Application of a hybrid methodology for estimating potential salinity hazard (PSH) to a large and diverse test region in Alberta, Canada (NTS Sheet 82P)

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ABSTRACT

A new methodology for estimating the potential salinity hazard (PSH) of all 25 m grid cells in an area was initially developed and demonstrated for a test watershed of 14,000 ha in the County of Warner, Alberta. The success of this initial application led to a desire to apply and evaluate the methodology for a larger and more environmentally diverse region. The new method was applied to a complete 1:250,000 NTS sheet (82P) in order to evaluate its utility and applicability for analysis of PSH in a large (116 by 142 km) and environmentally diverse region (3 Ecoregions).

The hybrid method combined the computational approach used in multi-criteria evaluation (MCE) with an analysis of evidence similar to that used in evidential reasoning (Bayesian logic). The method used only widely available environmental maps and terrain derivatives computed from a 25 m gridded DEM. Previously prepared maps of visible salinity provided the evidence used to establish the probability of occurrence of 8 different types of salinity given a particular map class (j) on each of (i=19) input maps. This information was re-scaled to compute factor scores ($FS_{I,j}$) that reflected the relative likelihood of a particular type of salinity occurring in a particular class (j) of any given map (i). The relative extent of each type of salinity within each unique map class was compared to the proportional extent of each map class to provide a measure of the relative ability of each classed map to explain the observed variation in mapped salinity. This measure provided an indication of the information content, or discriminating value, of each input map in terms of its usefulness in predicting the spatial distribution of visible salinity. The absolute values for information content were used to compute factor weights (WT_j) for the MCE equation for each type of input map for each type of salinity. Application of the MCE equation involved multiplying the re-scaled factor score ($FS_{i,j}$) for each class of each input map by the appropriate weighting factor (WT_i) for the map and computing the sum of these products for 19 individual input maps.

A randomly selected 10% subset of the available information on visible salinity was excluded from the analysis used to develop and apply the PSH rules for each type of salinity within the region of interest. This random subset was subsequently used to evaluate the ability of the PSH procedure to predict the relative likelihood of occurrence of visible salinity for each of 8 different kinds of salinity mapped in the region of interest. The PSH maps produced for each type of salinity agreed closely with the spatial distribution of mapped visible salinity. Of the mapped visible salinity included in the 10% random subset used to evaluate the PSH results, most (70-90%) was located within a limited proportion of the map sheet area (8 - 25%) with high values for PSH.

In addition to providing a highly effective portrayal of the most likely spatial distribution of potential salinity hazard (PSH), the technique generated a quantitative rule base of knowledge on the manner, direction and degree to which the examined environmental and topographical factors influenced the spatial occurrence of salinity. The rule base strengthens understanding of how environmental and topographical factors affect the occurrence of visible salinity. Application of the rules resulted in identification of other sites (or cells) with environmental and topographical conditions similar to those at sites of known visible salinity. The PSH value (0-100) may be interpreted as an indication of how similar other sites are to sites at which visible salinity is known to occur. The rules may be applied to presently unmapped areas to predict the most likely sites of visible salinity prior to field mapping. Alternately they may be re-applied to the areas used to develop the rules to identify sites which depart from the general conditions used to define the rules and which may, therefore, qualify as misclassified sites or outliers..

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INTRODUCTION

Background

This study arose from a previous project aimed at developing and documenting new procedures for assessing and addressing salinity at a watershed level in Alberta (MacMillan and Marciak, 1996a,b). A procedure for estimating the potential salinity hazard (PSH) of all grid cells in a region of interest was developed as part of the previous project (MacMillan et al., 1997). The apparent success of this new PSH methodology in the test watershed attracted the interest of the Soil Quality Program (SQP) component of Alberta Agriculture, Food and Rural Development's Environmentally Sustainable Agriculture Program (AESA). They were interested in evaluating the applicability and utility of the methodology when applied to large and diverse regions.

The SQP has a mandate to monitor and assess the quality of soils in Alberta. Dryland soil salinity is one of the factors considered when assessing soil quality in Alberta. In the context of soil salinity, the questions of concern to the committee include:

- What is the present extent and location of visible soil salinity on agricultural lands in Alberta
- What is the risk of change in the location and extent of visible soil salinity in Alberta in the foreseeable future?

The first question is primarily addressed by an existing program which involves mapping all known locations of visible soil salinity within a County or MD at a scale of 1:100,000. To date, this program has resulted in the production of maps of visible salinity for 16 rural counties and MDs in Alberta (Kwiatkowski et al., 1995, 1996, 1997). These maps provide a snapshot of the location and extent of visible salinity within a county or MD at a given point in time. They provide no indication of other locations where visible soil salinity might appear at some future date, nor of the likelihood of expansion or contraction of visible salinity from its current extent.

The method used to estimate potential salinity hazard (PSH) was thought to offer possibilities for identifying other locations similar to those at which visible salinity is known to currently exist. There was also interest in evaluating the utility of the method to estimate possible changes in the location and extent of visible salinity under different conditions of land use or climate change. Finally, there was interest in PSH as a systematic, quantitative method for analyzing the available maps of visible soil salinity in the context of available environmental and topographical databases in order to develop improved understanding of relationships between soil salinity and environmental and topographical controls.

The mandate of the SQC applies to assessing soil quality on all agricultural lands within the "White Area" of Alberta. This region encompasses over 280,000 km^2 and includes ecological regions ranging from short grass prairie to Boreal forest. It was not known if the PSH methodology was capable of being scaled up from a relatively small local watershed (20 by 20 km) to a region as large and ecologically diverse as the entire White Area. There were concerns with both the volumes of data required to apply the method to a large region and with the applicability of the method across a large and diverse region.

It was decided to apply the PSH methodology to a large and ecologically diverse test region in order to assess its utility and adaptability in a scaled up application. The 1:250,000 NTS map sheet 82P was selected as an appropriate area for applying and evaluating a scale up of the PSH methodology. It contains eco-regions that encompass 3 different soil zones (Brown, Dark Brown and Black) and vegetation communities (short grass prairie, tall grass prairie and parkland). Salinity maps at a scale of 1:100,000 were already prepared and available for 3 different rural municipalities covering approximately 50% of the total extent of the NTS map sheet area. These maps indicated the presence of significant amounts of visible salinity of all 8 different types mapped by Alberta Agriculture. The 50% of the map sheet not covered by existing salinity maps offered the opportunity to test the ability of the PSH methodology to predict the most likely locations of salinity of each type in a presently unmapped area.

Literature Review

Methods for analyzing risk of development or change in salinity

There are few published studies directly concerned with predicting the potential for development of salinity based on data about known extent of salinity (Eilers, 1995). Of these few, the most germane are provided by Corwin et al., (1988; 1989) who described two different approaches for predicting potential for developing soil salinity. The first (Corwin et al., 1988) involved overlaying maps in which areas were identified that exceeded threshold levels with respect to four identified salinization factors (c.f. soil permeability, depth to groundwater, groundwater quality (E.C.) and leaching fraction, a measure of irrigation efficiency). Poor predictive performance of the initial threshold model led Corwin et al., (1989) to propose a set of three, more rigorous, multiple linear regression models that were able to weigh the relative importance of each salinization factor. Of note here is the demand these approaches place on the user to provide detailed, and expensive to obtain, point data in the form of drill hole records (depth to water table, groundwater quality as E.C.) and soil observations (permeability and leaching fraction). Even with such detailed point data, the final maps produced by Corwin et al., (1988) consisted of large polygons (blobs) representing three classes of low, medium and high risk for developing salinity.

Eilers (1995) described a procedure for predicting the risk, or potential for change, in soil salinity, expressed as a salinity risk index (SRI). This procedure represents virtually the opposite end of the spectrum from that described by Corwin et al., (1989). It was based primarily on expert knowledge and opinion, rather than statistical analysis, and utilized very general, but widely available, maps and data sets (c.f. 1:1 million scale Soil Landscapes of Canada). The primary criteria for assessing SRI were the type of land use in each polygon and the potential for change in management practices for each type of land use. The result was again a map consisting of large polygons ranked into classes of low, medium and high salinity risk index. This map had little spatial precision in the predicted location of high salinity risk and little ability to estimate the precise locations where new salinity might develop or existing salinity might disappear in response to changes in land use or environmental conditions.

Methods for analyzing spatial co-occurrence

Despite the relative lack of published procedures for predicting the locations of sites or areas at high risk of developing salinity, a number of studies dealing with other environmental phenomena with a spatial component were identified as relevant. The common thread in these various studies was their use of spatial co-occurrence to analyze relationships between a phenomenon of interest and a set of spatial databases thought to influence the phenomenon of interest.

Three related approaches were identified that all used spatial co-occurrence to analyze relationships between a phenomenon of interest (e.g. visible soil salinity) and a series of classed (choropleth) maps of environmental factors thought to control or influence the spatial distribution of the phenomenon of interest. The three approaches were mutual information analysis (Davis and Dozier, 1990), Bayesian logic (Skidmore et al., 1996; Aspinall and Veitch, 1993) and multi-criteria evaluation (MCE) (Eastman et al., 1995). In all of these, evidence, in the form of maps of a feature or phenomenon of interest, can be cross referenced against available maps of conditions considered likely to influence the spatial distribution of the phenomenon of interest to extract spatial co-occurrence matrices. Spatial co-occurrence can be interpreted to reflect the probability or likelihood of occurrence of the phenomenon of interest given each class on a classed input map and, ultimately, given some combination of classes from ***i*** input maps of interest.

To our best knowledge, none of these techniques have been applied elsewhere to investigate and quantify patterns of spatial distribution of soil salinity or risk of soil salinity. A significant attraction of these approaches is that they provide a systematic, quantitative methodology for utilizing inexpensive and widely available data sets of environmental (e.g. soil maps, geology maps, hydro-geology maps) and topographical information (e.g. DEMs and derivatives of DEMs).

OBJECTIVES

The overall objective of the present study was to evaluate the capability of the previously developed PSH procedure to predict the location and extent of areas of high potential salinity hazard (PSH) when applied to a large and ecologically diverse region.

A secondary objective was to identify and itemize costs, time requirements and significant technical impediments associated with scale up of the PSH procedures from a local watershed scale to a regional or province wide scale.

MATERIALS AND METHODS

Description of the 82P study area

NTS map sheet 82P encompasses an area of approximately 16,000 km^2 (1.6 million ha) between 51°and 52° N latitude and -114 to -112° W longitude. It stretches from the city of Calgary in the SW to Innisfail in the NW and Hanna in the east. Portions of the map sheet fall within 3 different soil zones, these being the Brown, Dark Brown and Black (Figure 1) which correspond to the short grass prairie, long grass prairie and parkland ecoregions.

Maps of visible soil salinity were available for 3 rural municipalities covering just under 50% of the total extent of NTS map sheet 82P, these being the county of Wheatland No. 16, and the MDs of Rock View No. 44 and Starland No. 47 (Figure 1 and Table 1).

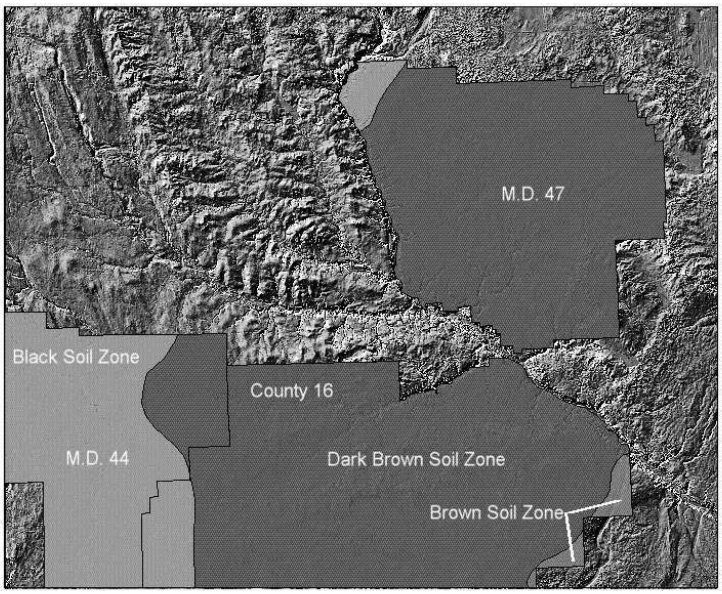


Figure 1. NTS map sheet 82P with 3 rural municipalities and 3 soil zones superimposed

Table 1 . Extent of visible salinity by type in the MD's and County within NTS sheet 82P

Type of Salinity	Extent of Salinity in	MD 47	Extent of Salinity in	MD 44	Extent of Salinity in	CO 16	Extent of Salinity in	Total Area
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Artesian	0.00	0.00	2.31	0.00	69.81	0.02	72.13	0.01
Canal Seep	4.19	0.00	1702.75	0.99	1341.88	0.38	3048.81	0.39
Contact	177.13	0.07	2125.56	1.24	1570.13	0.44	3872.81	0.49
Coulee	160.13	0.06	60.94	0.04	2479.44	0.70	2700.50	0.34
Depression	1606.06	0.61	4848.75	2.82	2366.63	0.67	8821.44	1.12
Natural	0.00	0.00	240.50	0.14	793.63	0.22	1034.13	0.13
Outcrop	3.06	0.00	57.56	0.03	250.81	0.07	311.44	0.04
Slough Ring	361.19	0.14	26.56	0.02	279.31	0.08	667.06	0.08
Total Salinity	2311.75	0.88	9064.94	5.27	9151.63	2.57	20528.31	2.60
Non Saline	259304.63	99.12	162852.75	94.73	346406.38	97.43	768563.75	97.40
Total Area	261616.38	100.00	171917.69	100.00	355558.00	100.00	789092.06	100.00

Table 2. Extent of mapped visible salinity by type in the 3 Soil Zones within NTS sheet 82P

Type of Salinity	Black Soil Zone	Extent	Dark Brown Soil Zone	Extent	Brown Soil Zone	Extent	Total Area	Extent
	ha.	%	ha.	%	ha.	%	ha.	%
Artesian	0.00	0.00	70.88	0.01	1.25	0.01	72.13	0.01
Canal Seep	1204.38	0.71	1844.44	0.30	0.00	0.00	3048.81	0.39
Contact	1983.31	1.17	1889.00	0.31	0.50	0.01	3872.81	0.49
Coulee	166.88	0.10	2369.13	0.39	164.50	1.77	2700.50	0.34
Depression	4038.69	2.39	4782.75	0.78	0.00	0.00	8821.44	1.12
Natural	27.50	0.02	1006.63	0.16	0.00	0.00	1034.13	0.13
Outcrop	58.44	0.03	225.50	0.04	27.50	0.30	311.44	0.04
Slough Ring	29.75	0.02	637.31	0.10	0.00	0.00	667.06	0.08
Total Salinity	7508.94	4.44	12825.63	2.10	193.75	2.08	20528.31	2.60
Non-saline	161670.50	95.56	597781.94	97.90	9111.31	97.92	768563.75	97.40
Total Area	169179.44	100.00	610607.56	100.00	9305.06	100.00	789092.06	100.00

All of the 8 different types of visible soil salinity mapped by Alberta Agriculture, Food and Rural Development were present, to at least some extent, within the portions of the 82P map sheet for which visible soil salinity maps were available (Table 1). The total extent of all types of salinity ranged from less than 1% in MD 47 to over 5% in MD 44 (Table 1). Total salinity of all types was greatest within the Black Soil Zone (4.44%) and lower within the Brown (2.08%) and Dark Brown (2.1%) Zones (Table 2). The 82P map sheet was judged to contain a sufficient number of occurrences of each of the 8 types of mapped salinity to permit the creation of rules based on spatial co-occurrence of visible salinity in the context of a number of input maps of environmental and topographical variables.

