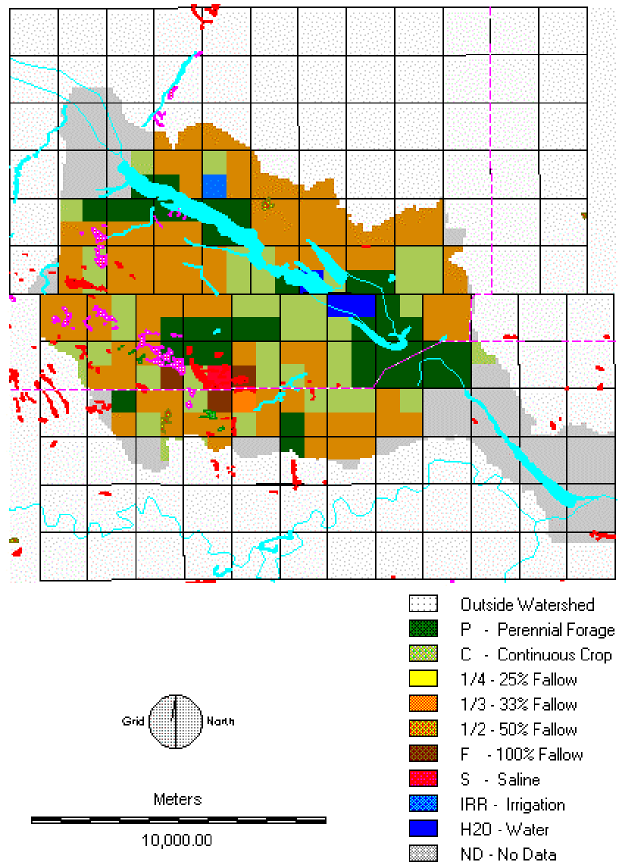


Figure 9. Illustration of a land use map for a watershed

Analyzing land use by watershed:

The extent of each defined land use class by watershed can be computed using procedures similar to those discussed previously for assessing extent of salinity by type by watershed. These data can help to identify watersheds with management practices that can be changed to reduce salinity.

Municipal Level Technical Activities

Determining the extent of soil capability within a municipality

Factual data on the location and extent of different soil capability classes in a municipality can be extracted from published soil survey maps or digital databases. Municipal scale ***soil surveys*** with all soils rated in terms of agricultural capability are available as paper maps for many rural municipalities in Alberta.

Recently, the Agricultural Region of Alberta Soil Inventory Database (AGRASID) was released (CAESA - Soil Inventory Project Working Group 1998). It provides a consistent and uniform digital soils database for the entire agricultural portion of Alberta. It is suggested that AGRASID be used as the principal source of municipal-scale soil information. As of writing, soil capability ratings had not yet been associated with each of the map units in the new digital database. Users should contact AAFRD to obtain copies of AGRASID and to determine if updated soil capability ratings have been assigned to all map units. If not, it is relatively simple to assign each soil map unit to a capability class manually.

Both digital and digitized hard copy maps need to be registered to the municipal base map. This process can reveal discrepancies when the digital base map used for the municipality differs from that used to compile the original soil map.

Analyzing soil capability by watershed:

The purpose of collecting and digitizing soil data for a municipality is to assist in identifying those watersheds with the greatest extent of higher capability soils. It is assumed that greater benefit is achieved by addressing soil salinity in areas of higher capability soils than in areas of lower capability soils.

Characterizing environmental factors within a municipality

Secondary source environmental data can be used to study and quantify relationships between these data and known locations of soil salinity by type. The procedure recommended here involves cross-tabulating the extent of salinity by type against each map class of each secondary source environmental map.

Analyzing environmental factors:

Relationships between salinity and other environmental data are analyzed for two reasons:

1. To establish and improve understanding of the type and strength of relationships between soil salinity and environmental factors thought to affect salinity.
2. To use the improved quantitative understanding of these relationships to identify other locations similar to those at which salinity currently occurs.

The first of these turns raw data into quantitative local knowledge. The second uses the improved knowledge to predict the most likely locations for potential future salinity of each type. A detailed explanation of procedures used to analyze relationships between soil salinity and other environmental data is given in the Section *Major Watershed Level Technical Activities*.

Determining potential salinity hazard within a municipality

Assessment of the potential salinity hazard (PSH) arising from changes in climate or land use is not as direct as mapping the present extent of visible soil salinity. A method developed expressly for the Pilot Project is described in the Section *Major Watershed Level Technical Activities.*

The same method may also be applied to an entire municipality to identify all locations with environmental and topographical characteristics similar to those that exist at locations of known salinity. Knowledge of PSH may be used in predicting where salinity may expand and the extent of vulnerable areas.

Municipal Level Technical Activities

Prioritize major watersheds within a municipality

Prioritizing major watersheds ensures that technical and organization efforts to address salinity are concentrated where they will do the most good and have the greatest chance of succeeding.

The first factor considered in prioritization is based on the assumption that ***some salinity types*** (Table 3) ***are more likely to be controlled than others***. Saline seeps considered to have the greatest likelihood of successful remediation are those in which a significant portion of the groundwater flow contributing to the seep originates from local recharge in the immediate vicinity of the seep.

The second factor considered in prioritization is ***land use***. It is assumed that some types of land use or land management are more likely to result in increased moisture use and reduced groundwater recharge than others (see Table 2). A higher priority is assigned to watersheds with extensive areas of land use of types that, if changed, would likely result in higher water use and reduced recharge. Clearly, if a watershed is already almost entirely seeded to perennial forages, there is little scope for changing to practices that could further increase consumption of soil moisture. Conversely, areas with extensive amounts of fallow land offer the possibility for reducing recharge by converting some of the fallow to high-water-use crops.

The final assumption is that efforts to control or reduce salinity should be concentrated in ***areas of higher capability soils***. The basis for this assumption is that the potential return on actions undertaken to reduce salinity is likely to be greater for high capability soils than for soils with a lower agricultural capability (Table 4).

No attempt is made to explicitly link each saline seep in each watershed to an associated class of soil capability. Rather, it is assumed that the greater the extent of high capability soils in a given watershed, the greater the likelihood that a reduction in salinity will occur on high capability soils, thereby increasing their productivity.

Another factor that could be added is to consider ***public opinion***. The factor would be based on the degree to which landowners and managers consider salinity to be a problem and their willingness to address salinity.

Table 3. Relationship between salinity type and assumed groundwater flow

Salinity Type	Assumed Groundwater Recharge Source Area & Likelihood of Responding to Controls
Non-saline	Not applicable
Contact	Most flow originates from the immediately upslope local recharge area. High likelihood of response to agronomic controls.
Outcrop	Most flow originates from regional recharge into the water-bearing aquifer at some distance from the outcrop site. Moderate likelihood of response to structural controls.
Artesian	Most flow originates from regional recharge into the water-bearing aquifer at some distance from the artesian seep. Moderate likelihood of response to structural controls.
Slough Ring	Most flow originates from surface runoff and local subsurface groundwater recharge into the slough. Moderate likelihood of response to agronomic controls.
Coulee Bottom	Flow originates from both local surface runoff and discharge of regional flow from water-bearing layers that outcrop along the coulee. Low likelihood of response to any controls.
Depression Bottom	Much of the flow originates as surface runoff from immediately adjacent upslope areas. Moderate likelihood of response to agronomic or structural controls.
Irrigation Canal	Most of the flow originates as leakage from canals. High likelihood of response to structural controls.
Irrigation/ Natural	Flow originates from both natural groundwater sources and from excess irrigation or canal seepage in irrigated areas. For natural water sources, moderate likelihood of response to agronomic controls. For irrigation water sources, high likelihood of response to structural controls.

Table 4. Assumed relationship between soil agricultural capability class and desirability for reduction of salinity

Capability Class	Assumed Desirability of Reclaiming Soil	Index Value
1	Soil would benefit most from remediation	1.0
2	Benefit nearly as great as for class 1 soil	0.9
3	Benefit nearly as great as for class 2 soil	0.8
4	Benefit nearly as great as for class 3 soil	0.7
5	Only 1/2 as likely as class 1 soil to benefit	0.5
6	Very little benefit from remediating salinity	0.3
7	Hardly any benefit from remediating salinity	0.1

Municipal Level Technical Activities

Technical procedures for prioritizing watersheds

This section describes the technical procedures for prioritizing major watersheds within a municipality in terms of their need for, and likely benefit from, salinity control measures.

The technical procedures for computing ratings and assigning rankings to each watershed mirror those described in greater detail in the Section *Major Watershed Level Technical Activities*.

The first step is to construct a database that contains either factual data, or a reasonable estimate, for the extent of each class of salinity, land use and soil capability within each major watershed or sub-watershed (Table 5).

The second step is to calculate a ***salinity factor***, a ***crop factor*** (land use) and a ***soil factor*** (soil capability) for each watershed.

Factor scores are computed as weighted averages of the extent of each class of each variable of interest (e.g. salinity type) multiplied by an assigned index value. Index values vary between 0 and 1. For example, a high salinity index value indicates that a particular salinity type is likely to respond to control measures. Similarly, a high index value for land use indicates that changing that type of land use has a high potential for reducing recharge and lowering the water table.

The factor scores should be ***standardized*** into a range of 0 to 100 to compensate for the low absolute values for the salinity factor that result from saline seeps only covering a very small percentage of any given watershed. An overall ***watershed rating*** value should be computed by cross multiplying the three factor scores for each watershed and taking the cubed root of the result. Watershed ratings; therefore, also fall into the range of 0 to 100. Higher ratings indicate a higher overall need for, and suitability for, application of salinity control measures.

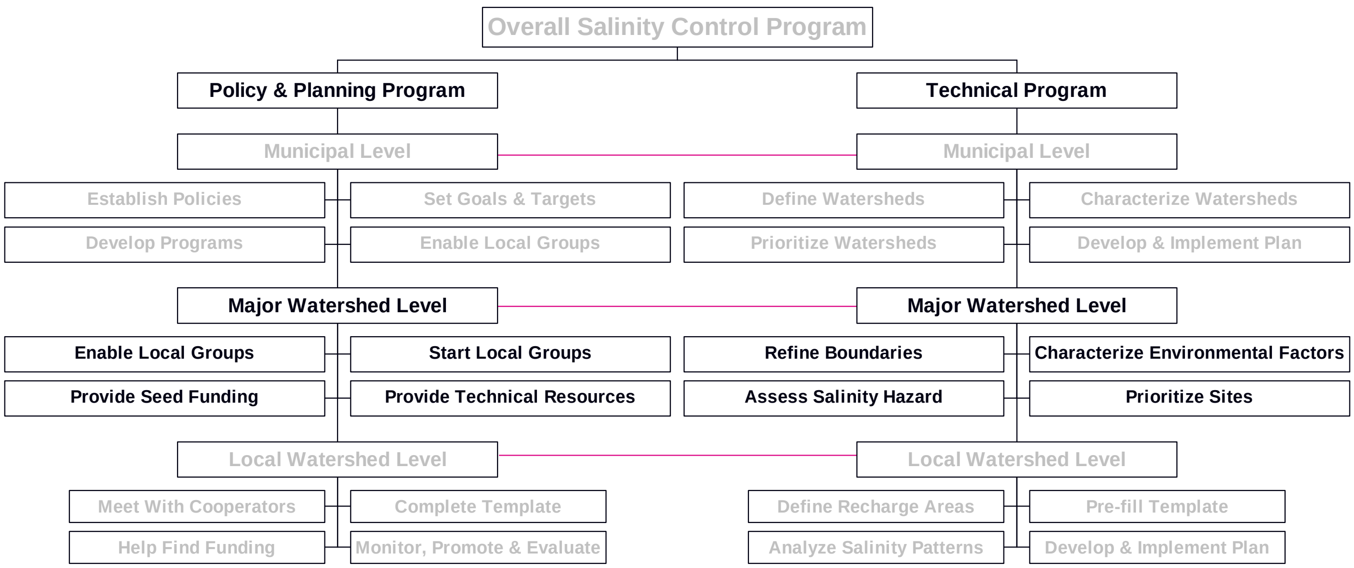
Watershed ***rank*** is computed by sorting the database in descending order by rating, by salinity factor, by crop factor and by soil factor. The order of the watershed in the sorted database becomes the watershed's rank value.

A custom program was used in the Pilot to process the tabular data to compute factor scores watershed ratings and watershed ranks. A similar result can be achieved using the scripting capabilities of commercial GIS or database packages.

Table 5. Schematic illustration of the structure and content of the database used to prioritize watersheds

Watershed Attribute (Field Name)	Index Value	Data Value
Watershed ID Number		132
Size (ha)		14045.0
Non-saline (ha)	0.0	13234.8
Contact (ha)	1.0	106.6
Outcrop (ha)	0.6	0.0
Artesian (ha)	0.6	15.0
Slough Ring (ha)	1.0	0.0
Coulee Bottom (ha)	0.1	678.1
Depression Bottom (ha)	0.8	10.4
Irrigation Canal (ha)	0.5	0.0
Irrigation/Natural (ha)	0.6	0.0
Salinity Factor		
Perennial Forage (ha)	0.0	
Continuous Crop (ha)	0.2	
25% Fallow (ha)	0.4	
33% Fallow (ha)	0.6	
50% Fallow (ha)	0.8	
100% fallow (ha)	1.0	
Saline Field (ha)	.01	
Irrigated Field (ha)	0.7	
Water Body (ha)	0.0	
Crop Factor		
Soil Capability Class 1 (ha)	1.0	0.0
Soil Capability Class 2 (ha)	0.9	0.0
Soil Capability Class 3 (ha)	0.8	
Soil Capability Class 4 (ha)	0.7	
Soil Capability Class 5 (ha)	0.5	
Soil Capability Class 6 (ha)	0.3	
Soil Capability Class 7 (ha)	0.1	
Soil Factor		
Watershed Rating		
Watershed Rank		

Major Watershed Level Module



Major Watershed Level Policy and Planning

Policy and planning objective

The main objective of programs to address salinity at the level of a major watershed or sub-watershed is to help landowners and managers to work together to safeguard the long-term agricultural productivity, environmental health and economic viability of their operations. This is done by minimizing the adverse impacts of actual or potential soil salinity on their soil and water resource base.

Policy and planning activities

The following activities are required to support the major watershed level policy and planning objective:

Formation of watershed groups

Formation of watershed groups requires both an enabling legal framework and stimulation of interest and activity.

Local, grassroots groups are effective because decisions about whether salinity is a problem in a watershed and how to address it are best made by the affected landowners and land managers. Such decisions require input in the form of both ***facts*** and ***opinions***.

Land managers need to know the location and extent of salinity within the watershed, the spatial distribution of that salinity and, if possible, whether the extent of the salt-affected area is expanding or contracting.

Input in the form of opinion is important to assess the degree to which land managers in the watershed consider salinity to be a problem and their willingness to adopt and fund measures to address salinity.

Establishing policies, goals and targets

Once relevant facts and opinions are known, it is up to landowners in a watershed to decide if salinity is a concern in their watershed and, if so, what should be done about it.

If soil salinity is judged to be a concern, then one of the first steps is to establish ***a watershed-based policy*** on salinity. Policies define a general consensus on whether soil salinity is a concern and, if so, what should be done to address it.

Specific ***goals*** and ***targets*** should reflect the intent of the general policy, but also need to be feasible and based on realistic assessments of known data on salinity type and extent. The importance of specific goals is that they are measurable and provide a means of determining whether policy objectives are being achieved.

Identifying funding mechanisms

Adoption and ongoing maintenance of programs for salinity control require secure, sustainable funding.

Local watershed scale salinity control groups may wish to involve municipal, provincial and/or federal staff to help identify funding alternatives and apply for funding. Beever (1998) outlines possible funding options.

Establishing specific plans & programs

Specific plans and programs provide the means of realizing the goals and attaining the targets set in support of watershed policies.

This Manual documents mechanisms for organizing and delivering plans and programs by watershed area. Information should be collected or collated by the agricultural fieldman for presentation to landowners and managers in the watershed.

Formal watershed plans need to be prepared that specify what actions are to be undertaken, where they will be implemented, by whom, when, how, and how they will be financed. Watershed salinity control plans must also state how success will be measured, by whom and when.

Major Watershed Level Technical Activities

Technical objective

The main objective of technical activities at the major watershed level is to provide necessary input data and support for decisions or actions undertaken by local landowners to establish policies or develop and implement watershed level plans for addressing salinity.

Technical activities

The following technical activities are required to support the watershed level policy and planning activities.

1. Obtain the required data, specifically:
    a. a suitable base map,
    b. a comprehensive salinity map,
    c. a high resolution (25 m) DEM,
    d. secondary source environmental data.
2. Characterize the watershed by:
    a. refining the definition of the location and extent of current watershed boundaries,
    b. summarizing and illustrating data on the present location and extent of individual saline seeps in the watershed,
    c. analyzing the distribution of present salinity in terms of environmental and topographical controls.
3. Compute an assessment of the potential for future change in salinity within the watershed.
4. Develop a specific watershed plan including:
    a. a set of goals or targets for control or reduction of salinity in the watershed,
    b. a detailed list of priority saline sites within the watershed that require and would benefit from control measures,
    c. procedures for planning and implementing the planned controls at specific sites,
    d. an organizational structure stating who is responsible for doing what, where and when,
    e. a mechanism for funding salinity control measures within the watershed.

Acquire the GIS digital database

Most of the digital data required to support policy development and planning activities in a major watershed are likely to be already available from municipal level activities. In most cases, acquisition of the required database will simply involve extracting a subset from the municipal level data sets.

Digital base map

The procedures defined for this Manual do not require highly detailed base map information. For this reason, the simple, generalized base map used at the municipal level is sufficient for use at the watershed level. It may be necessary to add the quarter section boundaries if these are not in the digital base map. For maximum utility, the digital map layer of quarter section boundaries should be linked to an associated database identifying landowner names and addresses.

Field checked salinity map

The municipal scale salinity map prepared using AAFRD methods forms the initial basis for information on the location and extent of salinity within a watershed. This information should be verified by a detailed field inspection.

Field checking will usually require less than one day per watershed and will often result in few or no changes to the original data. It does; however, confirm all mapped seeps and identifies any that may have been missed.

Field checking can also provide an opportunity for landowners and managers to participate by touring the watershed and gaining an appreciation for the extent of various salinity types in the watershed. This can be a powerful tool for creating interest among potential participants and for providing them with educational and background materials on salinity.

Increasingly, field tours will likely make use of digital maps of salinity and base features displayed on a portable computer linked to a global positioning system (GPS) receiver. Such systems can play a valuable role in creating interest by allowing field tour participants to match what they see on the ground to the computer map.

Major Watershed Level Technical Activities

High resolution (25 m) DEM

A DEM with a grid resolution of 100 to 500 m may be used at a municipal level but this is inadequate for many of the activities and analyses at the watershed level. The 25 m DEM data sets are the best choice for use at a major watershed level.

Due to potential problems with edge matching and registration of multiple 1:20,000 DEM data sets, the 25 m DEM for each watershed should be extracted from a single combined file covering the entire County or MD. AAFRD personnel should complete this task. There should be no need to register the DEM to the base map if both originated from the Alberta 1:20,0000 digital base map and both have the same projection and datum.

Available secondary source data

Most secondary source data required at a watershed level will likely have been compiled at a municipal level. The watershed level data may simply be obtained by extracting a window from the municipal data.

Additional data may be available and relevant for a particular watershed. In such cases, procedures described for importing and registering data at a municipal scale should be modified as required to import and register the data for a specific watershed.

Watershed boundaries

It is assumed that the best available DEM (the 25 m 1:20,000 data) will be used for all analyses at all scales. Thus, the watershed boundaries computed at the municipal level should require no further changes for use at the watershed level.

In the Pilot exercise, problems in acquiring, unpacking, combining and processing the 25 m 1:20,000 DEM data required the use of two separate DEM data sets. A 500 m grid was used to represent terrain at the municipal-scale and the 25 m DEM was used at the major watershed scale. It was therefore necessary to re-compute a more detailed boundary for each new major watershed area using the 25 m DEM data. This is no longer necessary due to growth in the processing capabilities of available GIS software and due to AAFRD's efforts to facilitate unpacking and mosaicing of the 1:20,000 DEM data set.

Characterize the watershed

The purpose of characterizing the watershed is to provide factual data on salinity and factors that affect salinity to help landowners and managers develop appropriate policies, programs and plans within their watershed.

Once watershed boundaries are finalized, the digital data sets of soil, salinity, land use and other environmental and topographical data can be analyzed for each major watershed. This provides statistical data to decide which sites in the watershed most require measures to control salinity. It also helps improve and quantify scientific understanding of how local environmental conditions affect salinity.

Illustrating salinity in the watershed

A map showing the location and extent of each known saline seep in a watershed can be a useful starting point for discussions of salinity among the watershed's landowners and operators (Figure 10). The map allows landowners and operators to locate all saline areas in their watershed, to identify the salinity type at each location and to relate the occurrence of salinity to legal locations and to landscape position.

To produce this map, a municipal-scale salinity map prepared by AAFRD needs to be imported into whatever GIS is being used to manage the spatial data. Each polygon outlining the location of a saline seep must be assigned a unique identification number. Each polygon must also be labeled as belonging to one of the eight types of salinity recognized by the AAFRD salinity-mapping program.

A map similar to that in Figure 10 is then prepared by overlaying vector layers for salinity and some base map information (e.g. rivers, roads, section lines) along with the watershed boundary (white line in Figure 10) onto a suitable backdrop image. A color image of the DEM was used in Figure 10, but any image backdrop, or even no image, could be used.

Major Watershed Level Technical Activities

Tabulating salinity within a watershed

The GIS salinity data should be cross-tabulated against a map of sections or quarter sections to produce a tabular summary of salinity by type in each section or quarter. The statistical summary (Table 6) can be used to explicitly identify the types and amounts of salinity affecting particular quarter sections of interest.

Cross-tabulation requires that each salinity polygon have a unique identification number (Site # in Table 6). It also requires the presence of a topologically structured digital map layer showing all quarter section boundaries. This layer must also have a unique number assigned to each quarter section and an associated database containing a description of the legal location of each quarter.

Analyzing environmental factors

Many conservation manuals do not provide explicit instructions on how to use or interpret the environmental factors affecting the characteristic of interest (e.g. salinity, wind erosion). Manuals that do provide explicit instructions may only give general "*rules of thumb*" such as "salinity is most likely to occur in lower landscape positions" or "salinity is more likely to occur in areas with shallow bedrock". There is no guarantee that these general rules apply to the particular conditions in a specific watershed.

A quantitative method of analyzing actual local relationships between salinity and the environmental factors thought to influence salinity was developed for this Manual. The method involves analyzing the known distribution of salinity against the mapped distribution of relevant environmental and topographical variables. The analysis provides quantitative insight into whether, and how, the distribution of salinity is influenced by the mapped environmental factors. The method is best explained using an example.

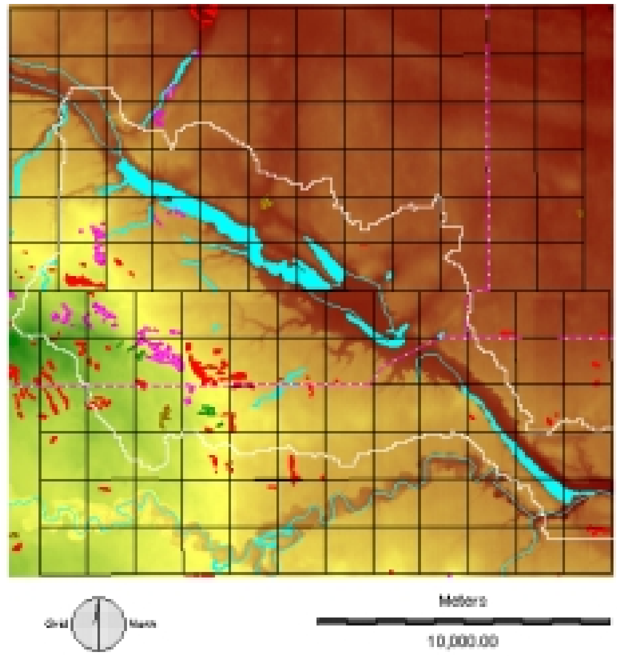


Figure 10. Example of a map showing the location and extent of salinity by type by quarter section within a major sub-watershed

Table 6. Statistical summary of extent of salinity by type (ha) by quarter section within a major sub-watershed

Site #	Legal Location					Known Salinity By Type & Total Salinity (ha)									
Site Number	Qtr	Sec	Twp	Rng	Mer.	Contact Salinity	Outcrop Salinity	Artesian Salinity	Slough Ring	Coulee Bottom	Depress Bottom	Irrig Canal	Irrig Natural	Total Salinity	Total Non-Saline
1															
2															
3															
4															

Major Watershed Level Technical Activities

An example analysis:

Consider the case of bedrock geology, which is generally acknowledged to influence the development of salinity (Figure 11). A cross-tabulation of the digital maps of salinity type against bedrock type within a given watershed produces a listing of the extent (ha) of each salinity type for each bedrock formation on the secondary source map.

The data can be summarized (Table 7) to identify relationships between bedrock type and salinity. The row totals (right column) represent the percent distribution of the four bedrock types mapped in the major watershed, while the column totals (bottom row) represent the distribution of each salinity type (and non-saline areas) expressed as a percent of the total watershed area. The individual column values represent the percent distribution of each salinity type by bedrock type.

The cross-tabulation data can be analyzed to develop a quantitative understanding of the actual relationships between salinity and bedrock type in the watershed. They may reveal relationships between bedrock type and the occurrence of any salinity, or of a specific salinity type.

In this example, the percent distribution of non-saline areas by bedrock type (column 2) is about equal to the overall percent distribution of each type of bedrock in the watershed (column 8). By subtraction, the percent distribution by bedrock type of all types of surface salinity taken together would also be about equal to the percent distribution of each bedrock type. This leads to the conclusion that there is no clear relationship between bedrock type, based on the available bedrock map, and the overall presence or absence of salinity.

The data do; however, support the conclusion that a relationship exists between bedrock type and frequency of occurrence of different types of surface salinity. For example, more than 55% of the contact salinity in the sub-watershed overlies the Foremost Formation despite the fact that the Foremost Formation only occupies 14% of the total sub-watershed area. This indicates that contact salinity is more likely to occur in areas underlain by the Foremost Formation than in areas underlain by any other types of bedrock.

Conversely, coulee bottom salinity occurs preferentially in areas overlying the lower (13.7%) and upper (78.6%) Milk River Formations when compared to the respective proportions of these two types of bedrock within the sub-watershed (5.8% and 50%).

In this example, it can be concluded that; overall, the type of bedrock does not exercise any significant control over whether salinity will, or will not, occur at any given site within the watershed. However, bedrock type does clearly exercise some control over salinity type.

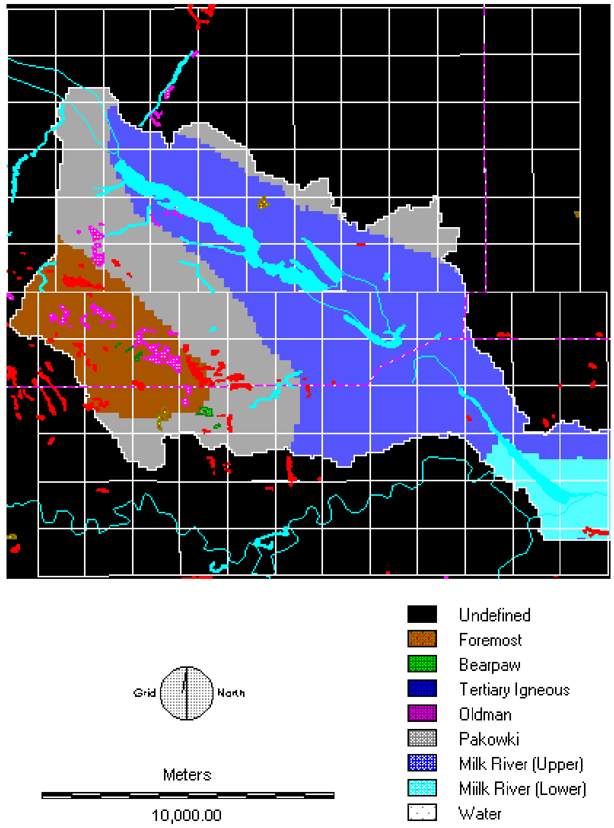


Figure 11. Illustration of the spatial relationship between salinity and bedrock

Table 7. Extent of salinity type (ha) by bedrock formation

Bedrock Formation	Non-Saline	Contact	Outcrop	Artesian	Coulee	Depression	% Watershed
Foremost	14.00	55.52	69.83	37.11	1.09	31.20	14.32
Pakowki	30.99	34.54	23.21	62.89	6.64	25.35	29.86
Upper Milk River	49.51	4.29	6.95	0.00	78.58	43.45	50.00
Lower Milk River	5.50	5.65	0.00	0.00	13.70	0.00	5.82
% Watershed	93.31	0.96	0.85	0.10	4.63	0.15	100.00

The observed relationship may reflect an actual linkage or an accidental association between bedrock and salinity. It is more likely that salinity is related to an attribute such as relative landscape position or depth to bedrock and that the depth to, and type of bedrock underlying an area, is also related to relative landscape position (e.g. Milk River Formation exposed in deeply incised valleys). In such a situation, there is no causal relationship between the type of bedrock and surface salinity, only a similar relationship between landscape position and both type of salinity and type of, or depth to, bedrock.

Environmental & topographical controls of interest:

Any number of available environmental or topographical data sets may be subjected to a quantitative analysis similar to that described. The Pilot study identified and analyzed 12 different environmental and topographical data sets (Table 8). Other data sets may be both available and relevant for analysis in other watersheds. The same basic technique may be applied to any thematic data set to assess the kind and degree of association between mapped salinity and assumed environmental controls.

Table 8. Environmental and topographical data sets

Variable	Data Source	Reference
Bedrock Type	Bedrock Geology of Alberta	Green, 1972; contact Alberta Geological Survey (AGS)
Bedrock Depth	Soil reports or hydro-geology maps	various; contact AGS or AAFRD
Groundwater Flow Rates	Hydrogeology maps	various; contact AGS
Groundwater chemistry TDS	Hydrogeology maps	various; contact AGS
Groundwater Chemistry Sulfate/Carbonate	Hydrogeology maps	various; contact AGS
Surficial Geology	Quaternary Geology of Southern Alberta	Shetsen, 1987; contact AGS
Soils	Alberta Soil Survey maps and reports	various; contact AAFRD publications
Land Use	Not available	collect as needed
Landscape Position (relative relief)	1:20,000 DEM	MacMillan, 1996b
Slope Gradient	1:20,000 DEM	Eyton, 1991
Slope Azimuth	1:20,000 DEM	Eyton, 1991
Profile Curvature	1:20,000 DEM	Eyton, 1991
Plan Curvature	1:20,000 DEM	Eyton, 1991

Assess the potential salinity hazard (PSH)

The occurrence of readily visible salts on the soil surface varies considerably in time and space. Salts present at a given location at one time may not be visible at a future date. Similarly, areas free of visible salts on a given date may later develop visible salt accumulations.