Preparation and input of available spatial data layers

Since the project was designed to examine the feasibility of applying the PSH technique to the entire "White Area" of Alberta, it was necessary that it utilize only environmental and topographic data that were widely available for the entire agricultural region of interest.

The principal data sets that met this criterion were:

- the 1:2 million scale map of Bedrock Geology of the Province of Alberta (Green, 1972)
- the 1:250,000 scale maps of bedrock topography contours prepared by the Alberta Geological Survey (various authors)
- the 1:500,000 scale map of the Surficial Geology of Southern Alberta (Shetsen, 1987)
- the 1:100,000 scale AGRASID digital soils data base (CAESA, 1998)
- the PFRA data set of land use classifications prepared from LandSat TM 30 m grid cell remotely sensed imagery (PFRA, 1995)
- the 1:250,000 scale series of provincial hydro-geological maps available from the Alberta Geological Survey (various authors).
- the 1:20,000 digital elevation model (DEM) database available for most of Alberta and distributed by the Spatial Data Warehouse.

All of these, except the bedrock contour and digital elevation model data sets, present their information as classed choropleth maps with abrupt, fixed boundaries and a single value, class or description applied to each outlined polygonal area. This choropleth representation of spatial variation for most of the environmental factors of interest necessitated identifying and utilizing an analysis method that could use classed data effectively.

Table 3. Description of the 19 spatial data layers of environmental and topographical data used in the final PSH analysis

No.	Map Name	Description	Source Map	Reference
1	82P_BRT	Type of bedrock (classes)	Geological Map of Alberta	Green (1972)
2	82P_Z2BR	Depth to bedrock (classes)	Bedrock Contour Map	unattributed
3	82P_SG	Surficial Geology (classes)	Surficial Geology of Southern Alberta	Shetsen, 1987
4	82P_SALC	Soil Map Unit salinity classes	AGRASID Digital Soil Map	CAESA, 1998
5	82P_LU25	Land Use Classes	PFRA classification of TM data	PFRA, 1995
6	82P_B316	Band 3 data in 16 equal classes	Raw unclassified TM data	PFRA, 1995
7	82P_B416	Band 4 data in 16 equal classes	Raw unclassified TM data	PFRA, 1995
8	82P_B516	Band 5 data in 16 equal classes	Raw unclassified TM data	PFRA, 1995
9	82P_FLOW	Rate of groundwater flow in aquifer	Hydrogeology Map of Drumheller, AB	Borneuf, 1972
10	82P_TDS	Total Dissolved Solids in groundwater	Hydrogeology Map of Drumheller, AB	Borneuf, 1972
11	82P_DCRC	Discharge/Recharge areas on map	Hydrogeology Map of Drumheller, AB	Borneuf, 1972
12	82P_SLPC	Slope gradient classed as per CSSC	Computed from 25 m DEM	Eyton, 1991
13	82P_ASPC	Slope azimuth (aspect) (classes)	Computed from 25 m DEM	Eyton, 1991
14	82P_PROF	Plan curvature (classes)	Computed from 25 m DEM	Eyton, 1991
15	82P_PLAN	Profile curvature (classes)	Computed from 25 m DEM	Eyton, 1991
16	82P_PCTU	Percent length upslope from depression (10 equal classes from 0 - 100)	Computed from 25 m DEM	Custom method
17	82P_L2ST	Length from cell to pit or channel in m (classes)	Computed from 25 m DEM	ESRI, 1996
18	82P_FILZ	Maximum depth of ponding (m) if all depressions were to fill to capacity	Computed from 25 m DEM	ESRI, 1996
19	82P_Z2WT	Depth to water table (m) (classes)	DEM & TM Imagery	Custom method

Table 4. Identification of additional spatial data layers used in the PSH analysis

No.	Map Name	Description	Source Map	Reference
20	82P_SACO	25 m raster map of all types of salinity in all 3 mapped rural municipalities	Maps of Dryland Salinity for 3 Rural Municipalities prepared by AAFRD	Kwiatkowski et al., 1996, 1997
21	82P_SA10	10% random subset of 82P_SACO	Extracted from 82P_SACO	Kwiatkowski et al., 1996, 1997
22	82P_SA90	90% of total salinity remaining after removal of a 10% random subset	Extracted from 82P_SACO	Kwiatkowski et al., 1996, 1997
23	82P_allmask	Mask file of mapped MDs & Soil Zones with cells of the 10% random subset excluded (set to missing value)	Soil Group Map of Alberta, MD boundaries 1:250k digital base map	ArcView clip
24	82P_STPD	Simulated extent of surface water in streams and ponds within 82P	Computed from a combination of TM imagery and DEM derivatives	Custom method
25	82P_25m3m	25 m DEM surfaced from 1:20,000 x,y,z input data supplied by AAFRD	1:20,000 x,y,z elevation data produced by Alberta Environmental Protection	Hemenway, 1997
26	82P_25m3HS	Illuminated hillshade image based on 25 m DEM filtered with a 3x3 mean filter	25 m gridded DEM surfaced from 1:20,000 DEM x,y,z input data	Spatial Analyst

Description of the principal data layers used for PSH analysis

These 7 initial sets of environmental and topographical data were used to construct 19 different spatial data layers for the 82P study area (Table 3). Each of these data layers was assumed to reflect, or exercise some influence on, the pattern of spatial distribution of visible soil salinity.

Most of the final data layers listed in Table 3 represent the culmination of several intermediate operations required to prepare, compute and reclassify one or more original input data sources. The individual steps required to produce each of the 19 final data layers used in the PSH analysis are itemized in Appendix 1 along with an estimate of the time required to produce each data layer and any direct or incidental costs associated with compilation of each data layer.

Type of bedrock (82P_BRT) was assumed to influence the type and amount of soluble salts available for dissolution in near-surface groundwater. Underlying bedrock formations were also assumed to influence the degree of soluble salts and salinity in local surficial deposits. Shallow depth to bedrock (82P_Z2BR) was assumed to increase the likelihood of soluble salts migrating upwards to the surface and to also increase the likelihood of development of shallow water tables or groundwater discharge related to shallow bedrock. The texture, thickness and mineral composition of surficial materials (82P_SG) was assumed to play a role in development of salinity by influencing permeability, amounts and rates of water movement and parent material salinity.

The digital soil survey database (AGRASID) was considered to portray classes of repeating soil-landform units which were expected to differ significantly with respect to likelihood of developing different kinds of visible surface salinity. The original AGRASID map contained over 1500 unique soil-landscape models within the mapped counties, many of which were represented by only one or two polygons. These 1500 unique models were grouped into 29 different salinity classes for each of the 8 types of visible salinity (82P_SALC). Groupings were based on consideration of the kind and extent of soils described as occurring in each of the 1500 map units and on an analysis of the distribution of observed visible salinity (82P_SACO) within the 1500 initial soil map units.

An initial assumption was that certain types of land use (e.g. cultivated cropland) might increase the likelihood of development of certain kinds of salinity and other kinds of land use (e.g. pasture) might simply reflect limitations in land use due to the presence of salinity (82P_LU25). The raw TM satellite imagery for each of the 3 available bands, level sliced into 16 equal classes, was included in the analysis (82P_B316, 82P_B416, 82P_B516) to investigate whether areas of known salinity exhibited any consistent pattern with respect to the range of values in spectral reflectance.

The hydrogeology map was interpreted to extract maps of flow rate (82p_FLOW) and content of total dissolved solids (82P_TDS) in the most commonly used local aquifer and to define regions of discharge and recharge (82P_DCRC) based on interpretation of TDS content of the local aquifer. It was assumed that visible salinity might be more common in discharge areas and over aquifers with high TDS and high rates of flow.

Five terrain derivatives, which were assumed to exercise some influence on the presence or absence of visible salinity of different types, were computed from the gridded DEM. Most types of salinity were considered more likely to occur on low gradient slopes than high (82P_SLPC) and on sites with strong local profile (82P_PROFC) and plan concavity (82P_PLANC). Most types of salinity were expected to occur more frequently at sites with a low percent (82P_PCTU) or absolute (82P_L2ST) distance upslope from a depression or stream (e.g. relatively close to a pond or stream). This might be more true for certain types of salinity (e.g. depression bottom, coulee bottom, slough ring) than for others (e.g. contact or outcrop).

Maps of maximum depth of ponding (82P_FILZ) and estimated depth to water table (82P_Z2WT) were constructed via a multi step process. The first step was to identify all cells considered likely to have a high likelihood of being open surface water. This was done by first computing surface flow patterns using the hydrology module of ArcView Spatial Analyst. Part of the process of computing flow topology in ArcView involves finding all pits or depressions in a DEM and "filling" them by raising the elevation of all cells within depressions to the elevation of the lowest overspill or pour point. When all pits are removed, a new modified DEM is created in which the elevation of all cells contained within a depression is raised to the elevation of the depression pour point. The original DEM was subtracted from this "filled" DEM to produce a map of maximum possible depth of ponding for each cell (82P_FILZ). This map was intersected with the Band 3 TM image to identify all cells that had both a positive value for depth of ponding (e.g. were within a filled depression in the landscape) and had a value for reflectance in Band 3 below a selected threshold (DN = 60). These cells were considered to represent a conservative estimate of the location of all cells with open (e.g. ponded) surface water. The most likely locations of stream channels were estimated by applying a threshold to the value computed for upslope area by the ArcView hydrology procedure. A combined map was created that indicated the location of cells considered to belong to either streams or ponds (82P_STPD). The original 25 M DEM was then multiplied by this binary (0/1) map of streams and ponds to obtain the elevation of all cells considered to reflect the location of streams or ponds. These cells were considered to represent outcrops of the local water table and their elevations were entered into a surfacing program to produce a new raster surface taken to approximate the elevation of the water table surface for the entire area of interest. This map of water table elevation was then subtracted from the original DEM elevation surface to compute a map of notional depth to water table (82P_Z2WT).

Description of additional data layers used for PSH analysis

A number of other spatial data layers were also required to complete the PSH analysis (Table 4). These included maps of visible surface salinity previously prepared by AAFRD for the 2 MDs and 1 county within NTS sheet 82P (Kwiatkowski et al., 1995, 1996, 1997), maps depicting the boundaries of the MDs and county for which salinity mapping was available, the Soil Group map of Alberta which depicts boundaries for the Soil Zones used in the analysis and a digital elevation model (DEM) surfaced to a regular 25 m grid for the 82P area of interest.

The DEM was prepared by surfacing x, y, z elevation data available for almost all of the province of Alberta and distributed for the government of Alberta by the Spatial Data Warehouse. The gridded DEM was produced using the program QSURF (Hemenway, 1996) which fits a multi-quadric surface exactly to all x, y, z input data points. Systematic patterns of regular linear variation were strongly evident in the initial surface fitted exactly to all x, y, z input elevations. The initial surface was therefore filtered once using a 3x3 mean filter. This reduced, but did not entirely remove, the most obvious patterns of systematic variation in the gridded DEM.

The 1:20,000 digital elevation data currently available for Alberta are considered to support interpolation to a DEM with a maximum horizontal resolution of 25 m. The elevation surface produced for the 82P study area was therefore prepared at this maximum effective resolution of 25 m. The resulting DEM surface consisted of over 26 million data points and required 4640 rows by 5680 columns of 25 m by 25 m grid cells to completely cover the 116 km (NS) by 142 km (EW) study area. All other data layers were converted to grid files of identical dimensions to maintain consistency and to facilitate overlay analysis.

All data layers expressed in terms of real numbers required at least 103 MB of disk space to store a grid of dimensions 4640 rows by 5680 columns. Real number grids were converted to integer or byte representations once they were classified for use in the final PSH analysis. The integer grids required up to 32 MB of disk space and the byte grids from 1 to 8 MB depending upon the amount of data compression that could be applied to any given map or image.

Including all original input files, intermediate calculation layers and final output layers, over 8 GB of data were processed to produce the final PSH maps for the 82P study area. The large volume of data processed to compute PSH for the test 1:250,000 map sheet was a factor affecting both the times and costs required to apply the PSH methodology to the test area. Data volumes will be a factor in deciding if application of the PSH methodology to the entire "White Area" of Alberta is feasible.

Documentation of the procedures used to compute PSH

Potential salinity hazard (PSH) was computed using a hybrid methodology which incorporated computational procedures based on Multi-Criteria Evaluation (MCE) (Eastman et al., 1995) with evidential reasoning based on Bayesian logic (Skidmore et al., 1996; Aspinall and Veitch, 1993).

The MCE equation described by Eastman et al., (1995) is a simple weighted average computed according to:

$$PSH_k = \sum_{i=1}^{n} FS_{k,i,j} * WT_{k,i} \quad (1)$$

Where:

PSH_k = The potential salinity hazard for the k^{th} type of visible soil salinity (where k = 1, 8)

$FS_{k,i,j}$ = A contrast stretched Factor Score for the j^{th} class of the i^{th} input map for the k^{th} type of visible soil salinity

$WT_{k,i}$ = A Weighting Factor representing the assumed relative importance of the i^{th} input map for predicting the k^{th} type of visible soil salinity

In most previously described applications of the MCE methodology both the factor scores (FS) and weighting factors (WT) were assigned arbitrarily based on expert knowledge and judgement. In the case of assessing the likely "suitability" of a site for developing visible surface salinity this would equate to an expert assigning values for the relative likelihood (FS) of salinity occurring given, for example, 3 different classes of depth to bedrock and also assigning a value for the importance or weight (WT) of the bedrock depth map relative to all other maps used to compute the overall suitability of the site for developing salinity. These assigned values were taken to represent the beliefs, held by the expert, regarding how an anticipated outcome (e.g. presence of salinity) might be affected by each of a series of (***i***) input variable maps, each with a number (***j***) of different classes.