This temporal variation raises the question of whether it might be possible to identify areas susceptible to ***future development*** of visible surface salinity based on patterns evident in the present distribution of visible salinity. This can be a powerful tool to help landowners visualize how extensive future salinity might become if measures are not taken to control it.

Methods for assessing PSH

The concept of predicting ***potential salinity hazard (PSH)*** was developed specifically for the Pilot Project. It uses tabulations of the extent of readily visible salinity of a specific type within each class of the mapped characteristics in several widely available secondary source maps.

The cross-tabulations are used to assess the extent to which secondary source map classes are related to the presence or absence of observed and mapped surface salinity of each type. The underlying assumption is that these cross-tabulations can reveal spatial dependencies between secondary source data and observed salinity. This approach has been termed ***evidential reasoning*** (Aspinall and Veitch 1993).

Two different methods were examined: ***Bayesian logic*** (Skidmore et al. 1996; Aspinall and Veitch 1993) and suitability analysis using ***multi-criteria evaluation (MCE)*** (Eastman et al. 1996). The MCE method was used to produce the results reported here (Figure 12). Elements of the Bayesian approach were adopted to establish values for ***conditional probabilities*** that visible surface salinity of a specific type will occur given a particular piece of evidence (class of data on a secondary source map).

The MCE method provides a clear indication of the kind and strength of relationships between different types of salinity and each class of data portrayed on a secondary source environmental map. The method is systematic, quantitative and scientifically valid. The available evidence is used to develop and apply a rule base that can be used to identify areas similar to those at which salinity is known to occur.

Major Watershed Level Technical Activities

Application of the MCE method – an example

The steps of the MCE method are outlined in the following example to compute and illustrate PSH:

Identify environmental factors of interest:

Environmental data are selected from widely available secondary source maps thought to exercise some control over the distribution of visible surface salinity (see Table 8).

Establish conditional probabilities:

A systematic procedure is used to convert the qualitative data of most of the secondary source maps (e.g. bedrock type, shown in Figure 13) into quantitative values that express a meaningful relationship between each map class and each salinity type within a major watershed (see Table 9).

The procedure computes conditional probabilities of finding visible surface salinity of each type mapped in the major watershed based on evidence extracted by cross-tabulating the extent of each salinity type against the extent of each class on each secondary source map.

The likelihood of a hypothesis (H_a) occurring given a piece of evidence (E_b) is thought of as a conditional probability (e.g. $P(H_a|E_b)$). For example, the probability of finding visible contact salinity (H_a) given a particular depth to bedrock (i.e.< 5 m, E_b) is estimated by dividing the total known extent of contact salinity (ha) overlying areas of shallow bedrock (< 5 m) by the total mapped extent of shallow bedrock (ha) in a sub-watershed of interest.

The conditional probabilities represent a restructuring of the previously discussed cross-tabulation data (Table 9). Each table consists of a list of the different classes of data defined by the map of interest (left column) cross-referenced to a list of the salinity types (including non-saline areas) mapped in the major watershed of interest (top row).

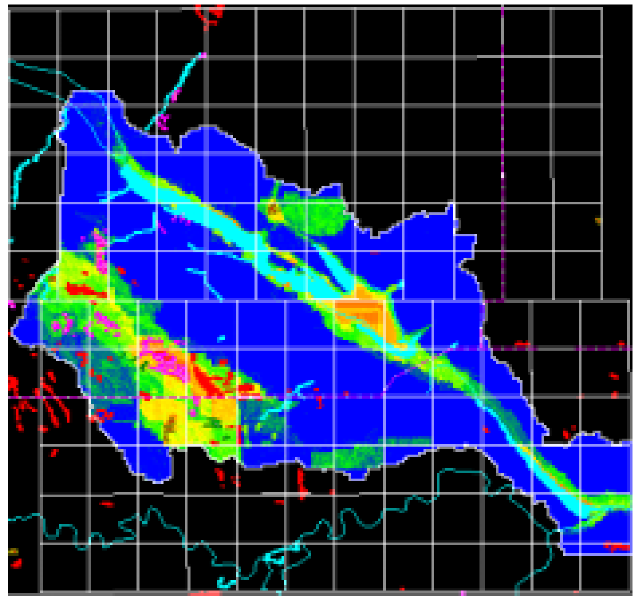


Figure 12. Potential salinity hazard with actual salinity overlaid

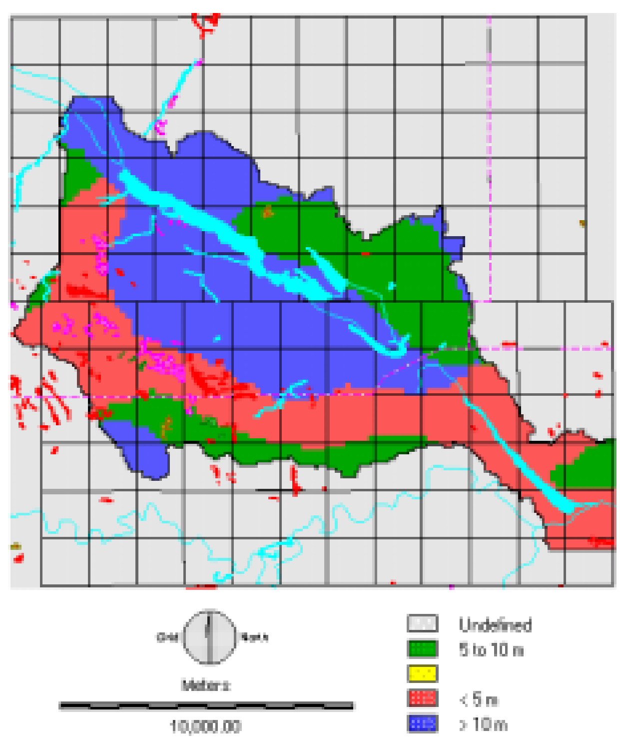


Figure 13. Spatial relationship between depth to bedrock and salinity by type

Table 9. Conditional probabilities for depth to bedrock versus salinity type

Depth to Bedrock	Non-Saline	Contact	Outcrop	Artesian	Coulee	Depress	% W'shed
< 5 m	92.56	2.35	2.19	0.20	2.70	0.00	33.75
5 - 10 m	96.81	0.43	0.08	0.15	1.91	0.62	23.75
>10 m	91.95	0.15	0.22	0.00	7.68	0.00	42.50
% W'shed	93.31	0.96	0.85	0.10	4.63	0.15	100.00

For the present purposes, a single table of conditional probabilities is presented for the environmental variable ***depth to bedrock*** (Table 9). Similar tables are required for each environmental variable of interest.

The right-most column (column 8) indicates the percent extent of the major watershed occupied by each class of mapped data for each map. The bottom row indicates the percent extent of the major watershed occupied by each salinity type (including non-saline areas) irrespective of the map classes on the thematic map. This row gives the ***prior probabilities*** for presence or absence of each salinity type within the entire map area. These are equivalent to ***subjective probabilities*** as defined by Aspinall and Veitch (1993).

The intersections of salinity type (columns) against map class (rows) indicate the percent extent of observed salinity of a specific type within all areas of the thematic map of a given class. For example, 2.35% of the total extent of shallow bedrock (< 5m) is occupied by saline seeps mapped as contact salinity. Based on these data, it can be assumed that any area underlain by shallow bedrock has 2.35 chances in 100 of exhibiting contact salinity for a conditional probability of salinity of 0.0235.

Produce standardized factor score maps:

The conditional probabilities (see Table 9) are used to re-code the original qualitative class maps into quantitative numerical maps on a ratio scale. A separate map is made for each salinity type (five types in this example) for each original secondary source map (12 maps in this example) for a total of 60 maps. The class codes of the original maps are replaced by the conditional probabilities computed for each code for each salinity type (data not shown). The maps of conditional probability are then standardized (scaled) into the range 0 to 255 (or 0 to 100) such that the highest probability on any given map is always scaled to 255 (or 100) and the lowest probability to 0. Thus all maps are comparable and the result map from any linear combination is also always scaled from 0 to 255 (or 0 to 100).

Develop factor weights:

Some of the original secondary source maps will always possess a stronger ability to predict salinity by type than others. This predictive capacity is captured by the absolute values of the conditional probabilities computed for each class of secondary source data for each type of salinity. Standardization removes the differences in relative predictive capacity inherent in the absolute values for conditional probabilities**.** Factor weights are therefore needed to place more weight on those secondary source maps that show a stronger relationship to mapped salinity of a specific type than do those where the relationship was weak.

Factor weights are computed separately for each type of secondary source map for each type of salinity using procedures based on the ***WEIGHT*** module in Idrisi (Eastman 1993). This procedure requires users to input pairwise comparisons of the relative importance of each factor map to every other factor map. It then computes an overall ***mean factor weight*** for each map that is consistent with all individual paired comparisons.

Normally, the paired comparisons represent subjective estimates of the importance of one data source relative to another. The present procedure uses a quantitative and systematic method to determine appropriate values for pairwise comparisons of the individual factor maps. It is based on evaluations of the relative strength of association between extent of salinity by type and extent of map classes on the secondary source maps as expressed by the computed conditional probabilities (e.g. as in Table 9).

One measure of the discriminating power of each conditional probability map is computed as follows. Compute the absolute value of the numerical difference between the overall subjective probability that salinity of a given type occurs anywhere on the map (bottom row of each column) and the individual conditional probabilities that salinity of that type occurs in each class of entity on the map (intersections of rows and columns).

A weighted average of ***N*** absolute differences between overall subjective probability and the ***N*** individual conditional probabilities is then computed (Table 10). The greater the value of this weighted average, the greater the discriminating power of the factor map in question. Using the same logic, individual map classes on the thematic map that show the greatest absolute difference between their conditional probability and the overall map subjective probability are assumed to have the greatest power to predict the presence (or absence) of salinity.

A weighted average is used to account for differences in the extent of each class of secondary source map data in preference to a simple arithmetic average. A map with little difference between the value for overall map subjective probability and conditional probability for classes that cover a large proportion of the map area will have less discriminating power than one in which a large proportion of the map area is occupied by classes with significantly different probabilities of salinity than the map area as a whole. Larger values in Table 10 are associated with maps with a strong ability to predict the salinity type of interest while low values indicate poor predictive power.

Once computed, the weighted averages (Table 10) are used to determine the relative weights to assign to any given pair of maps. For example, comparing the relative usefulness of the soil map (1.21) to the map of bedrock type (0.88) for predicting contact salinity produced an estimate that the soil map was 1.21/0.88 = 1.29 times as useful for predicting contact salinity as the bedrock map.

It is not essential to use the Idrisi WEIGHT procedure to compute a standardized set of factor weights which sum to 1.0 for the N selected factors (Table 11). Standardized weights can be computed by dividing the weighted average for each type of map by the sum of all weighted averages for all maps to be included in the analysis. Each standardized weight represents the relative importance of that secondary data source to predict the type of salinity.

Table 10. Weighted averages of the absolute value of differences between conditional probabilities and subjective probabilities by data source and salinity type

Data Source	Contact	Outcrop	Artesian	Coulee	Depress
Bedrock	0.88	0.94	0.12	3.37	0.05
Depth to Bedrock	0.94	0.90	0.09	2.59	0.23
GW Flow Rate	0.27	0.29	0.03	0.17	0.05
GW (TDS)	0.76	0.57	0.10	1.26	0.14
Surficial Geology	0.76	0.54	0.08	5.75	0.18
Land Use	0.80	0.43	0.11	3.12	0.18
Relative Relief	1.14	1.11	0.17	5.44	0.25
Slope Class	0.31	0.60	0.07	2.35	0.07
Soil Map Unit	1.21	1.10	0.11	6.22	0.27
Slope Aspect	0.44	0.66	0.08	1.10	0.06
Profile Curvature	0.30	.019	0.03	1.11	0.06
Plan Curvature	0.24	0.17	0.02	0.70	0.13

In the example data (Table 11), it is clear that the most useful sources of secondary data for predicting most salinity types are the soil map, relative relief, bedrock type, depth to bedrock (except for coulee bottom salinity) and land use (except for coulee bottom and outcrop salinity). The soil map is expected to be one of the better predictors as it incorporates many of the other data sets in defining its units and makes a particular effort to restrict saline soils to a limited number of soil map units.

A slightly different method of calculating factor weights was used in a more recent project aimed at applying the PSH technique to a much larger region (MacMillan and Marciak 1999). The results are essentially the same, but the computational procedure is somewhat simpler.

Calculate PSH maps using MCE:

A weighted average of likelihood of developing salinity is calculated for each salinity type based on the factor scores and factor weights described above. This can be accomplished by running the MCE module of Idrisi for Windows (Eastman 1993) once for each of the ***M*** types of salinity present in a given major watershed. Alternatively, the map calculator capability of almost any raster-based GIS can be used to compute overall PSH. A value of PSH is computed for every cell for each type of salinity that occurs in a given watershed. The final PSH value for each cell is the sum of the factor score for the map class at the grid cell for each of the ***N*** input maps times the appropriate factor weight for each of the ***N*** input maps.

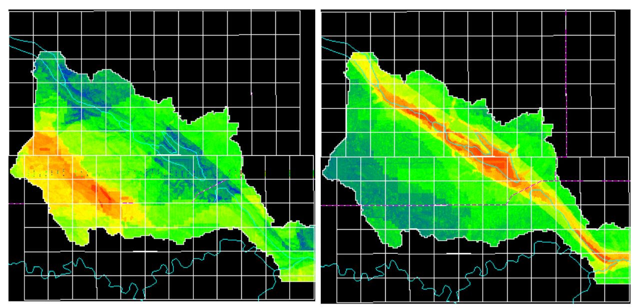


Figure 14. PSH maps for contact (L) and coulee bottom (R) salinity

The resulting maps (Figure 14) represent an average of the ***N*** individual factor scores multiplied by their associated factor weights. These "suitability index" maps indicate the PSH for each of the ***M*** types of salinity.

Table 11. Factor weights for each secondary data source and salinity type

Data Source	Contact	Outcrop	Artesian	Coulee	Depress
Bedrock	0.1001	0.1171	0.1194	0.1016	0.0299
Depth to Bedrock	0.1176	0.1119	0.0894	0.0780	0.1377
GW Flow Rate	0.0337	0.0357	0.0297	0.0052	0.0300
GW (TDS)	0.0952	0.0711	0.0989	0.0380	0.0837
Surficial Geology	0.0952	0.0670	0.0789	0.1744	0.1079
Land Use	0.1011	0.0533	0.1090	0.0944	0.1079
Relative Relief	0.1442	0.1377	0.1679	0.1648	0.1479
Slope Class	0.0390	0.0744	0.0692	0.0710	0.0418
Soil Map Unit	0.1517	0.2227	0.1091	0.1881	0.1619
Slope Aspect	0.0552	0.0719	0.0791	0.0299	0.035
Profile Curvature	0.0378	0.0209	0.0297	0.0335	0.0358
Plan Curvature	0.0303	0.0162	0.0197	0.0211	0.0778

Major Watershed Level Technical Activities

Compare predicted PSH to actual distribution of mapped salinity:

A visual analysis of the spatial pattern of PSH relative to the mapped extent of each salinity type (Figure 15) confirms that reasonable estimates of PSH are produced by the procedure.

Only minor differences are observed in the pattern of PSH estimated for contact (a), outcrop (c), and artesian (e) salinity for the study area sub-watershed. This similarity is expected, given the similarity in the location and known pattern of distribution of contact (b), outcrop (d) and artesian (f) salinity. The similarity in pattern of these three salinity types both as originally mapped and as predicted in terms of PSH suggests that they are not strongly differentiated by the PSH methodology using the available secondary source data sets.

PSH is correctly predicted for coulee bottom salinity (g) for the main channel of Verdigris coulee but not for minor coulee bottoms outside the main coulee (h). This arose from a limitation in the terrain derivative initially used to represent relative relief.