The procedure followed in the present project replaced factor scores and factor weights assigned based on expert beliefs with corresponding values computed following a systematic analysis of the spatial co-occurrence of the variable of interest (salinity of type ***k***) with respect to each class of each input map of interest. Evidence replaced belief as the method for selecting and assigning both factor scores and weighting factors.

Establishing Factor Scores ($FS_{k,I,j}$) for each type of salinity (***k***) for each class (***j***) of each map (***i***)

In MCE, factor scores (FS) (also called criteria scores) are meant to reflect the relative likelihood that a given site will be "suitable" for a desired outcome based on the degree to which the corresponding class ***j*** on each of ***i*** input maps favors, or supports, that outcome. Using the available maps of visible soil salinity, the question that can be posed is: "What is the likelihood or probability of encountering salinity of type ***k*** given the occurrence of map class ***j*** on input map ***i***?

Expressed in terms of probability, this statement becomes:

$$FS_{k,i,j} = P\ (H_{k,i,j} \mid E_{i,j}) \ldots\ldots where \quad (2)$$

$H_{k,i,j}$ = the absolute extent (ha) of salinity of type ***k*** that occurs in areas mapped as map class ***j*** on map ***i***.

$E_{i,j}$ = the absolute extent (ha) of areas on map ***i*** belonging to class ***j*** (e.g. shallow to bedrock)

In MCE the factor scores $FS_{k,I,j}$ are generally standardized by re-scaling the original absolute values for probability into the range of 0-100 or alternatively 0-255.

The absolute values for extent of each of ***k*** = 8 types of salinity within each of ***j*** classes on each of ***i*** maps were computed using the Tabulate by Area function in ArcView 3 Spatial Analyst (ESRI, 1996). A program was written to manipulate these absolute values to convert them first into values for probability of occurrence of salinity of type ***k*** given map class ***j*** on input map ***i*** and thence into contrast stretched factor scores (FS) in which the lowest absolute probability was assigned a value of 0, the highest absolute value of probability assigned a value of 100 and all other values were scaled accordingly between 0 and 100.

Establishing Weighting Factors ($WT_{k,i}$) for each input map (***i***) for each type of salinity (***k***)

In MCE, weighting factors (WT) are meant to quantify the relative importance of each of ***i*** input variables in arriving at a decision regarding the suitability of a given site for an activity or use of interest. Weighting factors are usually based on subjective, expert judgement. In the present project, a systematic analysis of the patterns of distribution of each of ***k*** types of salinity in each of ***j*** classes on each of ***i*** input maps was used to establish a quantitative measure of the usefulness or information content of each map with respect to predicting the occurrence of each of the ***k*** = 8 types of visible soil salinity.

The same raw data on absolute extent of each type of salinity (***k***) within each class (***j***) of each input map (***i***) was reprocessed to assess the degree to which each input map explained the observed variation in visible soil salinity. A four step process was followed.

In the first step, the absolute extent of salinity of type ***k*** within each class ***j*** of map ***i*** was divided by the total extent of salinity of type ***k*** within the entire area of interest. This provided a measure of the proportion of total salinity of type ***k*** that occurred within each of the ***j*** classes on map ***i***. In terms of probability, this may be thought of as the probability of occurrence of map class ***j*** on map ***i*** given salinity of type ***k*** and may be expressed as:

$$P\left(E_{k,i,j} \mid H_{k,i}\right) \ldots\ldots where \qquad \textbf{(3)}$$

$E_{k,i,j}$ = the absolute extent (ha) of areas on map ***i*** belonging to class ***j*** (e.g. shallow to bedrock) that occur within areas mapped as salinity class ***k***

$H_{k,i}$ = the total absolute extent (ha) of salinity of type ***k*** that occurs within map ***i***

The second step involved computing the absolute value of the difference between the proportion of the total salinity of type ***k*** (within each of the ***j*** classes on map ***i***) and the proportion of map ***i*** occupied by each class ***j***. The concept here is that, if the spatial distribution of salinity was not affected in any way by the factors portrayed by the current map of interest, then the proportion of salinity of type ***k*** in each of the ***j*** classes of map ***i*** would be exactly equal to the proportion of class ***j*** in map ***i***. The degree to which the proportion of total visible salinity that occurs in a given map class (***j***) is greater (or less) than the proportion of the map occupied by map class ***j*** provides a measure of the relative ability of that map class to predict the presence (or absence) of visible salinity at a site.

Consider the example of a map with 2 classes in 2 polygons each representing 50% of a map area of interest. If the information portrayed by the 2 polygons on the map bore no relation to the spatial pattern of distribution of the phenomenon of interest (e.g. visible salinity), then one would expect to find 50% of the salinity in each of the 2 polygons. If one were to find 90% of the salinity in one polygon and 10% in the other, one might reasonably conclude that the map provided some power to predict the pattern of spatial distribution of visible salinity. Computing the absolute value of the differences between percent visible salinity (90%, 10%) relative to the percent extent of the 2 map classes (50%, 50%) produces a quantitative measure of the discriminating power, or information content, of the current map (calculated as |90-50| + |10-50| = 80).

The third step in computing a weighting factor for each of the ***i*** input maps was to sum the absolute values of differences in proportion of salinity in each of ***j*** map classes relative to the proportion of map class ***j*** on a given map to compute an overall measure of the information content for each of the ***i*** input maps. This sum represented a quantitative measure of the absolute information content in each input map.

The fourth and final step in computing weighting factors was to re-scale the absolute values for information content for the ***i*** input maps into relative weighting factors that summed to 1.0 for all 19 input maps. This was accomplished by summing all of the values for absolute information content for all 19 input maps and then dividing the absolute value for information content for each individual input map by this sum which represented the total information content in all 19 maps.

Procedures used to evaluate the utility of the PSH estimates

The ability of the 8 individual maps of PSH to predict the likelihood of occurrence of visible salinity in locations not used to construct the rule base was evaluated by identifying and tabulating the distribution of a random subset of mapped visible salinity within 19 class ranges of PSH computed for each of the 8 kinds of salinity.

The evaluation subset was obtained by randomly extracting a 10% sample of salinity polygons from the maps of visible salinity used as evidence in the PSH analysis. The randomly selected sites of mapped visible salinity were excluded from all analyses used to produce the rule bases for computing PSH. This was accomplished by constructing a mask file which masked out all data for the randomly selected sites, as well as all data for regions of the study area that were outside the boundaries of the rural municipalities for which salinity mapping had been completed (see Figure 1). The rule bases were constructed by analysis of spatial co-occurrence of visible salinity against map classes for only those areas not excluded by the mask file. Once finalized, however, the rule bases were applied to the entire area occupied by the 1:250,000 map sheet with no regions masked out. This enabled extrapolation of the rule bases and application of the resulting classification to areas outside the region for which evidence was available.

The distribution of the random subset data for each of the 8 types of visible salinity within each of the 19 equal classes of PSH computed for each type of salinity was compared with the equivalent distribution of salinity of each type used to construct the rule bases. The maps of predicted PSH were considered to be validated if the randomly selected data displayed a distribution by PSH class similar to that of the main data set used to construct the rule base.

The expectation was that most of the random subset of visible salinity would occur within the higher PSH classes and that this distribution would be more or less equivalent to that of the original data set used to construct the rule bases. No statistics were run to quantify the degree of correspondence between the patterns of distribution exhibited by the 10% random subset and by the 90% of mapped salinity used to produce the PSH rule bases.

RESULTS AND DISCUSSION

Weighting factors as measures of relative utility of the selected input maps for predicting visible salinity

Comparison of the proportion of each kind of visible salinity in each map class to the proportion of the entire map area occupied by each map class provides an indication of the degree to which visible salinity is more, or less, likely to occur within a given map class. The greater the difference between the percent of total salinity in a given map class and the percent extent of the map class within the map, the greater the utility of the map in predicting whether visible salinity is likely to occur (or not occur) within a given map class. The distribution of visible salinity with respect to the three main bedrock formations in the study area (Table 5) can be analyzed to illustrate this concept.

Table 5. Distribution of each of the 8 kinds of visible salinity by bedrock formation in 82P

Map Class	Non saline	Depress	Coulee Bottom	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	Map Total
TKp	414369.375	5937.875	598.875	2894.063	212.625	208.375	49.625	610.813	2133.938	427015.563
Khc	331134.750	1796.563	1581.875	620.813	405.563	49.938	18.938	340.438	188.563	336137.438
Kbp	1574.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1574.000
Total	747078.125	7734.438	2180.750	3514.875	618.188	258.313	68.563	951.250	2322.500	764727.000
TKp	55.465	76.772	27.462	82.338	34.395	80.668	72.379	64.212	91.881	55.839
Khc	44.324	23.228	72.538	17.662	65.605	19.332	27.621	35.788	8.119	43.955
Kbp	0.211	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.206
Col %	97.692	1.011	0.285	0.460	0.081	0.034	0.009	0.124	0.304	100.000
TKp	0.374	20.933	28.377	26.499	21.444	24.829	16.540	8.373	36.042	55.839
Khc	0.369	20.727	28.583	26.293	21.650	24.623	16.334	8.167	35.836	43.955
Kbp	0.005	0.206	0.206	0.206	0.206	0.206	0.206	0.206	0.206	0.206
Total Wt	0.747	41.866	57.166	52.997	43.300	49.658	33.081	16.745	72.084	

The first four lines of data (Table 5) give the absolute extent in hectares of each of the 8 different kinds of visible salinity (and of non-saline areas) within each of the 3 bedrock formations mapped in the region of interest. In the next 3 lines, the absolute values are expressed as percent extent of total salinity of a given type within each of the 3 bedrock type classes. The column Map Total indicates the percent of the total map area occupied by each of the 3 bedrock formations. One can observe, for example, that 76% of all depression bottom salinity occurs within the Tertiary - Cretaceous Paskapoo Formation (TKp) which occupies only 55% of the total area of interest. It is reasonable to conclude that depression bottom salinity is slightly more likely to occur within this formation (TKp) relative to its extent within the area of interest, and is less likely to occur within the Horseshoe Canyon Formation (Khc) (23%) relative to its proportional extent (44%).

The degree to which each kind of visible salinity is over or under represented within each class of bedrock formation is evaluated by computing the absolute value of the difference between the percent extent of the bedrock formation map class within the area of interest (Map Total column) and the percent of the total salinity of each type in each of the bedrock formation map classes (e.g. |76-55| = 21). These absolute differences are reported in the next to last 3 rows of data for each of the 3 classes of bedrock type. The absolute difference values for each of the 3 bedrock classes are summed to compute an overall total (Total Wt) which is considered to provide a quantitative measure of the overall information content, or utility, of the bedrock type map for predicting the occurrence of each of the 8 kinds of salinity. The higher the value computed for total weight (Total Wt) the greater the assumed ability of the current map of interest (e.g. bedrock type) to predict the likely presence or absence of visible salinity of a given type.

The process illustrated above was repeated 19 times to compute the extent of each of the 8 kinds of salinity within each of the ***j*** classes of the ***i*** = 19 input maps. Space considerations preclude listing tables comparable to Table 5 for each of the remaining 18 input layers within the main body of this paper but the complete set of cross tabulation data is listed in Appendix 2.

Table 6. Absolute values for total weight computed for each of the 19 input maps

Map No.	Map name	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	Map Average
4	82P_salc	77.3	100.2	57.4	120.3	66.6	97.2	111.2	101.2	91.4
3	82P_sg	55.4	72.3	61.7	100.2	62.8	109.4	107.7	101.8	83.9
5	82P_lu25	72.0	103.2	19.4	86.8	52.6	73.6	81.1	89.3	72.3
19	82P_z2wt	99.7	82.8	53.0	98.2	16.0	62.4	58.4	70.8	67.7
2	82P_z2br	72.3	97.3	48.2	34.3	74.7	46.8	26.8	81.6	60.3
9	82P_flow	13.9	95.3	11.9	66.3	75.4	66.9	94.6	28.5	56.6
16	82P_pctu	69.6	75.4	39.4	92.4	39.0	15.0	34.1	41.8	50.8
17	82P_l2st	55.2	98.5	31.1	49.3	30.3	44.9	33.9	47.1	48.8
10	82P_tds	20.3	40.0	37.0	28.5	24.1	61.3	84.8	71.5	45.9
1	82P_brt	41.9	57.2	53.0	43.3	49.7	33.1	16.7	72.1	45.9
18	82P_filz	89.4	39.8	16.3	125.7	3.9	7.1	29.2	26.1	42.2
14	82p_prof	34.0	51.8	38.1	35.8	51.2	28.7	28.1	33.3	37.6
8	82P_b516	29.5	34.6	29.3	27.9	31.6	44.1	40.5	42.7	35.0
6	82P_b316	37.9	27.7	29.6	43.4	27.4	38.0	32.8	35.8	34.1
12	82P_slpc	38.3	27.2	35.6	36.2	40.9	20.1	35.2	35.1	33.6
11	82P_dcrc	39.3	40.8	34.1	1.0	32.6	30.2	49.0	38.1	33.2
15	82P_plan	31.3	31.8	32.9	28.3	32.7	25.2	30.2	29.6	30.3
7	82P_b416	36.6	41.4	25.5	30.4	17.5	21.4	15.8	31.0	27.5
13	82p_aspc	8.4	6.3	23.4	14.2	28.5	19.3	30.5	26.8	19.7
Indiv	PSH maps	113.8	140.8	96.1	128.1	118.2	126.1	150.9	135.5	126.2
	Max PSH	94.7	78.8	94.1	83.9	74.6	66.5	87.7	120.9	87.7

Table 7. Relative Weighting Factors computed for each of the 19 input maps

Map No.	Map name	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	Map Total
4	82P_salc	0.084	0.089	0.086	0.113	0.088	0.115	0.118	0.101	0.099
3	82P_sg	0.060	0.064	0.092	0.094	0.083	0.129	0.114	0.101	0.092
5	82P_lu25	0.078	0.092	0.029	0.082	0.069	0.087	0.086	0.089	0.077
19	82P_z2wt	0.108	0.074	0.079	0.092	0.021	0.074	0.062	0.070	0.073
2	82P_z2br	0.078	0.087	0.072	0.032	0.099	0.055	0.029	0.081	0.067
9	82P_flow	0.015	0.085	0.018	0.062	0.100	0.079	0.101	0.028	0.061
16	82P_pctu	0.075	0.067	0.059	0.087	0.051	0.018	0.036	0.042	0.054
17	82P_l2st	0.060	0.088	0.047	0.046	0.040	0.053	0.036	0.047	0.052
10	82P_tds	0.022	0.036	0.056	0.027	0.032	0.073	0.090	0.071	0.051
1	82P_brt	0.045	0.051	0.079	0.041	0.066	0.039	0.018	0.072	0.051
18	82P_filz	0.097	0.035	0.024	0.118	0.005	0.008	0.031	0.026	0.043
14	82p_prof	0.037	0.046	0.057	0.034	0.068	0.034	0.030	0.033	0.042
8	82P_b516	0.032	0.031	0.044	0.026	0.042	0.052	0.043	0.043	0.039
6	82P_b316	0.041	0.025	0.044	0.041	0.036	0.045	0.035	0.036	0.038
12	82P_slpc	0.042	0.024	0.053	0.034	0.054	0.024	0.037	0.035	0.038
11	82P_dcrc	0.043	0.036	0.051	0.001	0.043	0.036	0.052	0.038	0.037
15	82P_plan	0.034	0.028	0.049	0.027	0.043	0.030	0.032	0.030	0.034
7	82P_b416	0.040	0.037	0.038	0.029	0.023	0.025	0.017	0.031	0.030
13	82p_aspc	0.009	0.006	0.035	0.013	0.038	0.023	0.032	0.027	0.023

The overall total weight (bottom line of Table 5) for each of the 19 input maps (Table 6) provides a quantitative measure of the utility of each map for predicting each of the 8 kinds of visible salinity. Table 6 lists the maps sorted in order of decreasing mean absolute information content.

The AGRASID soil map, classified into 29 salinity classes had the highest overall utility for predicting all 8 different kinds of visible salinity, while the map of slope aspect had the least. The exact order of importance of the 19 maps varied somewhat for each of the 8 different kinds of salinity. In general, however, the same 4 or 5 input layers were consistently the most useful (soils, surficial geology, land use, depth to water table and depth to bedrock) and the same 4 to 5 layers were least useful (aspect, TM band 4, plan curvature, discharge-recharge areas and slope gradient). Depth of ponding (82P_filz) was an interesting anomaly, as it had a high utility for predicting depression bottom and slough ring salinity but a low utility for all other kinds of salinity. This was considered reasonable, as both depression bottom and slough ring salinity are restricted in occurrence to sites within, or at the margins of the closed depressions which are strongly related to the map of depth of maximum ponding and independent of bedrock depth.

The absolute values for overall information content of each of the 19 input maps (Table 6) were re-scaled to compute relative weighting factors (WT) which summed to 1.0 for all 19 layers (Table 7). This was accomplished by simply summing the values of total weight for each of the 19 layers for each of the 8 kinds of salinity and then dividing each absolute value by this sum. The result is identical to that obtained by using the same absolute values for overall map utility as input to the pairwise comparisons of the Idrisi WEIGHT procedure (Eastman et al., 1997). Since the WEIGHT procedure of Idrisi is limited to a maximum of 15 input layers, it was neither possible, nor necessary, to use it to compute weights for all 19 input maps.

The weighting factors computed for each of the 19 input layers (Table 7) provide a quantitative measure of the relative utility of each of the 19 input layers for predicting each of the 8 kinds of visible salinity. The weights can be reviewed to assess whether expert assumptions regarding the environmental conditions which most strongly influence the spatial distribution of visible salinity are valid. One might, for example, expect the spatial distribution of visible salinity to be strongly influenced by profile or plan curvature, with salinity occurring mainly in concavities or at inflection points in the landscape. If the computed relative weighting factors do not support this expectation it may be that it is incorrect to expect the spatial distribution of visible salinity to be influenced by landform curvature. Alternatively, it may simply indicate that the best available set of data for computing profile curvature was unable to capture terrain curvatures correctly, at the scale of interest. On the other side of the equation, the weight numbers can substantiate expert assumptions that the spatial distribution of salinity is strongly related to, for example, classified soil map units, surficial geologic materials, land use or depth to water table.

Factor scores as measures of probability of occurrence of visible salinity

Factor scores (Table 8) provide a systematic, quantitative estimate of the relative likelihood of encountering salinity of a specific type given the occurrence of a given map class on a given input map. The data on absolute extent of each of the 8 kinds of salinity within each of the ***j*** map classes of each of the 19 input maps were reworked to compute the probability of occurrence of salinity (of type ***k***) given each class ***j*** on each map.

The process is illustrated using type of bedrock as an example (Table 8). The absolute extent of salinity of a given type (e.g. depression bottom = 598 ha) within a given bedrock formation (e.g. TKp) was divided by the absolute extent of the bedrock formation within the area of interest (e.g. TKp = 427,015 ha) and multiplied by 100 to convert to percent. These absolute measures of probability of occurrence of visible salinity given a particular map class (e.g. TKp) were then contrast stretched to produce relative measures in which the class with the highest probability of exhibiting visible salinity received a value of 100 and the class with the lowest probability was assigned a value of 0.

Space limitations preclude listing factor score data for all classes of all 19 input data layers here (see appendix 2).

Relationships between visible salinity and bedrock type

Examination of the factor score data for type of bedrock (Table 8) permits evaluation of expert assumptions regarding which types of bedrock are more likely to be associated with visible soil salinity. In this instance, the data are at odds with expectations. Initial expectations were that salinity would be more extensive in areas underlain by the Cretaceous Bearpaw Formation (Kbp) which is characterized by mainly fine-grained marine sediments (shale) with low permeability and relatively high natural salinity. The sediments considered next most likely to be associated with visible salinity were the low permeability, non-marine sandstone, mudstone and shale of the Cretaceous Horseshoe Canyon (Khc) formation. Visible salinity was expected to be least extensive in areas underlain by higher permeability, non-marine, sandstone belonging to the Tertiary Paskapoo Formation (TKp). The observed pattern is opposite to what was initially expected. It may be that some other factor, related to bedrock type, such as groundwater flow rate or depth to bedrock, is responsible for the observed pattern of distribution of visible salinity. Alternately, it may be that there is no causal relationship between the spatial distribution of visible salinity and the distribution of bedrock type and that the observed relationship is simply fortuitous, and therefore not open to meaningful interpretation.

Table 8. Calculation of contrast stretched factor scores for the 3 bedrock formations

Map Class	Non saline	Depress	Coulee Bottom	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	Map Total
TKp	414369.375	5937.875	598.875	2894.063	212.625	208.375	49.625	610.813	2133.938	427015.563
Khc	331134.750	1796.563	1581.875	620.813	405.563	49.938	18.938	340.438	188.563	336137.438
Kbp	1574.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1574.000
Total	747078.125	7734.438	2180.750	3514.875	618.188	258.313	68.563	951.250	2322.500	764727.000
TKp	97.038	1.391	0.140	0.678	0.050	0.049	0.012	0.143	0.500	55.839
Khc	98.512	0.534	0.471	0.185	0.121	0.015	0.006	0.101	0.056	43.955
Kbp	100.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.206
Map Tot	97.692	1.011	0.285	0.460	0.081	0.034	0.009	0.124	0.304	100.000
TKp	0.000	100.000	29.801	100.000	41.270	100.000	100.000	100.000	100.000	0.000
Khc	49.746	38.436	100.000	27.251	100.000	30.444	48.478	70.804	11.225	0.000
Kbp	100.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Relationships between visible salinity and depth to bedrock

Conventional wisdom holds that visible surface salinity is more likely to occur at locations at which bedrock occurs close to the surface and results in shallow or perched water tables and increased likelihood of discharge of saline groundwater from bedrock formations. The spatial co-occurrence data (Table 9) support this assumption for most of the 8 kinds of visible salinity.

The bottom row of data in Table 9 indicate the extent of the total map area (in %) occupied by each of the 8 kinds of visible surface salinity. In any given column of data, numbers larger than this overall mean value for the entire map area indicate that salinity is more likely to occur within that map class than within the map area as a whole. Values smaller than the mean indicate that salinity is less likely to occur within a given class than within the area as a whole. The larger the difference, the greater the tendency for salinity to be preferentially over or under represented within the given map class.

Most kinds of visible surface salinity (except slough ring) were more likely to occur at locations with shallow depth to bedrock and were less common in areas characterized by thick surficial sediments. In general, salinity was proportionally most extensive in bedrock depth classes 1, 2 and 3 which represent depths to bedrock ranging from 0 m (bedrock outcrop) to a maximum of 1 m. The observed pattern was one of a regular and continuous reduction in proportion of visible salinity with increasing depth to bedrock. The major anomaly was slough ring salinity in which depth to bedrock seemed to exercise little effective control. If anything, slough ring salinity was more common in areas of relatively large depth to bedrock (classes 6-8, 5 to 30 m).

Artesian and natural salinity also displayed a tendency to be proportionally more extensive in areas of moderate depth to bedrock (classes 3 to 6) than in either the areas with very shallow depth to bedrock (classes 1 and 2) or very deep surficial sediments (classes 7 to 12). Slough ring salinity develops around the margins of wet depressions and does not require a shallow depth to bedrock to initiate conditions favorable to the development of salinity. It would appear that both natural and artesian salinity may also develop in areas of thicker surficial materials and shallow depth to bedrock is not a requirement for formation of these kinds of salinity.

Table 9. Raw (not stretched) factor scores relating visible salinity and depth to bedrock

Map No.	Class No.	Class Def.	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	% Extent by Class
2	1	Outcrop	2.343	1.448	0.497	0.071	0.058	0.002	0.061	0.444	6.906
2	2	Very Shallow	3.536	1.208	1.410	0.049	0.103	0.017	0.062	0.657	1.026
2	3	0.5 to 1 m	2.770	1.086	1.389	0.064	0.148	0.015	0.124	0.827	1.207
2	4	1 to 2 m	2.341	0.923	0.985	0.062	0.134	0.025	0.168	0.911	1.441
2	5	2 to 5 m	2.202	0.496	0.904	0.059	0.113	0.009	0.158	0.882	5.899
2	6	5 to 10 m	1.549	0.251	0.727	0.091	0.059	0.019	0.156	0.691	14.986
2	7	10 to 20 m	0.703	0.120	0.478	0.080	0.021	0.009	0.083	0.230	31.912
2	8	20 to 30 m	0.282	0.056	0.213	0.132	0.013	0.003	0.098	0.034	20.818
2	9	30 to 40 m	0.156	0.016	0.085	0.011	0.017	0.014	0.133	0.022	9.971
2	10	40 to 50 m	0.041	0.016	0.048	0.005	0.001	0.004	0.104	0.000	4.060
2	11	50 to 100 m	0.005	0.011	0.092	0.000	0.000	0.000	0.028	0.012	1.772
2	12	> 100 m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Extent of Map(%)	1.011	0.285	0.460	0.081	0.034	0.009	0.124	0.304	100.000

Relationships between visible salinity and type of surficial materials

It was assumed that salinity would vary in response to differences in the texture, permeability and inherent natural salinity of the various classes of surficial material recognized on the surficial geology map. The spatial co-occurrence data (Table 10) supported this assumption for most of the 8 kinds of visible salinity.

Most kinds of visible salinity occurred preferentially in surficial units representing undivided ice contact lacustrine and fluvial deposits (8), coarse eolian sediments (2a), eolian sand and silt (1), draped moraine up to 5 m thick overlying bedrock (9) and fine textured fluvial deposits (3b). The common feature of these sediments was not their texture or inherent salinity, but rather their tendency to be associated with environments characterized by higher than normal rates and volumes of water flow at or near the land surface. It appeared that these classes of surficial material provided some indication of whether water was more likely to be present at or near the land surface.

Several kinds of surficial materials showed a higher than normal likelihood of exhibiting one or more, but not all 8, kinds of visible salinity. These included undifferentiated till less than 3 metres thick overlying bedrock (10a) which was associated with increased presence of depression bottom salinity; fine textured lacustrine sediments (2b) associated with increased presence of coulee bottom, slough ring and natural salinity; coarse fluvial (3a) and fine ice-contact (6b) also associated with increased coulee bottom and slough ring salinity, and fine fluvial (7b) and coarse lacustrine ice-contact (6a) deposits associated with increased presence of depression bottom salinity. It was not unexpected to find fine lacustrine (2b), fine ice-contact (6b) and coarse fluvial (3a) sediments preferentially associated with salinity developed in coulee bottoms or sloughs as these landscape locations are frequently occupied by these kinds of sediments. Similarly, depression bottoms are commonly associated with fine textured sediments (7b) and lacustrine sediments of a variety of textures, including coarse (6a). In these cases, the association between parent material type and visible salinity is not strongly causal, but rather reflects a common tendency to occur in the same locations in the landscape (e.g. coulees or depressions).

Table 10. Raw (not stretched) factor scores relating visible salinity to surficial materials

Map No.	Class No.	Class Def.	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	% Extent by Class
3	1	10 d	0.236	0.000	0.004	0.000	0.008	0.000	0.000	0.000	2.016
3	2	12	0.872	0.000	0.146	0.004	0.027	0.000	0.000	0.000	1.166
3	3	10 a	1.580	0.140	0.436	0.012	0.029	0.005	0.000	0.055	11.371
3	4	10 b	0.596	0.104	0.177	0.069	0.017	0.001	0.004	0.005	16.863
3	5	7 a	0.000	0.000	0.038	0.000	0.000	0.000	0.000	0.045	0.210
3	7	10 c	0.302	0.040	0.080	0.031	0.010	0.000	0.000	0.000	8.314
3	8	8	6.188	1.706	0.806	0.028	0.001	0.000	0.018	2.555	1.919
3	9	2 a	1.139	0.241	0.597	0.212	0.113	0.014	0.323	0.828	11.206
3	10	1	3.084	0.114	0.416	0.000	0.065	0.128	1.512	0.780	2.153
3	11	9	1.225	0.315	0.907	0.023	0.038	0.004	0.110	0.481	23.613
3	12	2 b	0.305	0.685	0.328	0.317	0.021	0.004	0.255	0.086	10.605
3	13	3 a	1.028	2.241	0.000	0.116	0.000	0.000	0.000	0.000	0.527
3	14	3 b	1.211	1.134	0.791	0.003	0.000	0.012	0.003	0.388	3.108
3	15	4 a	0.000	0.030	0.004	0.000	0.000	0.000	0.000	0.000	2.151
3	16	6 a	1.457	0.072	0.029	0.000	0.022	0.000	0.000	0.000	0.110
3	17	14 a	0.278	0.134	0.024	0.001	0.022	0.046	0.002	0.128	4.140
3	18	6 b	0.069	1.670	0.083	0.112	0.040	0.000	0.000	0.000	0.438
3	19	7 b	2.236	0.000	0.023	0.000	0.000	0.000	0.000	0.000	0.068
3	21	15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022
		Overall Extent (%)	1.011	0.285	0.460	0.081	0.034	0.009	0.124	0.304	100.000

Calculation of potential salinity hazard (PSH) for each of the 8 kinds of visible salinity

A value for potential salinity hazard (PSH) was computed for each of the 8 different kinds of visible salinity. This was achieved by summing the 19 individual products that resulted from multiplying the stretched factor score for each class of each map by the weighting factor for each of the 19 input maps for each of more than 25 million 25 by 25 m grid cells within the study area.