Relief was initially computed relative to a single elevation taken as the outlet point for the watershed. A more useful measure of relative relief was developed subsequent to the pilot and is now recommended. It computes the elevation difference between each cell and the closest cell classified as a divide or a drainage channel cell. Relative relief is computed as the result obtained by dividing the elevation of a given cell above its closest channel cell by the total difference in elevation between the divide cell and the channel cell for the flow path that passes through the cell.

The PSH for depression bottom salinity (i) differs from both coulee bottom and the closely similar contact, outcrop and artesian salinity types. The predicted distribution of PSH is consistent with the known distribution of depression bottom salinity (j). There are, however, only two to three individual sites of depression bottom salinity mapped within the study sub-watershed. This is an insufficiently large training data set on which to construct a rule base, so the predicted distribution of PSH for depression salinity should be viewed with caution.

The foregoing discussion provides an indication of the kind of understanding that can be derived from a PSH analysis. The PSH analysis can help to identify whether different types of salinity tend to develop under similar or different environments. If two different kinds of salinity consistently develop in similar environments, they may not be all that different.

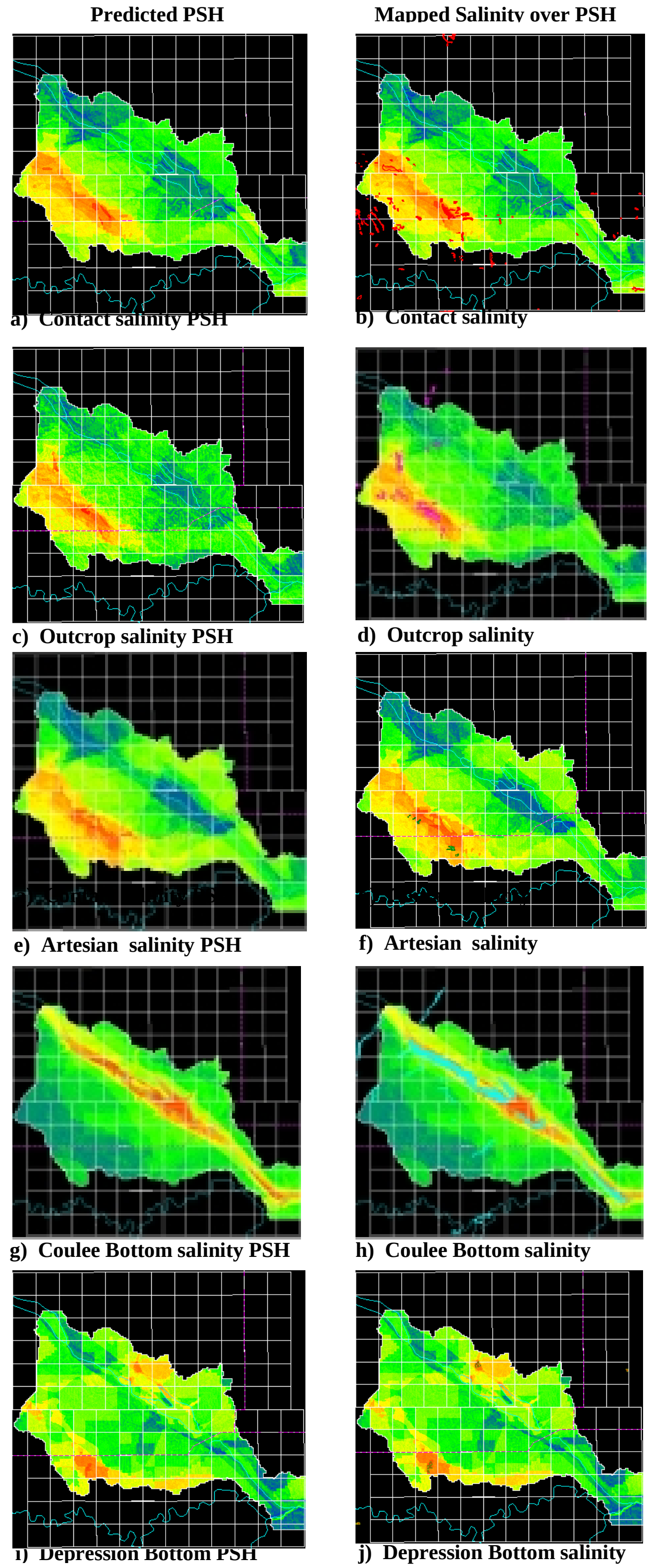


Figure 15. Comparison of PSH to actual mapped visible salinity

Major Watershed Level Technical Activities

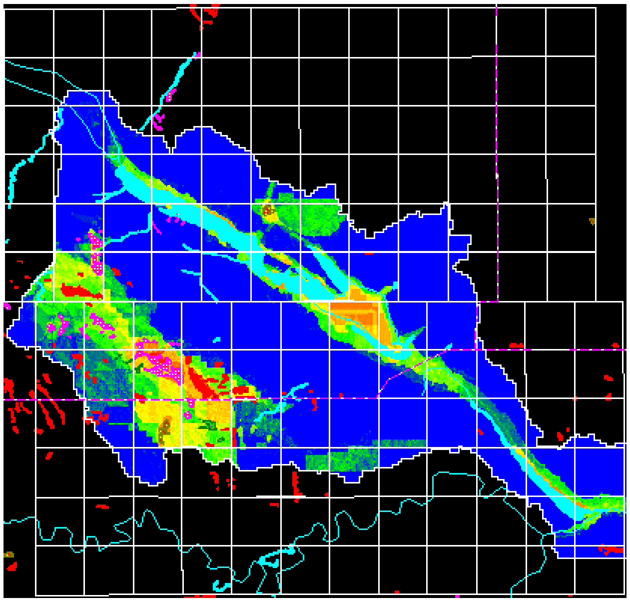


Figure 16. Comparison of overall PSH to all types of salinity

Use of PSH maps:

There are two possible uses for the PSH maps. The first is as a vehicle for discussing with farmers and landowners the possibilities for future spread of visible surface salinity. The second is as a means of assisting with the production and validation of future municipal scale maps of surface salinity.

Farmers and landowners can be shown maps depicting the present known extent of salinity overlain on the PSH maps (Figure 16). This will identify areas with environmental conditions similar to those at existing salinity sites, which might be expected to develop salinity at some future date. The farm owner or operator will gain an appreciation of the possible extent of future salinity if conservation practices are not adopted.

A possible extension of the technique might be to re-compute PSH maps using hypothetical input maps depicting different land use patterns. For example, high values of estimated PSH will likely be far more extensive if every section in the sub-watershed is assumed to be fallow, than if every section is assumed to be in perennial forage. Hypothetical variation in the extent and location of land use types may be a very useful exercise in predicting the possible consequences of land use change relative to increased or decreased visible salinity within the area of interest.

The PSH technique might also help in producing future municipal scale maps of visible salinity or for checking existing municipal scale salinity maps to identify outliers and possible miss-classified sites. As a pre-production tool, the PSH method could be used to develop factor scores and factor weights based on areas for which municipal scale salinity mapping has been completed. This “rule base” could then be applied to secondary source maps for nearby unmapped areas with similar environmental and topographical conditions. The estimated PSH for the unmapped area could be used as a guide for planning field mapping of actual visible salinity.

As a post-production tool, the PSH maps could be used to identify outliers, or saline sites classified as a particular salinity type that occur in areas that have a low predicted PSH for that type. Such areas may represent incorrectly classified sites or they may indicate that the same type of salinity can develop in two or more different environmental settings or through two or more different processes. This could help to improve understanding of the processes influencing salinity and of the most appropriate mechanisms for controlling that salinity.

The PSH procedures can help to turn data into knowledge. The knowledge can be used to improve understanding and make better predictions.

Major Watershed Level Technical Activities

Develop a watershed level plan

Developing a plan for salinity control and reduction in an individual watershed or sub-watershed is similar to developing a municipal level plan. A plan helps to ensure that measures to address soil salinity will be effective and that their effectiveness can be demonstrated or measured.

Two specific technical products are required to help landowners develop a salinity control plan for their watershed: a ***formal planning document*** helps to organize the process, and a ***detailed prioritization*** of individual saline seeps within the watershed ensures control efforts are implemented where they will do the most good.

Watershed level salinity control plan

A plan is a formal written document that identifies what is to be done to address salinity, why these actions are to be done, where they are to be done, when they are to be done, who is responsible for doing them and who is responsible for evaluating their success.

No plan is perfect or implemented exactly as originally conceived. However, a good plan provides a useful framework for implementing effective actions and evaluating the success of those actions. A good plan should also be flexible enough to permit modification as experience is gained during its implementation. A watershed level plan for salinity control need not be exhaustive. In most cases, a complete plan is no more than two or three pages long.

Preparing the plan

A watershed level plan to address salinity should be prepared by local landowners and operators after all relevant technical data and opinion have been obtained and analyzed. The plan should reflect the consensus of participating ratepayers.

Components of the plan

A watershed level plan for salinity control may include all or some of the following components:

Objectives:

Clearly specified and attainable objectives are essential for a successful plan. Landowners and operators in a watershed need to consider all available background information about salinity in their area to arrive at realistic goals and targets for addressing salinity.

They may wish to consider if it is desirable and feasible to reduce salinity in their area by a specified amount or whether current conditions are acceptable, in which case the goal may be simply to prevent any further expansion of salinity.

Participants in the planning process need to be aware that certain salinity types are more or less permanent and are not likely to respond favorably to most control efforts. It may be preferable to set targets for controlling or reducing specific salinity types in specific landscape settings.

Objectives must be specific and measurable. If they are not, it will be impossible to determine whether the actions to address salinity have had any beneficial impact

Methods:

The methods sections can simply list methods to be used and reference these to published manuals. It may simply list a number of steps such as:

1. Establish and organize a watershed-based salinity control group as per this manual.
2. Collect all relevant data and input into a GIS.
3. Define the major watershed boundaries.
4. Characterize sections in the watershed in terms of;
    a. extent of salinity by type,
    b. extent of land use by type,
    c. extent of soils by agricultural capability.
5. Prioritize individual saline sites (sections) in the watershed in order of their need for salinity control measures and likely success in response to control measures.
6. Schedule planning and implementation of salinity control plans at ***N*** of the highest priority local watershed sites (sections) in the watershed.
7. Summarize and report the results of the individual site plans, on both site and watershed basis.

Major Watershed Level Technical Activities

Work Plan:

The work plan simply summarizes who will do what and when. It is often developed as a table or chart with a list of tasks down the left-most column and a list of work days, weeks or months across the top row. Time lines are drawn in to show the start and finish times for each task. One or more individuals are assigned responsibility for each task and an estimate is included for the number of days, weeks or months needed to complete each task. The individuals' names and number of days assigned for completion of each task may be entered into separate columns at the end of each task row.

Budget:

A detailed work plan forms the basis for construction of a budget. The personnel costs associated with each task are calculated by multiplying the total number of hours or days that each individual is required by an hourly or daily rate for each individual. Non-personnel costs are usually broken down into operating costs (supplies and services) and capital costs (major purchases). Both of these sets of expenditures should be directly linked to a need to complete tasks that are listed in the work plan.

Reporting, review and evaluation:

This section should clearly indicate what types of reports or other deliverables will be produced, by whom and when. It should identify who reviews the project, how reviews will be made and when. It must include specific procedures for measuring success.

Prioritization of local watersheds

One of the main technical requirements of the watershed level planning processes is to prioritize individual saline sites in the watershed so programs and resources can be focused where they are most needed and will do the most good. This is crucial because unsuccessful efforts decrease landowner interest in, and commitment to, using control measures.

This technical activity analyzes the distribution of salinity by type and by section within the watershed. It considers the land use patterns and the capability of the soils affected by salinity in each section in the watershed. The result is used to identify those parcels most in need of control and most likely to benefit from such measures.

Prioritization of sites involves the following steps:

Acquire the digital database:

Most of the data required for rating and ranking individual sites of saline seepage are likely to have already been acquired and digitized in support of municipal level activities or other watershed level activities.

Data on location and extent of visible soil salinity are extracted from the municipal level map of soil salinity. These data should be subjected to additional field checking to verify their accuracy, remove any errors and add information for any major saline sites missing from the municipal map.

Data on land use by section are not usually available and must be collected by local field personnel. This could be accomplished by a rapid field inspection during the early growing season aided by analysis of aerial photographs taken during a similar time of year. Land use may be classified according to a provisional legend developed for the Pilot study (Table 2).

Data on soil capability are obtained by extracting and interpreting soils data for the watershed of interest. Most municipal scale soil survey reports provide a look-up table that rates each soil unit in the legend and on the map in terms of its capability for agriculture. The AGRASID digital soils database does not yet include information on soil capability linked to each soil polygon. Plans are in place to automatically associate each AGRASID polygon with a capability value based on a recently updated Land Suitability Rating System (Agronomic Interpretations Working Group 1995). A digital soil capability map can be produced by recoding the original soil map to replace each soil unit symbol with a corresponding soil capability rating.

Summarize the data by section:

Summaries of the extent of each class of salinity, land use and capability by section are generated by cross-tabulating digital maps of each of these three attributes against a digital map of section boundaries. This produces a text or tabular listing of the area in hectares of each class of data within each section.

Enter the summary data into a DBMS:

The section-based summary data are either retyped or imported into a relational database management system table. See Table 15 for an illustration of the required table's structure and sample contents.

Major Watershed Level Technical Activities

Rate and rank sections:

Sections are rated and ranked by applying the logic outlined in Tables 12 through 15. For the Pilot Project, a program was written in a database programming language (***FoxPro for Windows™***) to compute ratings and rankings automatically. It essentially filled in Table 15 for each section and computed the salinity factor, crop factor and soil factor for each section. Users will have to reproduce the logic of this program using a spreadsheet or database program of their own design to achieve a similar result.

Tabulate and illustrate the results:

The results of rating and ranking sections should be tabulated for review by ordering sections by rank. A map of ranked sections may also prove useful. It can be produced by recoding each section in a section map with the rank assigned to that section.

Assumptions underlying the prioritization procedure

Three specific factors are identified that affect the suitability of a saline site for remediation:

1. The type of visible soil salinity.
2. The type of land use looking at how each land use consumes soil moisture, and how each land use inhibits drainage and reduces recharge.
3. The soil capability class emphasizing rehabilitation of the best quality soils to obtain the greatest benefit from efforts.

Assumptions regarding salinity type:

Perhaps the major assumption is that the type of saline seep strongly influences whether the seep is amenable to local control. Some types of saline seeps are related mainly to groundwater flow systems that are not amenable to local control (Table 12).

Upwelling of regional groundwater flow under pressure, for example, causes Artesian salinity. The water source is far removed from the saline site and the supply of water is virtually unlimited. It is unlikely that a specific recharge area of limited dimensions can be identified and that effective local control measures can be put in place.

Outcrop salinity lacks the upward flow component of artesian salinity but is otherwise similar. The inferred source of the groundwater is an outcrop of a bedrock aquifer, which is supplied by regional and intermediate recharge over a very large, diffuse area. The local flow component is assumed to make a minor contribution to the overall volumes of flow, so efforts to reduce local flow are unlikely to have a significant impact on reducing total flow rates or lowering the local water table.

Similarly, coulee bottom salinity is most often related to ongoing discharge from regional and intermediate groundwater flow systems. Coulee bottoms are the lowest locations in the landscape and receive continuous discharge from both bedrock aquifers and immediately upslope locations. They are often very large, continuous, structural features. Local efforts to reduce the water table are unlikely to have a significant impact. Even if local efforts could be effective, most coulee bottoms are largely maintained in pasture anyway so there is little opportunity to change management practices to increase crop use of water.