Visual illustration of the pattern of spatial distribution of each of the 8 kinds of visible salinity relative to the predicted PSH for each of the 8 salinity types was not practical for the entire study area due to the large size of a 1:250,000 map sheet and the small size of many of the mapped occurrences of salinity. Effective illustration would have required production of 8 sets of full sized maps printed at a scale of at least 1:500,000 and preferably 1:250,000. A smaller subset of the entire 1:250,000 map sheet was selected to illustrate the spatial relationships (Figures 2 & 3). The subsetted region was selected mainly because it contained examples of all 8 kinds of visible salinity within a relatively small area that was amenable to less than page sized illustration.

Figure 2 illustrates the complete range of variation in PSH for each of the 8 kinds of visible salinity for the subsetted area. The shades of gray represent 20 equal classes of PSH ranging from 0 (dark gray) to 100 (nearly white). The type of visible salinity corresponding to the predicted PSH is over-plotted on each map in the color normally used to portray that type of salinity on county scale salinity maps prepared by Alberta Agriculture, Food and Rural Development (AAFRD). Examination of the illustrations reveals that actual mapped occurrences of visible salinity most often occur in areas with high predicted PSH for that kind of salinity. Also evident is the fact that significant areas rated as having high PSH have no visible salinity currently mapped within them.

In figure 3, areas with high values of PSH, equal to or greater than the values associated with areas of known and mapped visible salinity, are illustrated using a color legend. The color legend uses shades of green to represent values of PSH in the range of 35-50, shades of yellow for PSH values from 55-70, shades of orange for PSH from 70-85 and shades of red for PSH from 85-100. All areas with PSH values less than the selected minimum were rendered as transparent such that an underlying illuminated hillshade image of the topography of the subsetted area is displayed. Actual mapped salinity of the type predicted by the depicted PSH map is over plotted and displayed in the appropriate color. These images more strongly portray the close spatial relationship between visible salinity as mapped by AAFRD and areas rated as having a high PSH for that type of salinity. For most kinds of visible salinity, the PSH maps identify areas with site conditions and landscape positions that are closely similar to those at the locations of known and mapped visible salinity.

An analysis of the distribution of mapped salinity by PSH class for each of the 8 kinds of visible salinity expands upon and quantifies the impression of strong spatial association arising from visual examination of the illustrations of spatial patterns of PSH in figures 2 and 3. The absolute (Table 11) and cumulative (Table 12) percent extent of each of the 19 class ranges of predicted PSH within the total area for which maps of visible salinity were available provide an indication of the usefulness of the PSH maps for isolating sites or regions with high potential salinity hazard. High values of PSH (greater than 50) occupied less than 5% of the total extent of each of the maps of predicted PSH for all PSH maps except contact salinity PSH for which high values occupied more than 25% of the total area.

For depression bottom salinity PSH classes covering less than 25% of the entire map area (PSH > 25-30) contained over 80% of the visible depression bottom salinity mapped by AAFRD and classes covering less than 10% of the total area (PSH > 35-40) contained over 60% of observed salinity. The total weighting factor of 114 computed for the depression bottom PSH map was greater than any of the absolute weighting factors computed for the individual input maps (Table 6). This supports the conclusion that the map of predicted PSH provides a superior estimate of the likelihood of encountering depression bottom PSH than any of the individual input maps.

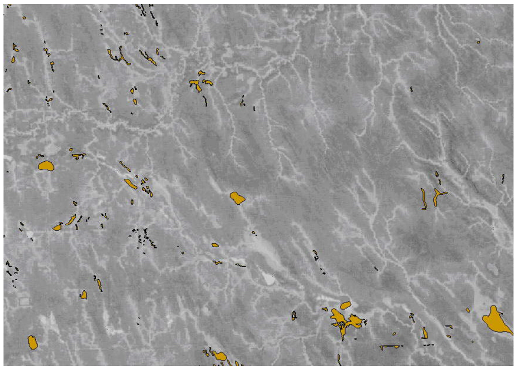
75% of the mapped coulee bottom salinity occurred within PSH classes than occupied less than 30% of the total map area (PSH values > 35) and 50% of the mapped salinity occurred in classes that occupied less than 8% of the total map area (PSH > 45). The overall weighting factor for the map of coulee bottom PSH was considerably greater than the largest weighting factor for any of the individual input maps (PSH = 141 vs. 103 for land use in Table 6).

Contact salinity was perhaps the least well explained type of salinity. 60% of mapped contact salinity occurred within PSH classes that occupied less than 15% of the total mapped area (PSH values > 55) and 40% fell in classes that occupied less than 7% of the total map area (PSH > 65). The final PSH map for contact salinity had the lowest weighting factor of all the PSH maps (96), but this was still considerably larger than the greatest value for any individual input map (62 for surficial geology). The data indicated that contact salinity occurred over a wider range of classes for all of the selected input maps than was the case for any of the other kinds of salinity. Contact salinity was therefore more difficult to predict because it occurred over a wider range of landform positions and site conditions.

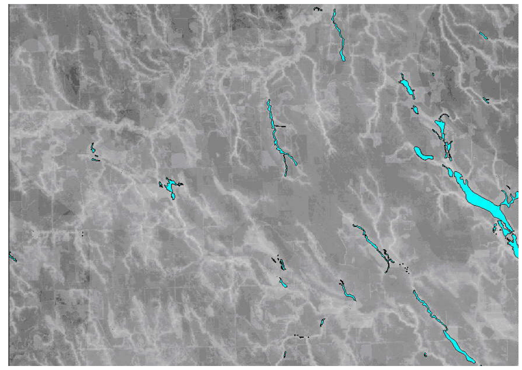
90% of observed slough ring salinity occurred in classes than occupied slightly more than 30% of the total map area (PSH > 25) and 70% of slough ring salinity occurred in classes covering less than 7% of the total area (PSH > 35). The final PSH map was only slightly better at predicting the spatial distribution of slough ring salinity (weight = 128) than the individual input maps for depth of ponding (82p_filz = 126) or classified soil map units (82p_salc = 120).

89% of outcrop salinity occurred in PSH classes that occupied less than 40% of the total map area (PSH > 40) and 70% was located in PSH classes that occupied less than 10% of the total map area (PSH > 50). This represented a considerably better success at predicting the spatial distribution of outcrop salinity than could be achieved using any of the individual input maps.

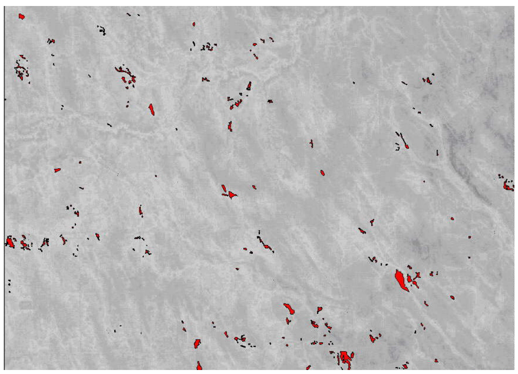
81% of artesian salinity occurred in PSH classes that occupied less than 19% of the total map area (PSH > 35) and almost 70% of all salinity occurred in PSH classes covering less than 8% of the total map area (PSH > 40). The map of artesian PSH had considerably greater predictive power than any of the individual input maps (weight = 126 vs. 109 for surficial geology).



a) Mapped depression bottom salinity vs. predicted PSH

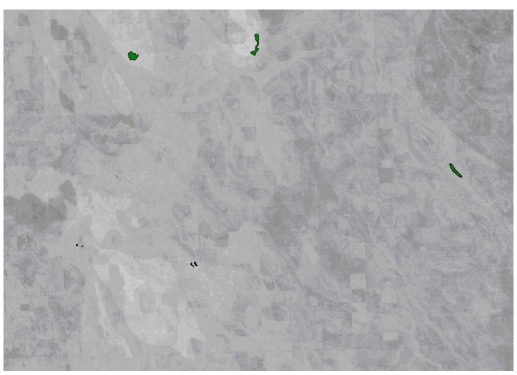


b) Mapped coulee bottom salinity vs. predicted PSH

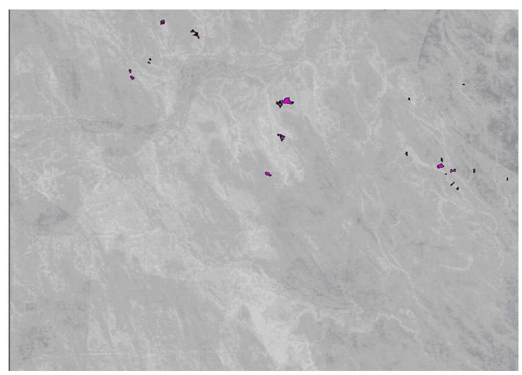


c) Mapped contact salinity vs. predicted PSH

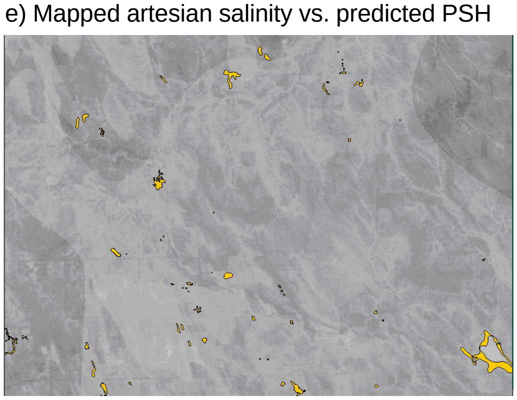
d) Mapped slough ring salinity vs. predicted PSH



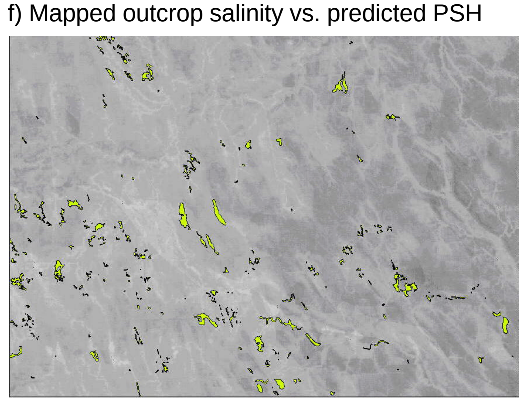
e) Mapped artesian salinity vs. predicted PSH



f) Mapped outcrop salinity vs. predicted PSH

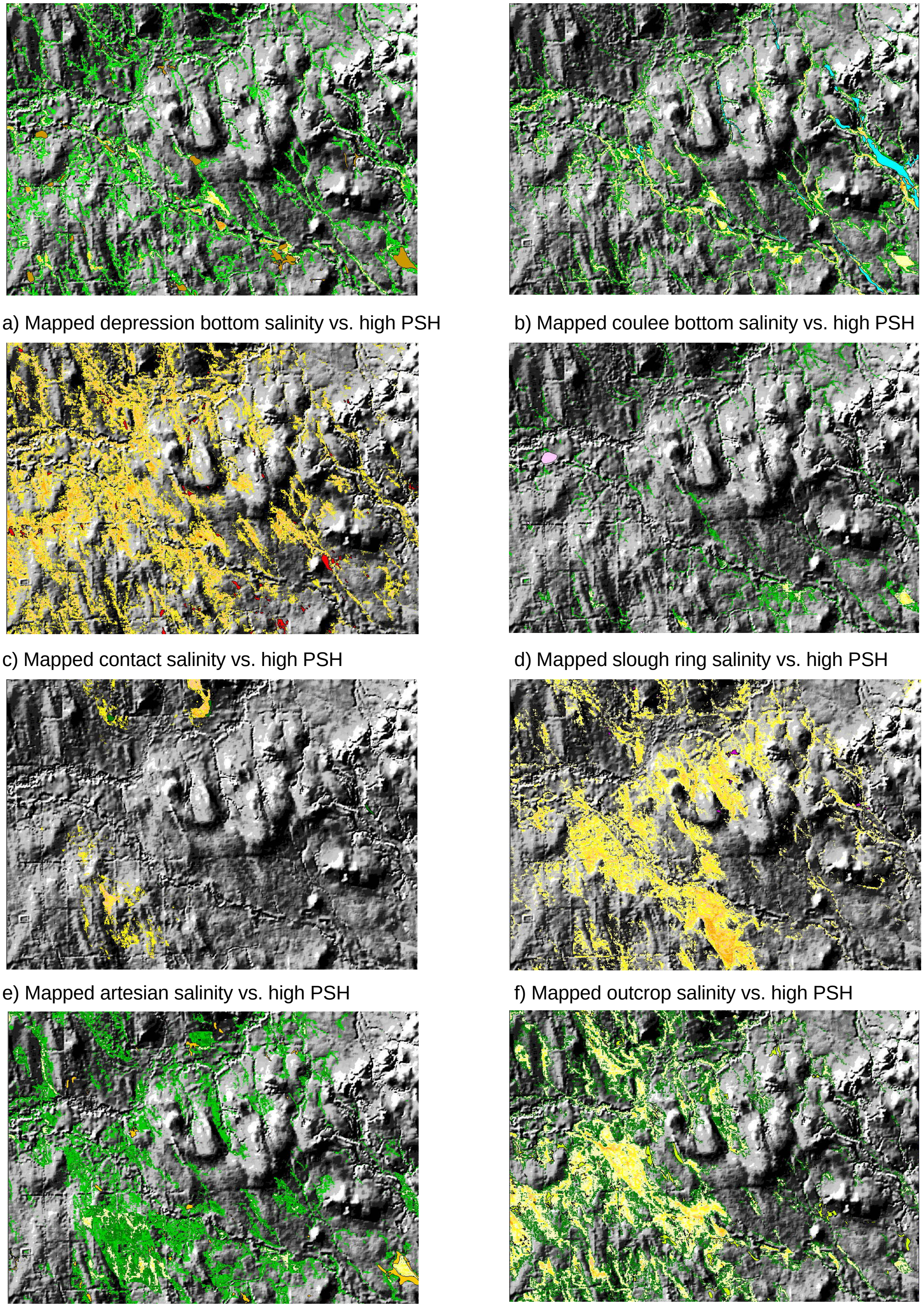


g) Mapped natural salinity vs. predicted PSH



h) Mapped canal seep salinity vs. predicted PSH

Figure 2. Illustration of spatial correspondence of predicted PSH to actual mapped salinity



a) Mapped depression bottom salinity vs. high PSH

b) Mapped coulee bottom salinity vs. high PSH

c) Mapped contact salinity vs. high PSH

d) Mapped slough ring salinity vs. high PSH

e) Mapped artesian salinity vs. high PSH

f) Mapped outcrop salinity vs. high PSH

g) Mapped natural salinity vs. predicted PSH

h) Mapped canal seep salinity vs. high PSH

Figure 3. Illustration of spatial correspondence of high values of predicted PSH and actual mapped salinity for each of the 8 kinds of visible salinity