In depression bottom salinity, depressions represent local sink points for surface and sub-surface water flow. This salinity type is mapped in small concave basins with no outlet for water flow. Recharge of the basins is from both local surface runoff and local to regional groundwater flow. Local efforts to reduce depression bottom salinity can be successful if recharge is not from too diffuse an area and from too diverse sources.

Assumptions regarding land use:

Land use immediately next to saline seeps is a second major consideration in identifying which sites might be most amenable to control (Table 13). The main assumption is that if most of the adjacent area is already in perennial forage or continuous crop, there is little opportunity to change the crop cover in the local recharge area to one that can increase water consumption and lower the water table. The index value assigned to perennial forage is therefore 0.

Assumptions regarding soil capability:

Soil capability is a final consideration in identifying which saline sites might most benefit from efforts to reduce salinity (Table 14). This assumes that it is better to control and reduce salinity in areas with the largest extent of high quality, productive soils rather than in areas with poorer and less productive soils. At present, soil quality is assessed in terms of the CLI Soil Capability for Agriculture ratings as reported in published soil survey reports such as the Soil Survey of the County of Warner (Kjearsgaard et al. 1984).

Major Watershed Level Technical Activities

Table 12. Assumed relationship of salinity type to control

Salinity Type	Assumed Groundwater Recharge Source Area & Likelihood of Responding to Controls	Index Value
Non-saline	Not applicable	0.0
Contact	Most flow originates from the immediately upslope local recharge area. High likelihood of response to agronomic controls.	1.0
Outcrop	Most flow originates from regional recharge into the water-bearing aquifer at some distance from the outcrop site. Moderate likelihood of response to structural controls.	0.6
Artesian	Most flow originates from regional recharge into the water-bearing aquifer at some distance from the artesian flow site. Moderate likelihood of response to structural controls.	0.6
Slough Ring	Most flow originates from surface runoff and local subsurface groundwater recharge into the slough. Moderate likelihood of response to agronomic controls.	0.6
Coulee Bottom	Flow originates from both local surface runoff and discharge of regional flow from water-bearing layers that outcrop along the coulee. Low likelihood of response to any controls.	0.1
Depression Bottom	Much of the flow originates as surface runoff from immediately adjacent upslope areas. Moderate likelihood of response to agronomic or structural controls.	0.8
Irrigation Canal	Most of the flow originates as leakage from canals. High likelihood of response to structural controls.	0.5
Irrigation/ Natural	Flow originates from both natural groundwater sources and from excess irrigation or canal seepage in irrigated areas. For natural water sources, moderate likelihood of response to agronomic controls. For irrigation water sources, high likelihood of response to structural controls.	.06

Other possible assumptions:

Several other factors can significantly affect the potential for successful salinity control. These include the depth to bedrock and depth to water table at the site, the slope and relief at the site, and the type and texture of geological or soil parent materials at the site. Many of these are to some degree related to the salinity type or CLI class and; therefore, considered indirectly when these factors are evaluated.

The ability and willingness of land owners to participate in efforts to control salinity could also be included as a consideration in rating the suitability of sites for salinity control.

Table 13. Assumed relationship of land use class to salinity control

Land Use Class	Assumed Water Consumption Behavior Relative to Lowering the Water Table	Index Value
Perennial Forage	Most efficient consumer of moisture. Roots extend to 5 to 6 m depth. Active consumer of soil moisture from early spring to late fall. Can extract water from the top 1 m and from the deeper water tables.	0.0
Continuous Crop	Not as effective as perennial forages but the most effective of all annual cropping methods. Compared to perennial forage, season for water extraction is shorter (because crops do not become effective water consumers until well established), and rooting depth is less than 1 m.	0.2
25% Fallow	The greater the extent of fallow, the greater the assumed increase in moisture storage and associated rise in water table levels.	0.4
33% Fallow	The greater the extent of fallow, the greater the assumed increase in moisture storage and associated rise in water table levels.	0.6
50% Fallow	The greater the extent of fallow, the greater the assumed increase in moisture storage and associated rise in water table levels.	0.8
100% Fallow	The greater the extent of fallow, the greater the assumed increase in moisture storage and associated rise in water table levels.	1.0
Saline Field	Fields mapped as mostly saline offer little scope for lowering water tables due to difficulties in seeding and establishing crop cover that will consume moisture and lower water tables.	0.1
Irrigated Field	Reduction in irrigation or more efficient use of irrigation water may reduce recharge.	0.7
Water Body	Planting water-loving vegetation, like willows, around the water body may lower the water table.	0.0

Table 14. Assumed relationship of soil capability to desirability of controlling salinity

Capability Class	Assumed Desirability of Reclaiming Soil	Index Value
1	Soil would benefit most from remediation	1.0
2	Benefit nearly as great as for class 1 soil	0.9
3	Benefit nearly as great as for class 2 soil	0.8
4	Benefit nearly as great as for class 3 soil	0.7
5	Only 1/2 as likely as class 1 soil to benefit	0.5
6	Very little benefit from remediating salinity	0.3
7	Hardly any benefit from remediating salinity	0.1

Major Watershed Level Technical Activities

A method for prioritizing sites

One mechanism for rating and ranking individual saline sites within a major watershed is to create a relational DBMS table as illustrated in Table 15.

The table contains data on the extent (in ha) of each class of salinity, land use and soil capability in each section in the watershed. Normally, these data would be obtained by using a GIS to compute the extent of different salinity types, soil capability classes and land use classes by section.

Sections are used as the spatial entity for amalgamating and analyzing data. This is done partly to associate spatially contiguous seeps and partly to establish spatial relationships between saline seeps and the land use and soil capability most closely associated with them. This approach also ties ratings and rankings to sections, which are basic land ownership and land management units.

Association of adjacent seeps by section ensures that several smaller seeps in close proximity are considered to be as serious a problem as a single large seep. Analysis of land use and soil capability by section assumes that land use in a specific section influences the saline seep(s) in the section. It further assumes that the quality of the land recovered from a remediated seep is related to the recorded capability of the soil in the section.

Calculation of a rating for each section is straightforward once the extent of each type of salinity, land use and soil capability class for each section of interest has been entered into a database modeled after Table 15. The ***salinity factor***, ***crop factor*** and ***soil factor*** are computed individually first. Each factor is computed as the weighted average of the extent of each class (e.g. contact salinity) times the index value for that class (e.g. 1.0).

A major watershed site rating is then computed by cross-multiplying the salinity, crop and soil factors. This rating measures the overall likelihood that a section contains the greatest extent of controllable saline seeps, the greatest extent of soils with a high agricultural capability and the greatest extent of land use practices that could be changed to increase moisture use and reduce groundwater levels.

As a final step, the database is sorted by rating value from highest to lowest. A sequential integer number, or ***rank***, is assigned to each section. The section with the highest rank is considered to contain the best combination of controllable salinity types, land uses that can be changed to increase water use, and high capability soils that will reward control efforts.

Table 15. Structure and content of the database used to prioritize individual sections in watersheds

Section Attribute (Field Name)	Index Value	Data Value
Section ID Number		144
Section		12
Twp		12
Rng		3
Mer.		4
Size (ha)		14045.0
Non-saline (ha)	0.0	13234.8
Contact (ha)	1.0	106.6
Outcrop (ha)	0.6	0.0
Artesian (ha)	0.6	15.0
Slough Ring (ha)	1.0	0.0
Coulee Bottom (ha)	0.1	678.1
Depression Bottom (ha)	0.8	10.4
Irrigation Canal (ha)	0.5	0.0
Irrigation/Natural (ha)	0.6	0.0
Salinity Factor		
Perennial Forage (ha)	0.0	
Continuous Crop (ha)	0.2	
25% Fallow (ha)	0.4	
33% Fallow (ha)	0.6	
50% Fallow (ha)	0.8	
100% Fallow (ha)	1.0	
Saline Field (ha)	.01	
Irrigated Field (ha)	0.7	
Water Body (ha)	0.0	
Crop Factor		
Soil Capability Class 1 (ha)	1.0	0.0
Soil Capability Class 2 (ha)	0.9	0.0
Soil Capability Class 3 (ha)	0.8	
Soil Capability Class 4 (ha)	0.7	
Soil Capability Class 5 (ha)	0.5	
Soil Capability Class 6 (ha)	0.3	
Soil Capability Class 7 (ha)	0.1	
Soil Factor		
Local Watershed (Site) Rating		
Local Watershed (Site) Rank		

Major Watershed Level Technical Activities

Illustrating and tabulating results of the prioritization procedure

Prioritization results need to be illustrated and tabulated for presentation to farmers and landowners in the watershed or sub-watershed.

Illustrating prioritization results:

One way to illustrate the results is to produce a map showing all sections in the major watershed and coloring or numbering each section in terms of its computed need for and suitability for measures to control salinity (Figure 17).

This figure can provide a basis for discussions among the landowners and operators about which salinity targets (sections) to address and in what order. The map's usefulness may be enhanced by showing actual mapped salinity overlaid on the color-coded and ranked sections.

Tabulating prioritization results:

Results can also be shown in a table that lists each section in the watershed in order of its calculated priority for salinity control measures (Table 16).

The table may report all data for each section or, more likely, it may report the values calculated for the three intermediate factor scores (salinity factor, crop factor, soil factor) as well as the final rating value and final rank for each section. The table can be sorted to report by order of rank, or by order of section number, sequentially from 1 to 36 within each township and range.

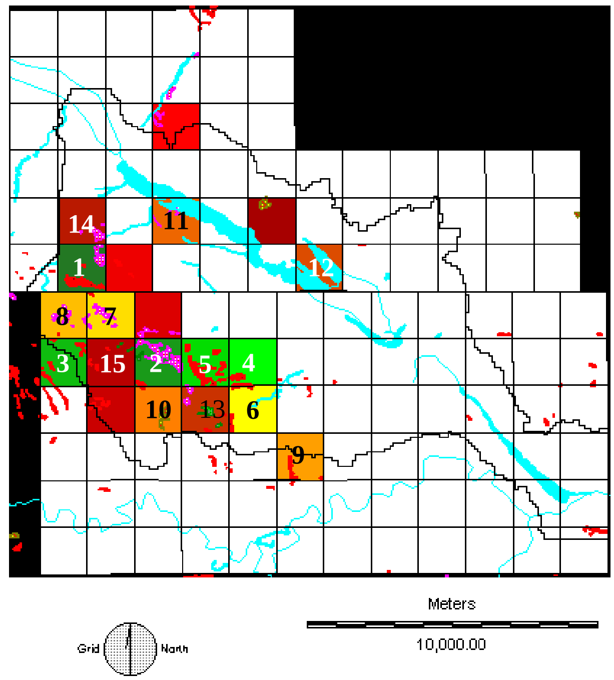
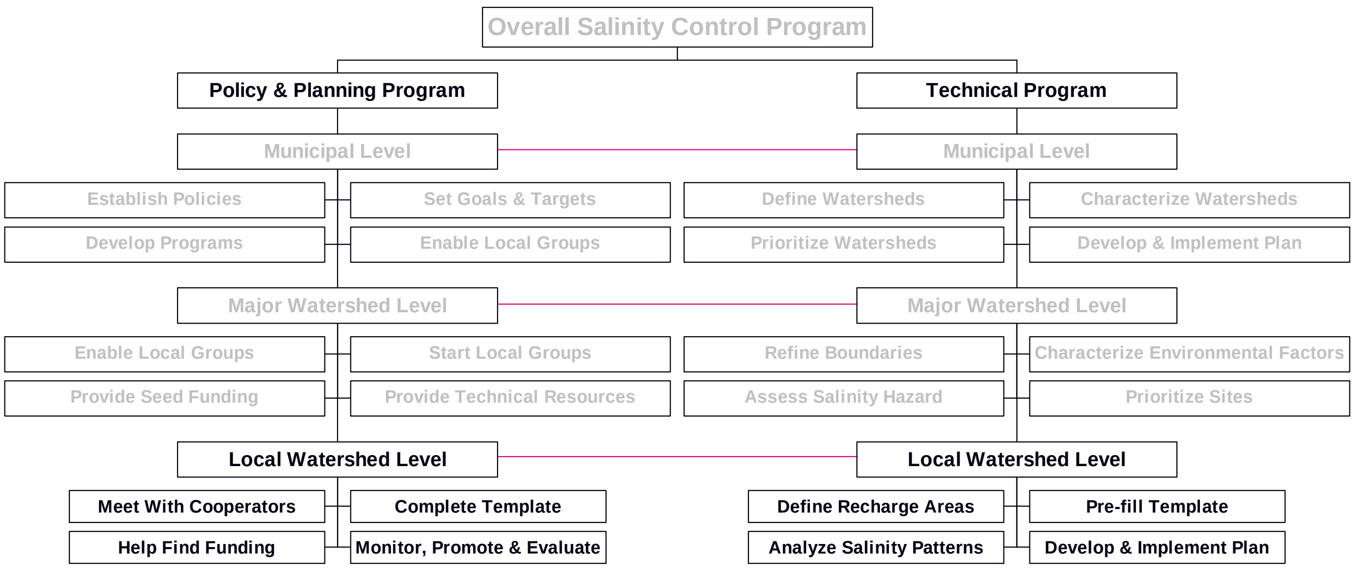


Figure 17. Map showing prioritization of sections

Table 16. Tabular listing of sections in an example watershed ranked by need for and suitability for salinity control

RANK	TWP	RNG	SEC	CROP_FACT	SAL_FACT	SOIL_FACT	RATING
1	3	15	5	63	84	92	80
2	2	15	28	63	79	89	77
3	2	15	30	75	41	92	58
4	2	15	27	8	100	89	52
5	2	15	26	69	35	86	52
6	2	15	23	75	25	96	46
7	2	15	32	63	26	96	45
8	2	15	31	100	21	97	45
9	2	15	13	50	24	96	41
10	2	15	21	88	18	93	40
11	3	15	10	50	26	71	39
12	3	14	6	81	26	37	38
13	2	15	22	75	16	96	37
14	3	15	8	56	18	91	36

Local Watershed Level Module



Local Watershed Level Policy and Planning

Policy and planning objective

At the local watershed level, the primary policy and planning objective is to help landowners and operators to apply specific measures to control specific saline seeps. A ***local watershed*** is a seep or collection of seeps selected for control measures and the recharge area or areas associated with these seeps.

Policy and planning activities

The following activities are required to support policy and planning objectives at the local watershed level:

Identifying specific parcels and owners

The first step in organizing salinity control efforts at the local watershed level is to define the local watershed boundaries and identify the individuals who own or manage land within those boundaries.

Identifying the local watershed boundaries is a technical activity based on processing a high-resolution (25 m) DEM to identify all paths of surface water flow that lead to a specific saline seep. The sum of all flow paths is taken to represent the extent of the local watershed area most likely to contribute to local groundwater recharge and, thus, to saline discharge.

Once the watershed boundaries are defined, they can be overlain on a map of ownership parcels to identify the individuals who own or manage parcels located wholly or partially within the boundaries. These individuals are the set of potential participants in the local watershed group.

Organizing local watershed groups

It is unlikely that affected landowners will organize themselves formally into watershed groups, at least until the practice proves effective and becomes widespread. Thus, a team consisting of an agricultural fieldman, AESA soil conservation coordinator, regional development specialists, AAFRD specialists, water quality specialists and interested landowners is best suited to organize a few key watershed groups.

Local watershed groups are an effective approach because affected landowners and land managers are the best ones to make decisions about whether salinity is a problem and whether actions are needed to address salinity.

Establishing site-specific plans

Once organized into a local watershed group, it is up to the participating landowners and operators to review available data on the type and location of salinity, land use, recharge areas and discharge areas. They must then discuss and select from among feasible and affordable salinity control options.

This Manual gives an example of a template to develop effective site-specific plans (see Appendix). The template provides a systematic approach to identifying, understanding and addressing salinity at the scale of a single site. The template can be modified to suit local needs.

Summarizing data by sub-watershed

Once detailed analysis and planning have been done for most local watersheds, data from the detailed plans may be collated and summarized to provide a detailed picture of salinity in each major watershed. The summary data could record not only the present extent of salinity in each major watershed, but also the direction and magnitude of past change in salinity, the extent of adoption of control practices and the expected future direction and magnitude of change in salinity in the major watershed.

Local Watershed Level Policy and Planning

A salinity investigation template

The Appendix provides a template to help guide landowners and managers through the process of collating data, reviewing options for controlling salinity and planning specific actions for specific local watersheds.

Objectives

The local watershed site investigation template and accompanying resource materials are intended to assist landowners and fieldmen to:

1. Delineate and record the extent and severity of readily visible surface salinity at specific saline seeps.
2. Identify and visualize specific areas of local recharge associated with specific saline seeps.
3. Identify and record details of land ownership and land management associated with each saline site or group of sites and their recharge areas.
4. Identify and record crop cover and management practices associated with specific areas of saline seepage and their associated recharge areas.
5. Develop an appreciation for the cause and effect relationships among farm management practices, groundwater recharge, water table levels and saline seep development.
6. Develop a commitment to addressing salinity by providing dramatic evidence to show the presence and historical change in soil salinity at given sites by using aerial photographs taken in different years
7. Understand the range of options for controlling salinity and how they work.
8. Evaluate the costs and benefits associated with adoption of typical salinity control methods.
9. Select and apply salinity control methods that are appropriate and feasible for a specific saline site.
10. Develop comprehensive, effective plans to control salinity at the scale of an individual site.

Applying the template

The local watershed site investigation template found in the Appendix consists of seven parts A to G, described below. It can be used with a variety of supporting publications.

Landowners and farm operators should be assured in writing that the personal information collected for the templates would be confidential and only released if authorized by the individual(s) concerned.

Procedures for completing each of the seven parts and how each of the parts addresses the 10 objectives are discussed below.

Part A: Overview of the local watershed

Part A provides a compilation of available relevant information about all quarter sections in a local watershed. It consists of one page of text and tables and a page of 2D and 3D illustrations. It should be completed before contacting the affected farmers and landowners. Technical staff employed by the agricultural service board or the local salinity control association may complete Part A.

The page of text and tables is designed to record the principal landowner or farmer operator, the technical staff involved in the investigation and their affiliations, and the names and status in the program of all owners or operators of sections in the local watershed. It also records a summary of the extent of each type of salinity and land use in each quarter section.

The 2D figure provides an overview to help farmers and landowners visualize the location and extent of surface salinity in relation to their quarter sections and field units. It consists of a scanned geo-corrected air photo over which vector lines have been laid to outline sections, quarter sections, all locations of known salinity (white lines) and the estimated recharge area associated with each saline site (yellow lines).

The 3D figure helps farmers and landowners understand the topographical relationships between saline seeps and their recharge areas. It shows how recharge areas are upslope from, and hydrologically connected to, their associated saline discharge areas.

Part A addresses objectives 1 to 5. It should help to clarify how surface salinity in one part of a quarter section can be related to recharge in another part of the quarter or an adjacent quarter. It should help to show how adjacent farm managers and landowners share a common relationship, by all having some extent of either seeps or recharge areas in their parcels. By identifying all farm operators who are either affected by or contributing to the salinity, the basis is laid for defining potential members for a group to address salinity in the local watershed. The decision on participating in the group is up to each operator, but the initial materials may help to convince them of the problem and their role in addressing it.

Local Watershed Level Policy and Planning

While working through the plan with land managers, Part A can be supplemented with additional materials. Helpful materials might include publications describing the principals of recharge and discharge, the features of each salinity type known to occur in the local watershed and the relationships among recharge, discharge and salinity as affected by differing levels of water use by different crops. These publications, along with the tabular data and 3D illustration, help to achieve objective 5.

Part B: Change in salinity through time

Part B addresses objective 6. Dramatic visual evidence of increasing salinity over time in the local watershed will likely help landowners and farmers become committed to addressing salinity.

Since a sequence of air photos taken in different years may not always be available, consider this section to be desirable, but optional. The form provides for the inclusion of scanned photos for up to four different years and for tabular data for up to 10 quarter sections. Local watersheds containing more than 10 sections will have to carry the extra data over to a second identical form.

The local technical specialist should scan any available air photos before visiting operators. The maximum extent of salinity should be determined as described above, by digitizing a colored line around each saline seep. These colored polygons can be superimposed on the same sites in other years to show the change over time. The polygon areas should be computed to fill in the data tables.

It is convenient to scan and geo-correct entire photos containing as many quarter sections of interest as possible. This limits duplication of registration efforts. It is also convenient to cut out square blocks containing either one or four sections and to fill in Part B for as many square blocks as are required. The regular square shape is simply more convenient to fill in.

Part C: Detailed quarter section records

Part C provides a record of known salinity and farm management practices by year and by field for each quarter section in a local watershed. It documents the relationship between extent of salinity and land management practices that may affect salinity.

Publications describing the relationships with crop cover, crop use of moisture, recharge, discharge and salinity can be consulted during completion of this form. They will assist in discussing how land management can affect the development and spread of salinity.

Part D: Detailed quarter section plans

Part D represents a detailed plan for crop selection and salinity reduction for each quarter section in a local watershed. It is meant to be completed by the operator of the section in question after completion of Part C. It may be completed individually or as part of a joint planning exercise involving all participating operators in the local watershed. Cooperative planning is expected to be more difficult but more effective. Individual groups of operators will have to determine for themselves which approach is better suited to their needs.

Completion of Part D requires reference to publications detailing the range of salinity control options appropriate to the local conditions. The operators and technical staff may wish to review the economic implications of the various options. It may also be appropriate to consult publications that provide guidelines for selecting appropriate varieties of forages, grasses or field crops and information to assist with seeding, establishing and maintaining these crops. These materials help address objectives 7, 8 and 9.

Parts C, D and E are intended to be completed in conjunction with individual operators or groups of operators participating in a local watershed group.

Part E: Simplified economic analysis

Part E represents a simple, multi-year economic analysis of the costs and returns associated with conversion of some or all of individual quarter sections from rotations of cereal crops to increased amounts of flex cropping, continuous cropping or perennial forages. It is based on the concept of net return to land exclusive of land costs (Smith et al. 1994). It is intended to provide a basis for discussion of net costs or gains associated with adoption of recommended salinity control measures.

This information may help operators decide whether certain options are feasible and, if so, how much land can affordably be converted to crops selected to control salinity. It could also form the basis of discussions about compensation or incentives among cooperating farmers and conservation agencies.

Ideally, the net costs of one operator would be offset by equivalent or greater net gains by those operators most affected by salinity, if the existing salinity were to be reversed and the land returned to productive use. In such cases, the operators who benefit from the reduction in salinity could use their increased returns to help compensate those who incur net costs.

Where net costs exceed net gains, some form of external incentive payments may be necessary to justify adopting conservation practices. These may have to be obtained by applying to government programs or non-governmental conservation agencies.

A systematic analysis of the economics of salinity control measures should help landowners and managers to determine which measures are economically feasible, how extensive an area can affordably be converted to crops with a higher consumptive use of water, and how much compensation or incentive is needed to enable adoption.

For more information, you may wish to contact your AAFRD Farm Management Specialist. Users may wish to set up the form as a computer spreadsheet.

Part F: Synopsis of overall plan

Part F summarizes, on a single page, the targets set for reducing salinity, the planned changes in crop cover and the potential economic cost or gain for every quarter section in the local watershed.

The 2D air photo image can be used to show the distribution of the planned changes and indicate, at a glance, what actions will be done and where.

This form, along with those completed for Part D, addresses objective 10.

Part G: Monitoring and follow-up plan

Part G is a framework for planning, recording and reporting the results of monitoring changes in salinity and water table depth at the site in response to the implemented salinity control measures. It consists of a 3D diagram of the locations of a minimum of three water well observation sites, a table for recording data collected at each site at regular (monthly) intervals and graphs to show changes in water table depth at each recording site through time.

Regular monitoring and reporting provide the feedback that the cooperating operators need to judge the success of their efforts and renew (or abandon) their commitment. Feedback is especially effective when the operators themselves are involved in collecting, recording and graphing the monitoring data.

Without clear indications of success, enthusiasm for salinity control measures will likely wane, both at individual local watershed sites and within the community at large. Part G is therefore critical to implementing a successful program for controlling salinity.

Circulating the completed template

All seven parts of the local watershed site investigation and planning document can be combined to form a comprehensive package of information.

Copies of completed plans based on the template should be distributed to each cooperating operator, the agricultural service board, and any participating conservation agencies (e.g. DSCA, AAFRD/C&D). Each package would ideally include copies of any relevant publications used to arrive at the plan. Copies of revised plans and of updated monitoring results should be distributed as required.

Any personal information collected for the templates must not be released unless authorized by the individual(s) concerned.

Summarizing completed plans

Detailed data from completed plans could form the basis for comprehensive summaries of the status of salinity and control efforts in individual sub-watersheds and entire municipalities.

The detailed quarter section data on the current extent of salinity and land use, past salinity and land use, and planned land uses aimed at reducing salinity could form the basis for verifying, updating and extending the original data on salinity collected for each sub-watershed. The updated data would describe not only the extent and type of current salinity, but also the change in salinity through time (not previously known) and the type and extent of measures taken to address salinity in each sub-watershed or municipality. The success of salinity control efforts could be gauged by analyzing the change in extent of land seeded to high-water-use crops or by comparing the extent of salinity in some future year to the extent at the time the program was initiated. To remove the effects of naturally occurring change, it may be best to compare the change in extent of salinity in watersheds in which salinity control measures were implemented, to the change in extent of salinity in sub-watersheds where no control efforts were implemented.

In any case, the database of completed local watershed salinity investigation templates is expected to provide a far superior assessment of present and future salinity than currently exists.

Local Watershed Level Technical Activities

Technical objective

The primary objective of technical activities at the individual site or local watershed level is to provide the input data and basic information required to help landowners and managers make knowledgeable decisions, develop feasible plans and undertake effective actions to address specific occurrences of soil salinity on parcels they manage.

Technical activities

Several technical activities are required to provide data to support local watershed level policy and planning activities.

Most of the local watershed planning activities are centered around preparing and completing the template for assessing and addressing salinity at a local watershed level. Completing the template requires the following specific data:

1. Clearly defined boundaries for local watersheds outlining the areas that contribute recharge to each individual saline site.
2. 2D and 3D diagrams clearly showing the spatial relationship between saline discharge areas and associated recharge areas.
3. A summary of known data on the location, extent and type of each saline seep and of each defined type of land use or land management within each quarter section in the local watershed.
4. A series of scanned photos documenting and illustrating historical change in visible salinity within each quarter section in the local watershed.

Local Watershed Level Technical Activities

Defining recharge area boundaries

Definition of local watersheds associated with each individual saline seep is required to identify the most likely source areas for the local component of groundwater recharge contributing to the development of each saline seep.

The defined local watershed boundaries identify which parcels of land, and therefore which landowners, are associated with each saline seep or collection of seeps.

Most strategies for controlling visible salinity are based on the premise that the best way to control salinity is to lower the water table beneath a saline seep by intercepting or consuming water in the upslope recharge area, before it flows downslope and contributes to a rise in the water table in the seep.

It is therefore necessary to have a reliable technical procedure for identifying and delineating the extent of ***local recharge areas*** associated with ***specific saline seeps*** (Figure 18). Detailed hydro-geological investigations are the most reliable method of defining the location and extent of recharge areas associated with individual saline seeps. Unfortunately, these investigations require costly field activities involving drilling and monitoring of many wells to record the changing water table depth.

A less expensive alternative to hydro-geological drilling is to define recharge areas using a detailed DEM of the surface topography around the seep. The method assumes that the local groundwater surface mirrors the local topographic surface. This assumption is acceptable in most cases.

This Manual describes a procedure based on automated processing of digital elevation data to define recharge areas for individual saline seeps. The greater accuracy of the approach based on detailed hydrogeological investigations is not feasible given the much higher costs of hydro-geological drilling compared to DEM analysis ($3,000 to $5,000 versus $200 to 500 per site).

Procedures for defining recharge areas

It may be easiest to work with the data for a single major watershed area at one time. The first step is therefore to extract or sub-set the DEM data for a regular rectangular region that fully encloses the current major watershed area of interest.

The DEM should be processed to compute the local direction of flow from every grid cell into the lowest of its eight possible downslope neighbors. Many GIS programs

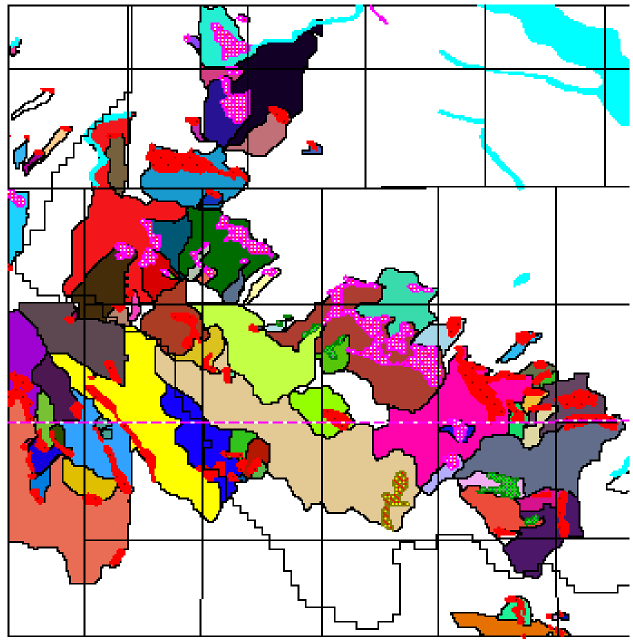


Figure 18. Recharge areas linked to saline seeps

now provide modules for computing flow directions and watersheds from DEM data (e.g. Arc/Info, ArcView Spatial Analyst, GRASS, Idrisi, PCI). Most of these packages simulate integrated flow by removing all depressions or pits in the DEM data set. This approach may result in estimates for the extent of the watershed associated with each saline seep target that are greater than desired. If the GIS software allows, only those pits that exceed a minimum threshold value for depth, volume or area should be removed.

The next step is to prepare a raster map showing the location and extent of all saline seeps in the area of interest. Each seep is assigned a sequential number to identify it uniquely as a ***saline seep target cell***. Most GIS programs contain vector-to-raster conversion facilities. These facilities should be used to convert the original vector polygon maps of visible salinity into raster maps with the same grid size as the DEM (25 m). Each saline seep polygon should be assigned a unique number.

After vector-to-raster conversion, all grid cells contained within a given saline seep polygon should be identified on the grid map by a unique polygon ID number. Grid cells having these unique numbers are used as target cells for defining the watersheds (or surface catchment areas) linked to each saline seep.

Local Watershed Level Technical Activities

Most GIS programs with watershed modules provide a capability to define and label watersheds based on tracing flow paths across a DEM to defined and labeled ***seed points***. All cells connected to a seed point with a given ID number are deemed to belong to a watershed that drains to the seed point. All such cells are labeled with the unique ID number of the seed point to which they drain (the target cell ID number).

All grid cells that are not affected by mapped salinity are assigned a value of 0 to indicate they are non-saline areas. In defining watersheds, all cells that do not drain to a defined saline seep target cell are deemed to belong to a watershed with a label of 0. These cells are not considered part of a recharge area linked to a saline seep.

The logic used to define recharge areas

The procedure used to define recharge areas for individual saline seeps can be accomplished using any of a large number of commercial GIS programs.