Table 11. Absolute percent of total map occupied by each PSH class on each PSH map

PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep
0-5	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
5-10	0.259	0.402	0.000	0.903	0.000	0.000	0.159	0.035
10-15	7.984	1.769	0.003	14.051	0.002	0.041	5.108	1.643
15-20	23.681	6.584	0.133	29.304	0.294	2.668	24.654	8.724
20-25	26.103	10.927	1.102	24.332	3.516	17.983	30.927	15.765
25-30	17.242	15.176	4.036	15.796	12.035	35.180	19.529	19.363
30-35	9.781	19.345	8.951	8.678	21.316	26.032	10.287	19.477
35-40	6.173	17.351	13.534	4.214	23.257	10.925	4.987	14.822
40-45	4.053	12.779	15.609	1.762	18.578	4.017	2.427	9.734
45-50	2.585	8.110	15.585	0.596	11.486	1.748	1.053	5.641
50-55	1.290	4.837	14.343	0.183	5.893	0.848	0.555	2.822
55-60	0.476	1.826	11.826	0.066	2.459	0.390	0.238	1.215
60-65	0.164	0.668	8.128	0.059	0.843	0.123	0.058	0.457
65-70	0.076	0.185	4.443	0.042	0.249	0.035	0.013	0.186
70-75	0.061	0.034	1.774	0.013	0.059	0.009	0.004	0.083
75-80	0.049	0.006	0.465	0.000	0.012	0.001	0.001	0.030
80-85	0.021	0.000	0.065	0.000	0.001	0.000	0.000	0.004
85-90	0.003	0.000	0.002	0.000	0.000	0.000	0.000	0.000
90-95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000

Table 12. Cumulative percent of total map occupied by each PSH class on each PSH map

PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep
0-5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5-10	0.26	0.40	0.00	0.91	0.00	0.00	0.16	0.04
10-15	8.24	2.17	0.00	14.96	0.00	0.04	5.27	1.68
15-20	31.92	8.76	0.14	44.26	0.30	2.71	29.92	10.40
20-25	58.03	19.68	1.24	68.59	3.81	20.69	60.85	26.17
25-30	75.27	34.86	5.27	84.39	15.85	55.87	80.38	45.53
30-35	85.05	54.20	14.23	93.07	37.16	81.90	90.66	65.01
35-40	91.22	71.55	27.76	97.28	60.42	92.83	95.65	79.83
40-45	95.28	84.33	43.37	99.04	79.00	96.85	98.08	89.56
45-50	97.86	92.44	58.95	99.64	90.48	98.59	99.13	95.20
50-55	99.15	97.28	73.30	99.82	96.38	99.44	99.69	98.03
55-60	99.63	99.11	85.12	99.89	98.84	99.83	99.92	99.24
60-65	99.79	99.77	93.25	99.95	99.68	99.96	99.98	99.70
65-70	99.87	99.96	97.69	99.99	99.93	99.99	100.00	99.88
70-75	99.93	99.99	99.47	100.00	99.99	100.00	100.00	99.97
75-80	99.98	100.00	99.93	100.00	100.00	100.00	100.00	100.00
80-85	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
85-90	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
90-95	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 13. Absolute percent of total salinity by type in each of the 19 PSH class ranges

PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep
0-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5-10	0.001	0.007	0.000	0.033	0.000	0.000	0.000	0.000
10-15	0.207	0.489	0.000	1.150	0.000	0.000	0.000	0.000
15-20	2.489	1.300	0.000	3.885	0.000	0.182	0.000	0.046
20-25	6.382	3.737	0.025	5.599	0.194	2.461	1.710	0.539
25-30	9.311	4.498	0.275	9.668	0.994	3.373	4.127	1.532
30-35	10.970	6.165	0.950	9.104	3.684	12.853	9.378	3.444
35-40	11.689	8.440	2.056	9.429	6.641	12.580	16.403	6.541
40-45	13.483	10.970	4.053	7.932	8.434	9.754	14.195	10.958
45-50	13.632	13.421	6.889	7.671	11.464	9.207	9.619	16.774
50-55	11.545	13.980	10.984	4.546	18.274	7.019	17.929	19.126
55-60	7.050	11.926	14.624	5.990	21.280	14.038	14.942	17.008
60-65	3.829	10.014	19.158	16.254	16.166	15.770	7.162	12.248
65-70	2.262	7.719	19.450	12.533	8.677	7.384	2.128	6.481
70-75	2.139	3.856	13.532	6.174	3.926	4.284	1.871	3.293
75-80	2.676	1.756	6.501	0.033	0.267	1.094	0.538	1.724
80-85	2.025	1.409	1.429	0.000	0.000	0.000	0.000	0.271
85-90	0.307	0.314	0.062	0.000	0.000	0.000	0.000	0.014
90-95	0.002	0.000	0.011	0.000	0.000	0.000	0.000	0.000
Total	0.926	0.258	0.451	0.079	0.035	0.009	0.106	0.299

Table 14. Cumulative percent of total salinity by type in each of the 19 PSH class ranges

PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep
0-5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5-10	0.00	0.01	0.00	0.04	0.00	0.00	0.00	0.00
10-15	0.21	0.50	0.00	1.19	0.00	0.00	0.00	0.00
15-20	2.70	1.80	0.00	5.07	0.00	0.18	0.00	0.05
20-25	9.08	5.53	0.03	10.67	0.19	2.64	1.71	0.59
25-30	18.39	10.03	0.30	20.34	1.19	6.02	5.84	2.12
30-35	29.36	16.20	1.25	29.44	4.87	18.87	15.22	5.56
35-40	41.05	24.64	3.31	38.87	11.51	31.45	31.62	12.10
40-45	54.53	35.61	7.36	46.80	19.95	41.20	45.81	23.06
45-50	68.16	49.03	14.25	54.47	31.41	50.41	55.43	39.83
50-55	79.71	63.01	25.23	59.02	49.69	57.43	73.36	58.96
55-60	86.76	74.93	39.86	65.01	70.97	71.47	88.30	75.97
60-65	90.59	84.95	59.01	81.26	87.13	87.24	95.47	88.22
65-70	92.85	92.67	78.46	93.80	95.81	94.62	97.59	94.70
70-75	94.99	96.52	92.00	99.97	99.73	98.91	99.46	97.99
75-80	97.67	98.28	98.50	100.00	100.00	100.00	100.00	99.71
80-85	99.69	99.69	99.93	100.00	100.00	100.00	100.00	99.99
85-90	100.00	100.00	99.99	100.00	100.00	100.00	100.00	100.00
90-95	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

For natural salinity, 95% of the mapped salinity occurred in PSH classes covering less than 20% of the total area (PSH > 30) and 70% occurred in PSH classes that covered less than 5% of the total area (PSH > 40). This represented a very effective prediction of the spatial distribution of both actual mapped natural salinity and potential future natural salinity. The weight computed for natural salinity PSH (151) was greater than for any other type of salinity and was also greater than for any of the individual input maps (151 vs. 101 for the classified soil map 82p_salc).

88% of canal seep salinity occupied PSH classes covering just over 20% of the total map area (PSH > 40) and 75% was found in classes covering just over10% of the total area (PSH > 45). This also represented relatively effective prediction of the locations at which canal seep salinity was most likely to occur. Again, the weighting factor for overall canal seep PSH was greater than for any of the individual input maps (126 vs. 91 for the classified soil map).

The usefulness of the maps of predicted PSH were also evaluated by comparing the percent extent of each PSH class occupied by actual mapped visible salinity to the percent extent of salinity in the map area as a whole, without regard to any other map or classification (Table 15). If the PSH map does not contain any useful information about the spatial distribution of observed salinity, it would be logical to expect that each PSH class would contain a percent extent of salinity more or less equal to the known extent of salinity in the map area as a whole (Map in Table 15). If, on the other hand, the PSH map was effective in predicting the relative likelihood of occurrence of potential salinity of a given type, some classes on the PSH map (specifically the classes with the highest values of PSH) should exhibit distributions of mapped salinity much greater than for the map area as a whole and some of the lower classes should have less extensive salinity than found in the map area as a whole.

Examination of Table 15 reveals that the extent of salinity in each of the PSH classes was consistently less than the total extent for the map area as a whole for the lowest classes and was consistently greater than the map average for higher classes. In fact, for all classes, the percent extent of mapped salinity increased logically and consistently from zero for the lowest PSH class to as much as 100% for the highest classes of depression bottom salinity and 20% to 90% for the highest classes of most of the other PSH maps. This was judged to be very encouraging.

Table 15. Percent of each of 19 PSH range classes occupied by salinity of each type

PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep
0-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5-10	0.003	0.001	0.000	0.003	0.000	0.000	0.000	0.000
10-15	0.024	0.007	0.000	0.006	0.000	0.000	0.000	0.000
15-20	0.097	0.013	0.000	0.010	0.000	0.001	0.000	0.002
20-25	0.226	0.052	0.010	0.018	0.002	0.001	0.006	0.010
25-30	0.500	0.081	0.031	0.048	0.003	0.001	0.022	0.024
30-35	1.039	0.167	0.048	0.083	0.006	0.005	0.097	0.053
35-40	1.754	0.358	0.068	0.176	0.010	0.011	0.350	0.132
40-45	3.081	0.828	0.117	0.354	0.016	0.023	0.622	0.337
45-50	4.884	1.729	0.199	1.012	0.035	0.049	0.971	0.889
50-55	8.288	3.135	0.345	1.958	0.109	0.078	3.434	2.027
55-60	13.726	6.340	0.557	7.159	0.305	0.337	6.678	4.185
60-65	21.621	14.695	1.063	21.738	0.676	1.203	13.123	8.017
65-70	27.659	36.733	1.974	23.702	1.226	1.977	18.039	10.446
70-75	32.599	45.106	3.439	37.858	2.327	4.430	49.786	11.926
75-80	50.725	50.189	6.298	21.429	0.814	13.636	0.000	17.038
80-85	91.507	71.237	9.976	0.000	0.000	0.000	0.000	20.971
85-90	100.000	92.233	15.207	0.000	0.000	0.000	0.000	20.000
90-95	100.000	0.000	66.667	0.000	0.000	0.000	0.000	0.000
Map	0.926	0.258	0.451	0.079	0.035	0.009	0.106	0.299

Calculation of overall (maximum) potential salinity hazard (PSH)

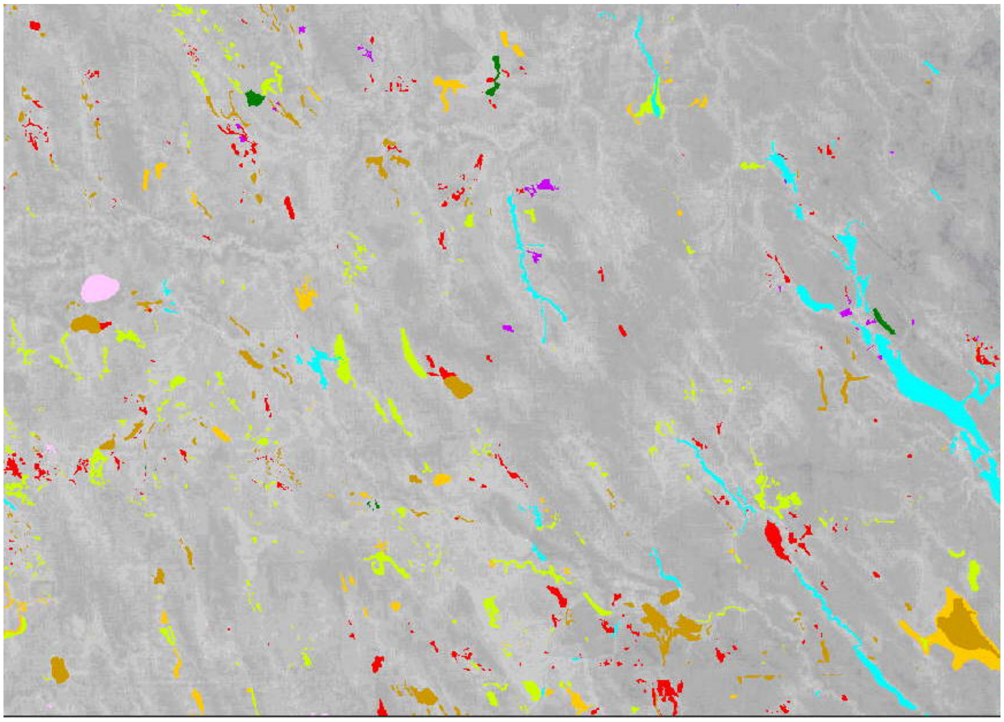
A map of overall potential salinity hazard (PSH) was prepared by identifying, and recording for each cell, the maximum value of PSH computed for any of the 8 different kinds of visible salinity. This map (Figure 4), identified the locations most likely to display salinity of any kind within the area of interest.