The GIS program used must be able to trace down flow paths along defined flow directions until a target cell is encountered that has a non-zero value for saline seep ID. If a flow path leads to a cell that is identified as belonging to a uniquely numbered saline seep, the assumption is made that the flow path, and all cells along the path, belong to a local watershed that contributes overland flow to that particular saline seep. The program should assign the unique sequential number for the seep in question to every cell along the path.

Some flow paths may flow all the way to a terminal cell, which is a pit or edge cell from which no further flow is possible, without traversing any cells that belong to defined saline seeps. Such flow paths are not considered to belong to a recharge area associated with any mapped saline seep. All cells along such flow paths are assigned a value of zero (0). These cells do not contribute overland flow to any location identified as a saline seep cell. They are therefore not considered to belong to a recharge area linked to any particular saline seep.

The process is complete when each cell has either been assigned a value of 0 or a non-zero value corresponding to the unique sequential number of the saline seep into which it drains.

The clear assumption is that sub-surface flow of groundwater is approximately similar to surface water flow as defined by paths of overland flow computed according to procedures described above. This is not always the case, but it does represent a useful first approximation in most instances.

Reformatting the data for display

It is convenient to have the recharge area boundaries available as vector polygons that can be traced over other raster images, such as scanned air photos.

For this reason, the raster map should be converted into a vector polygon coverage using a suitable raster-to-vector conversion utility (the Idrisi utility ***POLYRAS*** was used in the Pilot Project).

Producing figures linking recharge areas to saline seeps

The main purpose of producing 2D and 3D figures showing the link between saline seeps and upslope recharge areas is to help landowners and managers gain a better appreciation for the linkages between upslope recharge and downslope discharge. Understanding this linkage means understanding the need to implement biological controls in the upslope areas that are the source of most local groundwater recharge. These diagrams can be used as a basis for discussions among affected landowners about what controls to implement and where they are best implemented.

Procedures for producing 2D and 3D figures

The following steps produce 2D and 3D figures showing the location and extent of recharge areas linked to individual saline seeps.

1. Scan an aerial photo encompassing the entire area of the local watershed.
2. Geo-register the scanned photo image to the digital base map and the DEM.
3. Overlay the vector polygons for all saline seeps in the local watershed onto the scanned rectified photo.
4. Overlay vector lines showing the boundaries of the recharge area associated with each saline seep onto the scanned rectified photo.
5. Overlay any desired additional vector lines on the scanned photo (e.g. section lines, roads, canals) to provide context.
6. Save the combined overlay as a single composite 2D image.
7. Extract a subset of the DEM that exactly matches the location and dimensions of the scanned photo.

Local Watershed Level Technical Activities

8. Use a draping program to produce a 3D image of the composite 2D image draped over the terrain.
9. Save the draped 3D image as a bit mapped image (BMP, GIF).

Explanation of example 2D & 3D figures

Examples of figures produced by the procedures listed above are provided (Figures 19 and 20).

The 2D figure (Figure 19) shows each individual saline seep overlain on the scanned air photo. It is colored according to salinity type (red = contact, magenta = outcrop, brown = depression bottom and green = artesian). The white lines indicate the boundaries of the recharge area associated with each saline seep.

The 3D figure (Figure 20) shows the same area viewed from the northeast looking southwest. It helps visualize the relationship between topography and recharge area for each saline seep.

These figures may prove helpful in discussing the cause and effects of salinity with farmers and land owners. They may help farmers to visualize how water originating in a particular upslope location may be contributing to high water tables and salinity in a downslope location. Adding lines for sections and quarter sections can help to identify who owns particular parcels containing recharge areas that might be contributing to downslope salinity.

Summarizing known data by quarter section

Part A of the local watershed site investigation template is designed to provide an overview of all relevant information already known about a specific saline site or salinity target. Landowners and managers can review this information to assess if salinity is a problem on their lands and, if so, whether any efforts to control it are justified.

Part A requires four main sets of information:

Identification of all quarter sections that belong to a given local watershed

A ***local watershed*** is arbitrarily defined as one or more saline seeps designated for remediation and the recharge area or areas associated with each of the selected seeps.

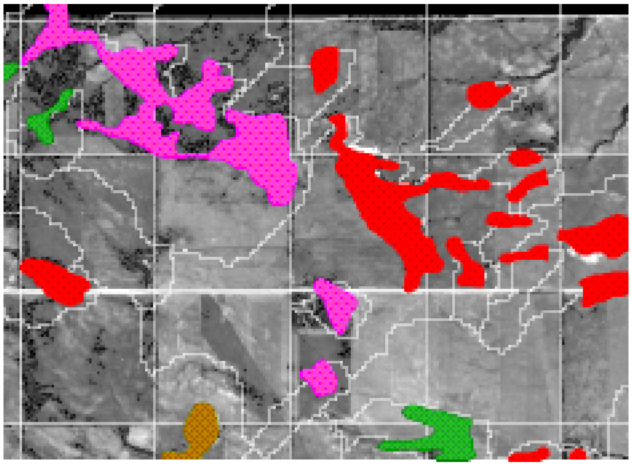


Figure 19. 2D illustration of saline seeps and associated recharge areas

In some cases, local staff may wish to identify a single saline seep as a target for remediation. More commonly, they may wish to identify a collection of several relatively small seeps near to one another as a salinity target.

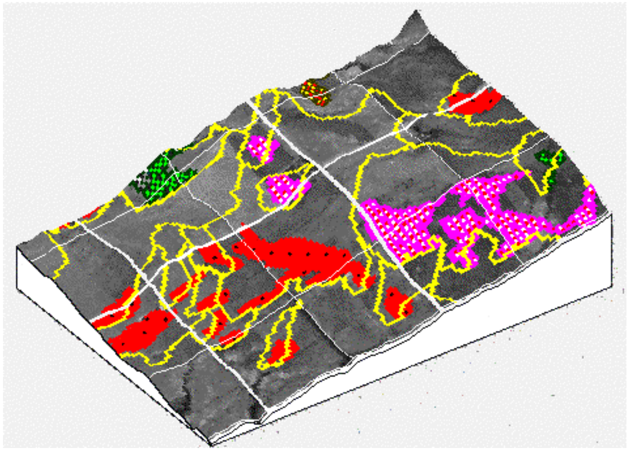


Figure 20. 3D illustration of saline seeps and associated recharge areas

Once a seep or collection of seeps has been identified as a target, the extent of the local watershed(s) associated with the selected seep(s) must be defined. A local watershed is defined by identifying all quarter sections that contain either a portion of one or more of the selected saline seeps or some or all of a recharge area linked to one or more of the selected saline seeps.

Local Watershed Level Technical Activities

A list of quarter sections considered to belong to the local watershed can be produced by reviewing the 2D figure showing the seeps and their recharge areas for each salinity target area. All quarter sections that contain some or all of a targeted saline seep or its associated recharge area are considered to belong to the local watershed and are listed in Part A of the local watershed template.

Identification of landowners and operators

Once all quarter sections in each local watershed are identified and listed, the names of registered owners and current operators for each quarter section can be identified.

Currently, names of landowners and operators are obtained by referring to the municipal land ownership map and manually copying the appropriate names for each quarter section of current interest. This procedure could be automated by building a link to the computer database of municipal assessment data. This automation has not presently been implemented.

Summary of salinity by quarter section

Summarizing salinity by quarter section provides factual data on the known location and extent of each salinity type in each quarter.

These data provide a starting point for discussions with landowners and operators about the extent of their salinity problem and the need for salinity controls.

The data can be obtained by cross-tabulating a digital salinity map against a digital map of quarter section boundaries. This requires use of a spatial cross-tabulation procedure available in most commercial GIS programs.

Summary of land use by quarter section

The template contains tables that summarize the extent of each type of land use or land management in each quarter section within a defined local watershed. These tables provide a factual record of the kind and extent of crop cover (or lack thereof) in each quarter through time. Review of these data by land managers in the local watershed may support assumptions regarding relationships between low-water-use crops, high water tables and increased salinity in downslope areas.

The land use survey conducted to support prioritization of salinity targets acts as the initial source of land use data for each quarter.

These data are already summarized by quarter section so local staff need only transcribe them into the appropriate places in Part A of the template. The data are used to lead landowners and operators into a discussion of the possible relationships between land use and salinity or land use and local groundwater recharge. The 2D and 3D figures can assist in this discussion.

The initial design recognizes five main classes of crop cover or farm management, specifically:

1. Permanent pasture
2. Perennial forage
3. Continuous crops
4. Annual crops
5. Fallow land

This initial list will likely require revision to differentiate sub-classes of annual crops (cereals, oilseeds, specialty crops) or different kinds of fallow (chemical fallow, cultivated fallow).

At present, the main intent is to identify fields and quarter sections that contain extensive areas with little or no crop cover during the non-winter period. It is assumed that forages are most effective at removing water from the water table. Next most effective is permanent pasture, because of its extended growing season and well-established root system. This is followed by continuous crops, then annual crops and finally fallow land which has the lowest rates of removal of soil moisture.

Recording historical change in salinity

Part B of the template allows an analysis of the change in salinity through time at a defined salinity target. This information can provide dramatic visual and tabular evidence of the historical change in salinity, helping landowners and operators develop a commitment to addressing salinity.

Explicit documentation and illustration of changes in visible salinity help to encourage individual landowners and operators to address salinity on their parcels and also provide a factual basis for determining if salinity is increasing or decreasing on a watershed or municipal level. This knowledge is needed to help develop appropriate policies and programs for addressing salinity.

Local Watershed Level Technical Activities

Analyzing salinity change

The procedures developed to analyze and illustrate trends in extent of salinity through time are based on identification of changes in visible salinity on a series of historical aerial photographs.

The template provides space for up to four photos to show the location and extent of salinity at four different times. The analysis should extend as far back in time as available historical photos permit. This may help to separate natural cycles in extent of salinity from progressive trends. In general terms, the procedure for analyzing historical changes in salinity involves the following steps:

1. Obtain up to four sets of aerial photos taken in different years over as long a period as is available (up to 60 years).
2. Scan one photo for each year of interest for each area (salinity target) of interest.
3. Geo-register each scanned photo to a common base map and projection.
4. Digitize polygons to outline the extent of visible salinity on each historical photo.
5. Compute and tabulate the areal extent of visible salinity in each quarter section in each historical year of record.
6. Identify and analyze changes and trends in the extent of salinity over time.

Historical aerial photos can be obtained from Alberta Environment or private sector agencies.

Scanning can be done using any commercially available scanner and the image capture and enhancement software that typically accompanies scanner hardware. Photo enhancement software is often required to improve the brightness and contrast of the original scanned photos.

Registration of scanned images is advisable to correct for distortions and differences in scale among different images. Corrected images allow production of more accurate calculations of the areal extent of salinity in each time period. Also, registering images permits vector lines extracted from one image to be overlaid on any other registered image of the same area to graphically illustrate changes in the location and extent of salinity from one point in time to another.

Many commercial GIS and image analysis programs now provide modules for geo-registering scanned images. The demonstration project used the ***Resample*** module in Idrisi for Windows™ for correcting images, but any suitable package can be used. For most images, the coordinates of four or more quarter section corners are usually sufficient to achieve a suitable registration. Quarter section corners are usually easily identified on most scanned photos. The map coordinates of the quarter section corners of interest are generally already known because they are needed to produce maps of quarter section boundaries required for other analyses (e.g. the prioritization procedure).

Once the scanned photos are geo-registered, GIS software can be used to digitize outlines around areas of clearly visible salinity on each air photo of each time period. In the pilot exercise, this was accomplished using the on-screen-digitizing module of Idrisi for Windows™. Any similar GIS software could be used in place of Idrisi.

The digitized vector outlines of visible salinity extracted from each air photo can be converted into raster maps using a raster-to-vector conversion utility. The raster maps of salinity by year can be cross-tabulated against the raster maps of quarter section boundaries to generate statistics on the extent of visible salinity by quarter by year of photo. The required data can also be produced by vector overlay of the salinity polygons on quarter section polygons. These statistics can be manually transcribed into the table provided in Part B of the salinity template.

Both the statistics and the illustrations of salinity by time period can be analyzed to identify changes in the extent of salinity through time. Clearly identified trends toward increased salinity can provide landowners and operators with motivation to address their current salinity problems.

Local Watershed Level Technical Activities

Illustrating salinity change

Illustrations of salinity change over time can be more compelling than tabular summaries of the same information. Therefore, Part B of the salinity template emphasizes graphical portrayal of the change in salinity at salinity targets.

All of the data needed to produce illustrations of any clear changes in salinity through time are generated in the course of producing the tabular statistics described above.

Producing these illustrations and adding them to the template document requires the following steps.

1. Assign a unique number and color to the salinity polygons for each year of interest.
2. Create composite images showing the photo for each different year overlaid with polygons of different color (or line type) for each year for which polygons were produced.
3. Save the composite images as bit maps (BMP) for import into the template document.
4. Import the BMP images into the template document (currently set up in ***MS-Word 97 for Windows™***).

Example illustrations of salinity change

An example of illustrations depicting changes in the location and extent of visible salinity for a local watershed salinity target is provided (Figures 21 and 22).

Salinity visible on photos taken in 1962 (Figure 21) is shown in solid red fill. Salinity visible in 1980 (Figure 22) is shown using yellow lines. The change between 1962 and 1980 can be estimated visually by identifying areas contained within yellow lines that are not colored solid red.

The example shows an increase in visible salinity between 1962 and 1980. The increase is related to both the increased size of existing saline seeps and the appearance of new seeps. New seeps are outlined in yellow and contain no solid red fill. Expanded seeps contain a core of red fill surrounded by a larger yellow polygon.

Completing local watershed plans

The technical activities discussed above are all intended to provide data or illustrations required to complete the proposed salinity assessment and planning template for a local watershed area. Detailed planning and implementation of appropriate salinity control measures at a local level is the most important aspect of the entire watershed-based salinity program. All efforts are geared to maximizing landowner interest in and commitment to identifying problem salinity and dealing with it effectively.

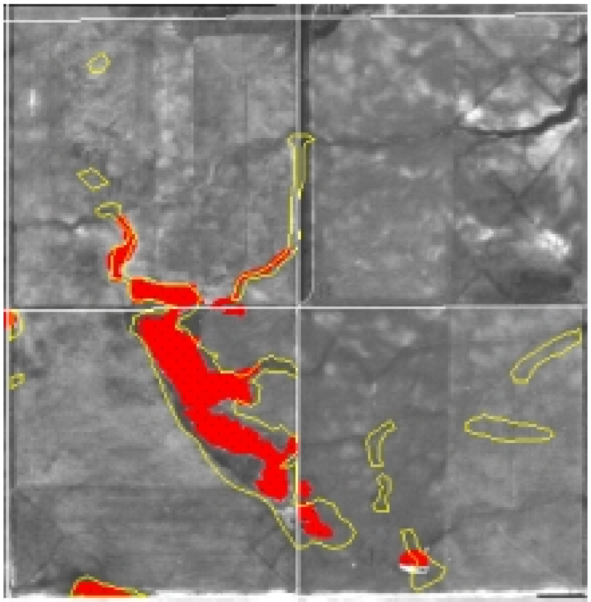


Figure 21. Salinity visible in 1962 (red)

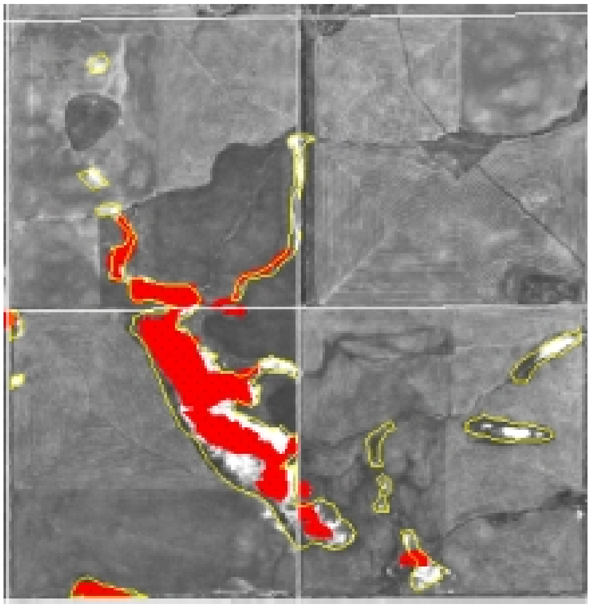


Figure 22. Salinity visible in 1980 (yellow)

Summary

Soil salinity is a serious soil conservation issue in many agricultural areas of Alberta. This Manual describes procedures to help municipalities to address soil salinity concerns. These concerns include assessing the salinity problem, setting goals for addressing it, and developing programs, policies and site-specific technical procedures for salinity control.