Table 16. Distribution of salinity by type by maximum PSH class range (expressed as absolute percent of total mapped salinity of each type in each PSH class range)

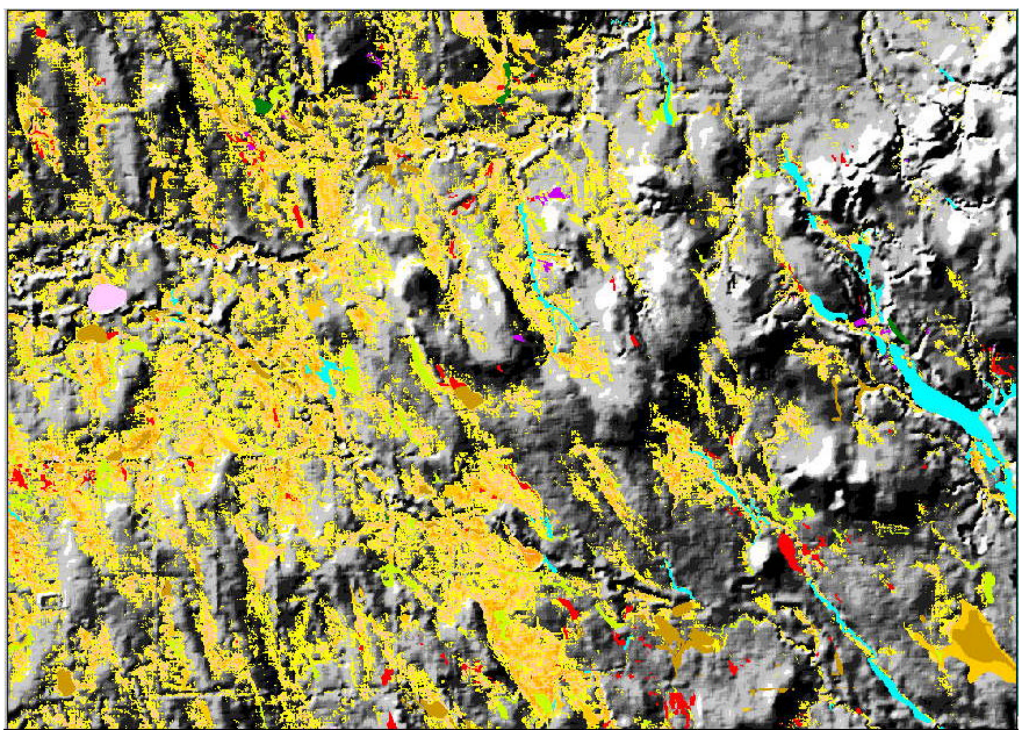
PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	Extent (%) of Classes	Cumulative Extent (%)
15-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.001
25-25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.107
25-30	0.04	0.06	0.07	0.08	0.12	0.00	0.00	0.00	1.97	2.079
30-35	0.46	0.65	0.66	0.61	1.67	0.27	0.04	0.02	7.60	9.676
35-40	1.69	2.03	1.98	1.28	4.58	2.92	0.72	0.35	13.69	23.363
40-45	4.03	4.92	3.95	3.73	5.94	13.13	3.52	1.08	16.46	39.821
45-50	7.17	9.22	6.79	8.90	8.39	13.22	8.25	2.44	16.47	56.291
50-55	10.79	15.26	11.02	14.97	13.62	8.84	15.71	7.19	15.24	71.531
55-60	14.62	19.71	14.79	18.77	20.09	13.95	24.87	14.68	12.55	84.082
60-65	17.46	19.46	19.47	25.90	20.02	22.15	24.03	20.73	8.60	92.682
65-70	17.55	16.04	19.62	16.62	17.01	15.31	14.96	23.65	4.74	97.420
70-75	13.65	7.97	13.59	8.08	7.95	8.39	6.47	18.93	1.93	99.351
75-80	8.54	2.86	6.56	0.96	0.61	1.82	1.43	8.98	0.55	99.900
80-85	3.62	1.50	1.44	0.10	0.00	0.00	0.00	1.85	0.10	99.995
85-90	0.37	0.31	0.06	0.00	0.00	0.00	0.00	0.09	0.01	100.000
90-95	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	100.000
Extent of Map	0.93	0.26	0.45	0.08	0.04	0.01	0.11	0.30	100.00	100.000

Table 17. Distribution of salinity by type by maximum PSH class range (expressed as cumulative percent of total mapped salinity of each type in each PSH class range)

PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	Extent (%) of Classes	Cumululative Extent (%)
15-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.001
25-25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.107
25-30	0.04	0.06	0.07	0.08	0.12	0.00	0.00	0.00	1.97	2.079
30-35	0.51	0.71	0.73	0.68	1.79	0.27	0.04	0.03	7.60	9.676
35-40	2.20	2.74	2.71	1.96	6.37	3.19	0.76	0.38	13.69	23.363
40-45	6.23	7.66	6.66	5.70	12.31	16.32	4.28	1.46	16.46	39.821
45-50	13.41	16.88	13.45	14.60	20.70	29.54	12.53	3.90	16.47	56.291
50-55	24.19	32.14	24.47	29.57	34.32	38.38	28.24	11.09	15.24	71.531
55-60	38.81	51.85	39.26	48.34	54.41	52.32	53.11	25.77	12.55	84.082
60-65	56.27	71.31	58.73	74.24	74.43	74.48	77.14	46.50	8.60	92.682
65-70	73.82	87.35	78.35	90.87	91.44	89.79	92.10	70.15	4.74	97.420
70-75	87.47	95.33	91.94	98.95	99.39	98.18	98.57	89.09	1.93	99.351
75-80	96.01	98.19	98.49	99.90	100.00	100.00	100.00	98.06	0.55	99.900
80-85	99.63	99.69	99.93	100.00	100.00	100.00	100.00	99.91	0.10	99.995
85-90	100.00	100.00	99.99	100.00	100.00	100.00	100.00	100.00	0.01	100.000
90-95	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00	100.000
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.000



a) Maximum PSH portrayed using 20 gray level classes vs. actual mapped salinity of all 8 types



b) High values of maximum PSH with actual mapped salinity of all 8 types over-plotted in appropriate colors

Figure 4 . Illustration of spatial correspondence between maximum PSH and actual mapped salinity

The map of maximum PSH irrespective of type of salinity being predicted (Figure 4) was less effective in predicting all types of salinity than were the individual PSH maps prepared for each different type of visible salinity. A comparison of the weighting factors computed for the map of maximum PSH versus that computed for the individual maps of PSH for each kind of salinity (Table 6) revealed the degree to which the individual maps of PSH were more effective than the combined map of maximum PSH. Except for depression bottom and canal seep PSH, the map of maximum PSH was never as effective in explaining the observed spatial distribution of visible salinity as the most useful of the individual PSH maps.

Not withstanding this observation, the map of maximum PSH concentrated between 23% and 54% of mapped visible salinity in classes that occupied less than 8% of the total map area (max PSH > 60). Similarly, PSH classes occupying less than 16% of the total map area (PSH > 55) contained between 45% and 75% of the total extent of mapped visible salinity and classes occupying less than 30% of the total mapped area (PSH > 50) contained between 70% and 90% of the total mapped visible salinity (Table 17). This suggests that the map of maximum PSH of any type might still prove useful for identifying areas likely to exhibit salinity of any type.

Table 18 . Percent extent of each maximum PSH class range occupied by visible salinity of each type

PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	Extent (%) of Classes	Cumulative Extent (%)
15-20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.001
25-25	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.11	0.107
25-30	0.019	0.007	0.016	0.003	0.002	0.000	0.000	0.000	1.97	2.079
30-35	0.057	0.022	0.039	0.006	0.008	0.000	0.001	0.001	7.60	9.676
35-40	0.115	0.038	0.065	0.007	0.012	0.002	0.006	0.008	13.69	23.363
40-45	0.227	0.077	0.108	0.018	0.013	0.007	0.023	0.020	16.46	39.821
45-50	0.403	0.144	0.186	0.042	0.018	0.008	0.053	0.044	16.47	56.291
50-55	0.656	0.258	0.326	0.077	0.031	0.005	0.110	0.141	15.24	71.531
55-60	1.079	0.405	0.531	0.118	0.056	0.010	0.211	0.350	12.55	84.082
60-65	1.880	0.584	1.021	0.237	0.082	0.024	0.297	0.721	8.60	92.682
65-70	3.431	0.874	1.867	0.276	0.126	0.030	0.336	1.493	4.74	97.420
70-75	6.550	1.066	3.172	0.329	0.145	0.041	0.356	2.933	1.93	99.351
75-80	14.406	1.345	5.383	0.137	0.039	0.031	0.277	4.890	0.55	99.900
80-85	35.465	4.091	6.845	0.081	0.000	0.000	0.000	5.843	0.10	99.995
85-90	59.091	13.930	4.839	0.000	0.000	0.000	0.000	4.692	0.01	100.001
90-95	16.667	0.000	50.000	0.000	0.000	0.000	0.000	0.000	0.00	100.001
Map Mean	0.926	0.258	0.451	0.079	0.035	0.009	0.106	0.299	100.00	100.00

Examination of the percent extent of each maximum PSH class range occupied by visible salinity (Table 18) revealed a progressive increase in occurrence of visible salinity with maximum PSH class. In general, all classes with a maximum PSH greater than 55 contained a greater extent of mapped visible salinity than computed for the map area as a whole and all classes less than 55 contained less salinity than the average for the map area as a whole (Map Mean in Table 18). Classes with PSH values greater than 55 occupied about 16% of the total map area and contained between 78% and 45% of the total extent of mapped visible salinity of the 8 different kinds (Table 17). The map of maximum PSH was therefore able to identify relatively restricted regions (< 16% of the total area) that had a high likelihood of containing visible salinity of any type and which, in fact, contained most (45-78%) of the mapped visible salinity.

The close spatial association of mapped visible salinity with high maximum PSH was also evident upon visual examination of the map of actual visible salinity overlain on predicted maximum PSH (Figure 4). The map of maximum PSH may prove useful for predicting the most likely locations at which salinity of any type may occur both at present and in the future.

Comparison of predicted PSH and a randomly selected subset of actual mapped visible salinity not included in the predictive data set

The total cumulative percent extent within the 19 equal PSH classes of each of the 8 kinds of visible salinity included in the 10% randomly selected test subset (Table 19) was compared with the cumulative percent distribution of the area occupied by the classes themselves (Table 12) as well as with the cumulative distribution of the known and mapped salinity used to construct the rule bases (Table 14). The observed distribution of visible salinity from the randomly selected 10% subset closely resembled the distribution of mapped salinity used to construct the rule bases except for slough ring, artesian and natural salinity PSH. These types of salinity had the fewest number of polygons in the 10% random subset test data set (12, 2 and 18 polygons respectively), so this may explain the poor correspondence for these types. For all of the other salinity types, the randomly extracted test data set placed roughly equivalent amounts of salinity of each type into each of the 19 equal PSH classes.

Table 19. Cumulative percent of total test subset salinity occurring in each PSH class on each PSH map

PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep
0-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5-10	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10-15	0.311	0.000	0.000	2.368	0.000	0.000	0.000	0.032
15-20	3.230	0.066	0.000	15.789	0.000	0.000	0.000	0.064
20-25	9.880	0.198	0.000	35.263	0.000	0.000	2.392	0.194
25-30	19.035	1.210	0.199	58.947	0.139	0.000	16.937	0.593
30-35	29.756	3.608	0.996	73.947	0.695	68.421	31.195	2.514
35-40	42.191	9.899	2.656	90.789	1.529	80.702	65.932	7.090
40-45	55.897	20.216	6.463	96.578	6.119	80.702	88.994	17.235
45-50	67.335	30.731	12.660	100.000	20.584	80.702	97.319	37.686
50-55	77.997	44.875	23.528	100.000	52.017	91.228	99.903	56.885
55-60	87.026	59.591	36.830	100.000	81.502	100.000	100.000	71.962
60-65	93.092	74.043	54.758	100.000	95.271	100.000	100.000	84.761
65-70	95.419	86.208	75.099	100.000	100.000	100.000	100.000	92.208
70-75	97.104	94.237	92.452	100.000	100.000	100.000	100.000	97.334
75-80	99.513	99.406	99.513	100.000	100.000	100.000	100.000	99.654
80-85	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
85-90	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
90-95	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000

Distribution of the 10% random subset of salinity within the classes of the maximum PSH map (Table 20) was also similar to that observed for the main data set used to construct the rule base (Table 17). For certain kinds of salinity (depression bottom, slough ring and canal seep) slightly more of the randomly selected subset of occurrences of visible salinity occurred in the mid range PSH classes (45 - 55) than in the upper PSH classes (> 55) but the differences were minor. For all of the other kinds of salinity, slightly greater amounts of the observed test salinity occurred in the higher PSH classes then in the lower classes, but again the differences were not great.

The relatively close correspondence between the distribution of the test data set of randomly selected sites of visible salinity within PSH classes and the training data set of mapped visible salinity used to develop the PSH procedures was judged to be meaningful. One objective of the present study was to assess the possibility of using maps of PSH to predict or estimate the extent of visible salinity of each type in adjacent unmapped areas. In order to use the PSH maps to this end, it is necessary to have confidence that each PSH class in an adjacent unmapped area will contain approximately the same extent of salinity of a given type as was encountered within the training area. The test data appeared to support this assumption.

Table 20. Distribution of the 10% random subset of visible salinity by type by maximum PSH class (expressed as cumulative percent of each type of salinity in the sub-sample)

PSH Range	Depress	Coulee	Contact	Slough Ring	Outcrop	Artesian	Natural	Canal Seep	Class Extent	Cumul Extent
0-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5-10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10-15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15-20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
20-25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.106	0.107
25-30	0.000	0.000	0.066	0.000	0.139	0.000	0.000	0.011	1.972	2.079
30-35	0.133	0.022	0.619	0.789	0.139	0.000	0.000	0.065	7.597	9.676
35-40	1.485	0.330	2.456	6.315	0.834	0.000	0.287	0.141	13.687	23.363
40-45	6.229	3.146	6.020	21.841	2.781	5.263	1.627	0.303	16.458	39.821
45-50	15.849	9.085	12.195	36.315	12.795	21.052	4.211	1.501	16.470	56.291
50-55	30.309	23.889	23.018	46.578	30.041	68.420	13.111	6.606	15.240	71.531
55-60	49.549	43.995	36.055	56.578	53.268	80.701	35.121	24.553	12.551	84.082
60-65	67.105	64.057	54.271	77.104	69.680	89.473	66.604	51.695	8.600	92.682
65-70	80.272	81.567	75.055	92.367	87.900	100.000	88.614	76.290	4.738	97.420
70-75	91.555	93.182	92.452	100.000	97.079	100.000	98.470	92.759	1.931	99.351
75-80	98.456	99.407	99.513	100.000	99.722	100.000	100.000	99.483	0.549	99.900
80-85	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	0.095	99.995
85-90	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	0.006	100.001
90-95	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	0.000	100.001
Map Mean	0.926	0.258	0.451	0.079	0.035	0.009	0.106	0.299	100.000	100.000

DISCUSSION OF RESULTS

Utility of the PSH maps for predicting the extent of salinity in unmapped areas

A primary goal of the present project was to assess whether maps produced following the outlined PSH procedure could be used to arrive at a quantitative, reproducible and accurate estimate of the extent of the 8 kinds of visible salinity in unmapped areas based on an analysis of the patterns of spatial distribution in a currently mapped area. It was also considered desirable to have, not just an estimated number for the extent of each kind of visible salinity, but also a map indicating the most likely locations at which each kind of salinity might be expected to be found.