The Manual recommends a watershed-based approach to addressing salinity. Watersheds are logical natural units for identifying the sources of water causing saline seeps and for applying effective control measures. Salinity is mainly a problem of excess water and since a watershed encompasses all of a given area draining to a given location, all or most of the water causing soil salinity in the watershed likely originates within the watershed. As well, landowners in a watershed share a common interest in managing their shared water resource and in minimizing the adverse effects of management practices that affect water movement.

The Manual details procedures for addressing salinity concerns at three levels: a municipality; major watersheds in the municipality; and local watersheds within major watersheds. For each level, it describes the policy and planning activities as well as the technical activities needed to accomplish the policy and planning objectives.

More information

More information and technical assistance for developing salinity control programs is available from the following sources:

Technical information on salinity and landscape management

- Don Wentz, salinity specialist AAFRD
- Dryland Salinity Control Association
- Private consultants specializing in soils and landscape issues
- AAFRD factsheets
    - Dryland saline seeps: Types and causes, Agdex 518-12
    - Perennial crops for recharge control of saline seeps, Agdex 518-13
    - Annual crops for recharge control of saline seeps, Agdex 518-14
    - Perennial crops for salinity control of discharge areas, Agdex 518-15
    - Structural controls for dryland saline seeps, Agdex 518-16
- Watershed approach to saline seep reclamation (Holzer n.d.)

Development of watershed-based groups

- AESA soil conservation coordinators, AAFRD regional development specialists and agricultural fieldmen

Value of watershed-based approach

- Integrated catchment management rediscovered: an essential tool for a new millennium. Available at: http://www.landcare.cri.nz/conferences/manaakiwhenua/papers/index.shtml?bowden.
- Watershed protection. United States Environmental Protection Agency. Available at: http://www.epa.gov/owow/watershed/.

Activities at the municipal and major watershed level are mainly oriented towards documenting the extent of salinity and establishing priorities for addressing salinity.

The local watersheds are the key level for operational activities to control or reduce salinity. Activities at this level are structured around completion of a detailed salinity control plan for each seep.

A standard template is described for defining and implementing a salinity control plan at the local watershed level. This template and the procedures followed to complete it, can be used to guide operational activities at the local watershed level. The template and procedures can be modified to suit local needs.

It is hoped that municipalities and concerned landowners find the procedures outlined in this Manual useful in helping them to plan and take action to address soil salinity in their areas.

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Appendix

Local Watershed Site Investigation Template

Part A: Overview of the local watershed

Part B: Change in salinity through time

Part C: Detailed quarter section records

Part D: Detailed quarter section plans

Part E: Simplified economic analysis

Part F: Synopsis of overall plan

Part G: Monitoring and follow-up plan

Dryland Salinity
Local Watershed Site Investigation
PART A

municipality name

Landowner/Operator Information		Investigator Information	
Last Name	First Name/Initial	Salinity Target No.	
		Investigator 1	
Address		Investigator 2	
		Investigator 3	
Town/City			
		Date Started:	
Postal Code	Telephone	Date Completed:	

Owners and Operators of Quarter Sections Associated with the Salinity Target

Legal Location					Registered Owner		Current Operator		Status as Participant in Watershed Program				
Qtr	Sec	Twp	Rng	W	Name	Phone	Name	Phone	Total Acres	Saline Acres	Recharge Acres	Forage Acres	Will Participate

Summary of Conditions on All Quarter Sections Associated with the Salinity Target

Legal Location					Known Salinity by Salinity Type (Acres)								Farm Management & Crop Cover (Acres)				
Qtr	Sec	Twp	Rng	W	Contact Salinity	Outcrop Salinity	Artesian Salinity	Slough Ring	Coulee Bottom	Depress Bottom	Irrig Canal	Irrig Natural	Permanent Pasture	Forage Crops	Contin Crops	Annual Crops	Fallow Land

Dryland Salinity
Local Watershed Site Investigation

municipality name

PART A

PAGE 2

Site Plan for Sections and Quarter Sections Associated with the Salinity Target

Township **Range** **Mer** **Sections**

2D Plan View of Salinity Target Area

N

SCALE:	

3D Perspective View of Salinity Target Area

Dryland Salinity
Local Watershed Site Investigation

municipality name

PART B

Analysis of Change in Salinity Through Time For:

Legal Location					**Year 1**			**Year 2**			**Year 3**			**Year 4**			**Overall Change**	
Qtr	Sec	Twp	Rng	W	Year1	Total Salinity	Percent Saline	Year2	Total Salinity	Percent Saline	Year3	Total Salinity	Percent Saline	Year4	Total Salinity	Percent Saline	Total Change	Percent Change

N

Year 1 =	1948	Scale =	1:63,360		Year 2 =	1960	Scale =	1:60,000
Year 2 =	1982	Scale =	1:30,000		Year 4 =	1995	Scale =	1:15,000

N

Dryland Salinity
Local Watershed Site Investigation

municipality name

PART C

PAGE: 4

Detailed Archive Information for Quarter Section:

Qtr	Sec	Twp	Rng	Mer
NE	26	4	13	4

N

SCALE:	

Past Salinity and Farm Management Data

Year	Field	Known Salinity by Type and Total Salinity (Acres)									Farm Management Practices & Crop Cover (Acres)					
Year	Field Number	Contact Salinity	Outcrop Salinity	Artesian Salinity	Slough Ring	Coulee Bottom	Depress Bottom	Irrig Canal	Irrig/ Natural	Total Salinity	Permanent Pasture	Forage Crops	Contin. Crops	Annual Crops	Fallow Land	Total Acres
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																
20																

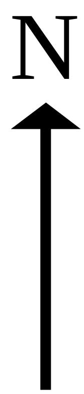
Dryland Salinity
Local Watershed Site Investigation

municipality name

PART D

Detailed Salinity Control Plan for Quarter Section:

Qtr	Sec	Twp	Rng	Mer
NE	26	4	13	4



SCALE:	

Salinity Reduction & Farm Management Conservation Plan

Year	Field	Planned Crop Selection				Salinity Reduction Plan						
Year	Field Number	Planned Crop	Crop Variety	Planned Acres	Comments	Recharge Area	Initial Cover%	Current Cover%	Percent Change	Initial Salinity	Target Salinity	Percent Change
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

Dryland Salinity
Local Watershed Site Investigation

municipality name

PART E

PAGE: 6

Comparative Economic Analysis for Quarter Section:

Qtr	Sec	Twp	Rng	Mer
NE	26	4	13	4

Crop Selection and Simplified Economic Analysis:

Year	Field Data		Planned Crop Selection & Costs									Economic Analysis			
Year	Field Number	Area (acres)	Planned Crop	Seeding Rate/ac	Seeding Costs/ac	Fertilizer Rate/ac	Fertilizer Cost/ac	Herbicide Rate/ac	Herbicide Costs/ac	Tillage Costs/ac	Total Input Costs/ac	Actual or Expected Yield/ac	Selling Price $/tonne	Contrib. Margin $/ac	Net Return To Land $/ac
1994															
1994															
1995															
1995															
1995															
1996															
1996															
1996															
1997															
1997															
1998															
1998															
1998															
1999															
1999															
2000															
2000															
2000															
2001															
2001															

Summary of Economic Analysis:

Year	Field	Return with No Additional Forages or Conservation Crops				Return with Additional Acreage Seeded to Forages and Conservation Crops						Effect of Incentives	
Crop Year	Total Seeded Area (acres)	Types of Annual Crops	Area Seeded to Annual Crops (acres)	Net Return to Land of Annual Crops	Net Return Per Acre of Annual Crops	Potential Total Return with No Forages Seeded	Types of Forages or Cover Crops	Extent of Forage Crops (acres)	Net Return to Land from Forages	Net Return Per Acre from Forages	Total Return Including Forages and Annuals	Total Net Gain or Loss with Forages	Total Value of Incentive Payment	Total; Net Difference with Incentive Payment
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														

Dryland Salinity
Local Watershed Site Investigation

municipality name

PART F

Township	Range	Mer	Sections and Quarter Sections

Synopsis of Conservation Plan for

N

SCALE:	

2D Plan View of Salinity Target Area

Summary of Conservation Plans by Quarter Section

Legal Location					Salinity Reduction Targets			Planned Changes in Crop Cover or Farm Management Practices						Economic Cost Benefit			
Qtr	Sec	Twp	Rng	W	Initial Salinity (acres)	Target Salinity (acres)	Planned % Change in Salinity	Initial Cover Crops (acres)	Planned Cover Crops (acres)	Percent Change in Cover Crops	Initial Fallow (acres)	Planned Fallow (acres)	Percent Change in Fallow	Net Gain or Loss with New Forages	Annual Incentive Payment	Total Incentive Payment	Net Change with Incentive Payment

Dryland Salinity
Local Watershed Site Investigation

municipality name

PART G

PAGE: 8

Synopsis of Monitoring Plan for Salinity Target No:

Township	Range	Mer	Sections and Quarter Sections

2D Plan View of Monitoring Well Sites & Change in Salinity

N

SCALE:	

Change in Extent of Salinity with Time by Quarter Section

Legal Location					Year 1			Year 2			Year 3			Year 4			Overall Change	
Qtr	Sec	Twp	Rng	W	Saline Acres	Percent Saline	Percent Change	Saline Acres	Percent Saline	Percent Change	Saline Acres	Percent Saline	Percent Change	Saline Acres	Percent Saline	Percent Change	Total Change	Percent Change

Dryland Salinity
Local Watershed Site Investigation

municipality name

PART G

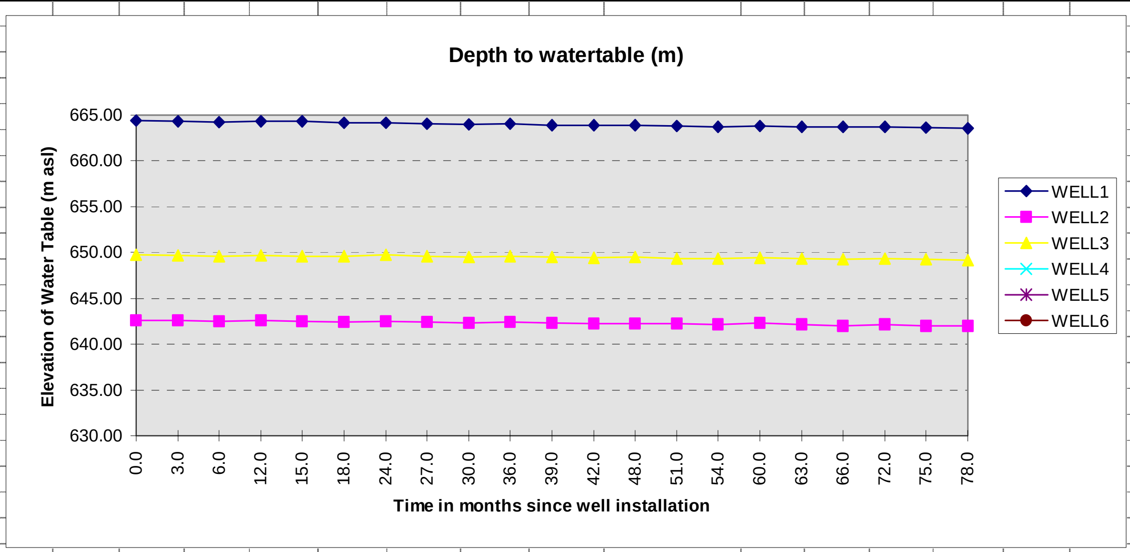
PAGE: 9

Location & Description of Water Table Monitoring Wells

Well ID	Well Location	Data Pertaining to Well

Shed ID	Year	Well No.	Qtr	Sec	Twp	Rng	W.	UTM Easting	UTM Northing	Elevation of Top (m)	Depth Of Well (m)	Slope Position	Date Installed	Installed By	Monitored By	Monitoring Frequency	Initial WT Depth (m)
V	97	01															
V	97	02															
V	97	03															
V	97	04															
V	97	05															
V	97	06															

ELEVATION OF TOP OF WELL	686.13	664.12	650.58	644.39	614.93	598.24		SAMPLING SCHEDULE		686.13	664.12	650.58	644.39	614.93	598.24
WELL ID	**WELL1**	**WELL2**	**WELL3**	**WELL4**	**WELL5**	**WELL6**	**TIME STEP**	**DATE**	**MONTHS SINCE WELL INSTALLATION**	**WELL 1**	**WELL2**	**WELL 3**	**WELL4**	**WELL5**	**WELL6**
	1.70	1.50	0.85				**DATE1**	**4/1/97**	**0.0**	664.43	642.62	649.73			
	1.80	1.55	0.90				**DATE2**	**7/1/97**	**3.0**	664.33	642.57	649.68			
	1.90	1.60	0.95				**DATE3**	**10/1/97**	**6.0**	664.23	642.52	649.63			
	1.85	1.55	0.90				**DATE4**	**4/1/98**	**12.0**	664.28	642.57	649.68			
	1.85	1.60	0.95				**DATE5**	**7/1/98**	**15.0**	664.28	642.52	649.63			
	2.00	1.70	1.00				**DATE6**	**10/1/98**	**18.0**	664.13	642.42	649.58			
	1.95	1.65	0.85				**DATE7**	**4/1/99**	**24.0**	664.18	642.47	649.73			
	2.10	1.75	0.95				**DATE8**	**7/1/99**	**27.0**	664.03	642.37	649.63			
	2.15	1.80	1.05				**DATE9**	**10/1/99**	**30.0**	663.98	642.32	649.53			
	2.10	1.70	1.00				**DATE10**	**4/1/00**	**36.0**	664.03	642.42	649.58			
	2.20	1.80	1.10				**DATE11**	**7/1/00**	**39.0**	663.93	642.32	649.48			
	2.25	1.90	1.15				**DATE12**	**10/1/00**	**42.0**	663.88	642.22	649.43			
	2.20	1.85	1.10				**DATE13**	**4/1/01**	**48.0**	663.93	642.27	649.48			
	2.30	1.90	1.20				**DATE14**	**7/1/01**	**51.0**	663.83	642.22	649.38			
	2.40	1.95	1.25				**DATE15**	**10/1/01**	**54.0**	663.73	642.17	649.33			
	2.30	1.80	1.15				**DATE16**	**4/1/02**	**60.0**	663.83	642.32	649.43			
	2.40	1.95	1.25				**DATE17**	**7/1/02**	**63.0**	663.73	642.17	649.33			
	2.45	2.10	1.30				**DATE18**	**10/1/02**	**66.0**	663.68	642.02	649.28			
	2.40	2.00	1.25				**DATE19**	**4/1/03**	**72.0**	663.73	642.12	649.33			
	2.50	2.10	1.35				**DATE20**	**7/1/03**	**75.0**	663.63	642.02	649.23			
	2.60	2.15	1.40				**DATE21**	**10/1/03**	**78.0**	663.53	641.97	649.18			



Record of Change in Depth to Water Table with Time