In terms of the first objective, the PSH procedure appears to offer a systematic method for arriving at a credible estimate of the likely extent of salinity in areas for which salinity maps do not currently exist. Consider, for example, depression bottom salinity. A credible estimate of the total extent of visible depression bottom salinity can be produced by first determining the absolute extent of each of the classes of depression bottom PSH in a presently unmapped area and then multiplying each of these values by the corresponding value for relative percent extent of visible salinity of the selected type within each of the 19 PSH classes as determined from the mapped area training set data (Table 21). The sum of the estimated extent of visible salinity of the selected type within all 19 PSH classes can be offered as a defensible estimate of the total likely extent of salinity of that type within a presently unmapped area.

The logic supporting this estimate is that each of the defined PSH classes represents an assemblage of environmental and topographical conditions that is more or less the same in portions of the study area for which salinity maps are both available and unavailable. It is then assumed that classes with similar environmental and topographical conditions will contain similar distributions of salinity of the current type. This assumption was partially validated by the analysis of the distribution of the 10% random subset discussed above.

The example provided (Table 21) is perhaps not optimum as the distribution of PSH range classes in the unmapped area is virtually identical to that in the previously mapped area. This being the case, one need only to determine the ratio of unmapped to mapped area and multiply the total extent of depression bottom salinity in the previously mapped area by this ratio to arrive at a suitable estimate of the extent of depression bottom salinity in the unmapped area. It does, however, clearly illustrate the concept of using knowledge of the distribution of salinity within a presently mapped area to predict the likely extent of salinity within an area for which detailed maps of visible salinity are currently lacking.

Table 21. Illustration of the procedure for estimating the extent of salinity in an unmapped area based on the known distribution in a previously mapped area

PSH Range	Mapped Area (ha)	Unmapped Area (ha)	Total Extent (ha)	Mapped Area (%)	Unmapped Area (%)	Mapped Area Salinity (%)	Mapped Area Salinity (ha)	Predicted Salinity (ha)	Total Salinity Extent (ha)
0-5	0.1	0.1	0.2	0.000	0.000	0.000	0.0	0.0	0.0
5-10	1894.6	1198.4	3093.1	0.258	0.172	0.003	0.1	0.0	0.1
10-15	58493.9	40103.0	98596.9	7.954	5.752	0.024	14.0	9.6	23.7
15-20	173601.8	167591.3	341193.1	23.606	24.038	0.097	168.4	162.6	331.0
20-25	191581.8	204881.9	396463.6	26.051	29.386	0.226	433.0	463.0	896.0
25-30	126753.4	121461.1	248214.5	17.236	17.421	0.500	633.8	607.3	1241.1
30-35	72067.1	64282.4	136349.6	9.800	9.220	1.039	748.8	667.9	1416.7
35-40	45603.6	38389.9	83993.4	6.201	5.506	1.754	799.9	673.4	1473.2
40-45	30023.6	26611.6	56635.1	4.083	3.817	3.081	925.0	819.9	1744.9
45-50	19202.3	17387.3	36589.6	2.611	2.494	4.884	937.8	849.2	1787.0
50-55	9674.3	8862.6	18536.9	1.315	1.271	8.288	801.8	734.5	1536.3
55-60	3629.8	3716.3	7346.1	0.494	0.533	13.726	498.2	510.1	1008.3
60-65	1276.8	1855.0	3131.8	0.174	0.266	21.621	276.0	401.1	677.1
65-70	588.0	744.4	1332.4	0.080	0.107	27.659	162.6	205.9	368.5
70-75	467.1	111.4	578.5	0.064	0.016	32.599	152.3	36.3	188.6
75-80	379.8	7.3	387.0	0.052	0.001	50.725	192.6	3.7	196.3
80-85	154.3	0.4	154.7	0.021	0.000	91.507	141.1	0.4	141.5
85-90	20.8	0.0	20.8	0.003	0.000	100.000	20.8	0.0	20.8
90-95	0.1	0.0	0.1	0.000	0.000	100.000	0.1	0.0	0.1
Total	735413	697204	1432617	100.000	100.000	0.926	6809.9	6456.1	13266.0

Utility of the PSH maps for predicting the location of salinity in unmapped areas

The PSH procedure was less successful than hoped in terms of identifying the specific locations where salinity might occur. Under ideal conditions, one might hope that if the known extent of a particular type of salinity was, for example, 1% of the total map area then a successful map of PSH would contain all of the instances of actual mapped salinity of this type within classes that occupied not much more than 1% of the total map area, say perhaps 5-10%. The maps of predicted PSH were not able to demonstrate this level of specificity with respect to isolating all actual mapped visible salinity within PSH classes that occupied only a very small proportion of the total map area. The actual values obtained for PSH maps were more in the range of 60-90% of the total salinity isolated within PSH classes that occupied 25-30% of the total map area. It was encouraging to note that the highest PSH classes, occupying the final 7-10% of the total map area, contained a significant proportion of the total mapped salinity for each of the 8 types of visible salinity (specifically 60%, 50%, 40%, 70%, 70%, 70%, 70% and 75%). The inability to isolate ALL actual mapped visible salinity within PSH classes that occupied only a small proportion of the total study area (e.g. < 5%) illustrated limitations of the PSH procedure.

Reasons for error in the PSH maps

Several factors may have contributed to the observed limitations and errors in the PSH maps. Clearly, salinity must be assumed to occur over a range of environmental and topographical conditions, such that no single set of conditions can be used to identify a set of spatial entities with unique conditions under which salinity of a specific type can only occur. This was evident in analysis of the data on contact salinity. Contact salinity was shown to occur over quite a wide range of environmental and topographical conditions, in such a way that it was not possible to identify a single unique set of conditions under which areas could be assumed to exhibit a high PSH for contact salinity. Clearly, variation and randomness occur in nature and no amount of effort on our part can impose order where order does not exist.

In addition to natural variation in the conditions under which salinity of each type might form, the issue of data quality must also be acknowledged. None of the 19 input maps were perfect and some were based on very general, small scale, data sets. A stronger relationship may exist, for example, between salinity of a given type and depth to bedrock or type of bedrock than was uncovered by the present analysis but the available maps of bedrock depth and bedrock type might have been insufficient to capture and present the level of detail required to establish these relationships. The PSH methodology aims to make the most out of currently available map data and does not require or assume that all data is without error. It is, however, necessary to accept and live with limitations in the quality of the available input data, while striving where possible, to improve it.

Another possible reason for observed discrepancies might be error in the maps of visible salinity, which provided the evidence used in the analysis. It was assumed that these maps contained no error but this may obviously not be true. It is likely that type 1 errors, that is errors of commission in which areas mapped as saline are, in fact, not saline are not widespread on the available maps of visible salinity. Each mapped salinity polygon is supposed to have been verified by field checking but it is possible that some areas mapped as saline are not actually saline. A more likely situation might be the case of misclassification where a polygon classified as, for example, depression bottom salinity would have been better classed perhaps as slough ring salinity. This would introduce error into the PSH rule base and the resulting PSH classification. It is almost certain that the maps of actual salinity contained numerous type 2 errors, these being errors of omission in which sites that are actually saline have not been mapped as saline. An interesting test of the PSH maps would be to identify sites with very high PSH values that have not been mapped as saline and to visit them to determine whether any type of salinity actually existed at these sites, but was not mapped.

Hierarchy and scale influences on the PSH procedure

A common caution in using digital map data is the potential danger in mixing data sources of different scales and particularly of using generalized, small-scale maps inappropriately for analysis and prediction of features or phenomenon operating at a larger scale. It was interesting to observe the interaction of data sets of significantly different scales in the present PSH analysis. It was apparent that data sets of fundamentally different scales were being analyzed in different ways by the PSH procedure.

Generalized, small scale maps, (e.g. bedrock type & hydrogeology) tended to be used to identify areas or regions in which salinity of a particular type was observed to cluster preferentially. These maps did not identify individual sites with elevated potential for salinity, but rather identified zones or regions in which salinity of a given type was more (or less) likely to occur. More detailed, large-scale data sets (e.g. derivatives of the DEM) tended to address site specificity within the larger zones or regions defined by the more generalized maps. Thus, a hierarchy tended to emerge and impose itself upon the PSH classification procedure. In this hierarchy, the generalized data sources tended to define larger regions or zones of elevated PSH and the detained data served to differentiate specific sites within these zones as having greater or lesser PSH. This may be advanced as another advantage of the PSH methodology as described here.

Observations on the knowledge base produced by the PSH procedure

The analysis of spatial co-occurrence undertaken in support of the PSH procedures provides a formal, systematic and quantitative mechanism for constructing and testing hypothesis and for converting data into knowledge and knowledge into understanding. The knowledge base generated by application of the PSH procedures may well prove to be of greater and more lasting value than the maps of predicted PSH, which were viewed as the primary goal of the analysis.

Analysis of the spatial co-occurrence data can confirm whether an assumed relationship actually exists between visible salinity, as currently mapped, and any number of environmental or topographical variables as represented on currently available maps. The weighting factor computed for each layer of the PSH analysis represents a quantitative measure of the usefulness of a given map for predicting PSH. This measure replaces weights that would normally be assigned by experts based on their beliefs and experience. Evidence replaces belief in the model procedures and the evidence provides a formal quantitative measure of utility of any given layer for predicting PSH. In a similar manner, evidence replaces belief in determining a value to assign to each class of each input map to represent the relative likelihood of encountering visible salinity given a particular class on a particular input map. Factor scores express the likelihood of finding salinity of a given type given a particular class on a map of interest in a manner that is both quantitative and unambiguous. The procedure allows for the testing of hypothesis such as, for example, that visible salinity is more likely to occur in areas that are shallow to bedrock. It not only permits confirmation or rejection of this hypothesis, but also quantifies the strength and direction of relationships such as that between presence or absence of salinity and depth to bedrock.

The data layers identified and used for the present pilot project were those which were most widely available for the agricultural portions of Alberta and which were considered to have the highest likelihood of exerting some degree of influence on the pattern of spatial occurrence of visible surface salinity. Any number of additional layers of input data could be included in a PSH analysis, as long as there was some reason to believe that there might be some relationship between the spatial distribution of salinity and the spatial pattern of the variable of interest.

Observations on the utility of the PSH procedure

The PSH procedures described here proved to be both feasible to apply and reasonable in their results. What remains to be determined is whether the results can be used in a meaningful way to assist conservationists in their efforts to quantify the current extent of salinity in Alberta and to estimate any likely future changes in the extent of salinity arising from changes in climate or land management practices.

It seems clear that maps of actual visible salinity, as currently produced by AAFRD, provide a more specific picture of the location and extent of known occurrences of visible salinity than do the corresponding maps of PSH. What the PSH maps offer is a mechanism for speculating on the location and extent of sites that have not currently been recognized as saline, but which have all, or most, of the environmental and topographical attributes of sites currently known to be saline. The PSH maps may prove useful for identifying regions and sites with a high potential of developing visible salinity under changing climatic or management conditions. It will be necessary to test this assumption by attempting to use the PSH maps to identify locations that are not currently mapped as saline but which have a high PSH rating. These sites should be visited to ascertain if they exhibit any signs of current or incipient salinity and to determine why they were not initially mapped as saline. If a majority of such sites show a tendency to exhibit some measure of salinity the PSH maps might be proven to provide a useful function as tools for predicting the possible locations of future or incipient salinity. At a minimum, application of the PSH procedures extracts valuable knowledge and understanding from the currently available maps of visible salinity. Current maps identify the locations and extent of known occurrences of visible salinity, but do not offer insight into why sites are saline or what factors exercise control over the initiation and spread of visible salinity. The PSH maps offer this advantage.

CONCLUSIONS

- The PSH methodology was demonstrated to be scaleable from its initial scale of application at a local watershed level.
- It was shown to be feasible to apply the PSH methodology to a much larger and more environmentally diverse area, specifically an entire 1:250,000 NTS map sheet.
- The PSH procedures can be used to produce systematic, credible estimates of the likely extent of visible salinity in presently unmapped areas based on analysis of known salinity in presently mapped areas.
- The PSH procedure was only partially successful in realizing an ambition to isolate the locations of PSH values that contained most of the observed visible salinity.
    - A significant amount (40 - 75%) but NOT ALL of the total observed salinity of each type was isolated within PSH classes occupying less than 10% of the total map area.
- The PSH procedure represents a systematic, reproducible and effective way of testing and validating hypothesis regarding spatial relationships between observed salinity and environmental and topographical factors thought to influence this distribution.
    - PSH permits assessments to be made of whether, and the degree to which, a particular type of environmental or topographical factor influences the spatial distribution of observed visible salinity. These assessments are quantified as weighting factors.
    - PSH identifies the direction and magnitude in which any given class of a selected environmental or topographical input map influences the likelihood of occurrence of visible salinity in a given area. These are expressed as PSH factor scores.
- The PSH procedure represents a formal systematic method for producing knowledge bases from quantitative analysis of widely available data and evidence.
    - The PSH procedure turns data into knowledge and knowledge into understanding
- The utility of the PSH procedure and accompanying maps can only be assessed by its usefulness in assisting conservation personnel to arrive at and interpret estimates for the extent of actual current salinity and possible future salinity within a region of interest.
    - This requires further use of the PSH data before a final assessment can be made.
- Decisions on how PSH maps can best be applied and whether production of PSH maps for the entire "White Area" would be useful and justifiable cannot be made yet.
    - Decisions should only be made after attempts have been made to use the current pilot PSH map and to assess its relevance and utility for conservation planning.

RECOMMENDATIONS

- The PSH maps produced for the 82H 1:250,000 map sheet pilot area should be assessed in terms of their ability to provide information and knowledge in support of AAFRD conservation efforts.
- There should be no immediate decision on whether to implement the PSH procedures for the entire "White Area" of Alberta until assessments are completed into the utility of the initial PSH maps produced for the pilot area.
- The data base used to produce the PSH maps and the basic PSH procedure should be transferred to AAFRD and consideration given to using both for other AAFRD applications.
- The present manuscript documents a new, interesting and effective procedure and should be considered for submission to a refereed scientific journal in an abbreviated and revised form.

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