Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

REMEDIATION OF SALT AFFECTED SITES BY LEACHING

Report Prepared for:

PETROLEUM TECHNOLOGY ALLIANCE CANADA

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EXECUTIVE SUMMARY

Sodium chloride (NaCl) based brine known as "produced water" is frequently produced along with petroleum hydrocarbons in western Canada. Remediation of soils impacted by produced water spills is an ongoing challenge since sodium chloride salts can have a negative impact on soil productivity, penetrate soils rapidly potentially affecting groundwater quality, and do not biodegrade.

The objective of this study was to evaluate current soil leaching technologies as a remediation tool for sodium chloride-impacted soils in western Canada. The study used existing spill monitoring data provided by a number of companies operating in western Canada. Data from 35 spills were included in the study. Because of the requirement for soil monitoring over several years, sites made available to the study tended to be larger or more persistent spills; they were not necessarily a typical cross-section of spills in Alberta or Western Canada.

Results indicated that leaching often moves salts downward very rapidly, particularly in the first several years after the spill. Produced salts can move through the soil profile to a depth of 5 m or more within 10 years, in permeable soil. Both engineered and passive systems can be effective in restoring good crop growth but there is some evidence that tile drainage may enhance the rate of salt leaching, particularly if the system is well maintained.

Leaching was not effective in removing salts from the topsoil at all spills. At about 10% of the passively remediated spills, electrical conductivity (EC) and sodium adsorption ratio (SAR) increased in topsoil between monitoring events. Resalinization can occur if there is upward movement of salts by capillary action from a high water table, or if the spill occurred in a groundwater discharge area.

Calcium (Ca) amendments appear to be very important to the leaching process. Because calcium applied as gypsum has a much lower solubility than sodium chloride and therefore moves more slowly through the soil profile, subsoil SAR sometimes increases during the leaching process, until sufficient applied calcium reaches subsoil. Data showed that calcium applied to the soil as gypsum can leach effectively through the soil profile to a depth of 1.0 m or more within 10 years despite its low solubility.

Sufficient water is needed to flush salts out of the root zone or into tile drains. Otherwise, salts can accumulate in subsoil at the maximum depth of water penetration resulting in a “bulge” in EC and/or SAR values. If the volume of leaching water is insufficient, additional time may not help move the salt “bulge” deeper into the soil profile. Spill remediation monitoring including yearly vegetation monitoring and less frequent soil sampling was recommended.

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1.0 INTRODUCTION

Sodium chloride (NaCl) based brine known as "produced water" is frequently produced along with petroleum hydrocarbons (PHCs) in western Canada. Spills of produced water onto both agricultural and non-agricultural soils are common in many of western Canada's aging oil and gas producing fields. Remediation of soils impacted by produced water spills is an ongoing challenge since sodium chloride salts can have a negative impact on soil productivity, penetrate soils rapidly, potentially affecting groundwater quality, and do not biodegrade.

After a produced water release has occurred and initial spill clean-up is completed, the standard remediation practice for produced sodium chloride brine spills in western Canada is removal of the source followed by flushing of salts downward, out of the soil rooting zone. Calcium (Ca) amendments usually applied as calcium nitrate ($Ca(NO_3)_2$) or calcium sulphate (gypsum; $CaSO_4 \bullet 2H_20$) are frequently used to maintain soil physical properties so that leaching can effectively remove salts from the soil rooting zone.

Although leaching has been used extensively to remediate salt affected soils worldwide, information related to leaching rates of salts from sodium chloride spills in western Canada is lacking. It was concluded in a literature review of salt movement through soils disturbed during pipeline construction, that 8 to 11 years was sufficient time for naturally occurring soluble salts (primarily sodium sulphate) introduced into the rooting zone during construction to return to background levels (Finlayson, 1993). Since sodium chloride salts released in produced water spills are more soluble than the sodium sulphate salts redistributed during pipeline construction, produced water spills might be expected to return to background levels more quickly than soils disturbed by pipeline construction. However, soils impacted with produced water may contain levels of salts many times higher than found in naturally occurring saline soils.

Anecdotal evidence indicates 5 or more years may be required to restore agricultural capability of well-drained soils in east-central Alberta after a produced water spill. More than 10 years may be required to restore the agricultural capability of spills on poorly drained soils or soils with natural salts (Lowen et al., 2003). Restoration of agricultural capability may not be possible if continual upwelling of salts occurs in the shallow rooting zone or without active remediation (including possible source removal and applications of amendments to maintain soil permeability and tilth). Leaching as a remediation tool is considered effective, but data on rates of leaching and remediation endpoints under different site and spill situations are lacking.

The objective of this study was to evaluate current soil leaching technologies as a remediation tool for sodium chloride-impacted soils in western Canada. In evaluating leaching technology, climate, landscape, and soil parameters as well as remediation history must be considered.

1.1 Scope of Work

The following scope of work was undertaken:

- Approach major western Canadian oil and gas production companies for access to records or reports of salt spills or other salt impacted sites, which have been, or are currently being remediated using leaching techniques.

- Review records and reports made available on a confidential basis. Use this information to assess:

  - the reliability of leaching under different site and climate conditions;
  - the effectiveness of commonly applied amendments;
  - the effectiveness of systems constructed to collect leachate; and
  - the length of time required to complete remediation under different soil and climate conditions.

- Compare the relative costs and benefits of leaching enhancement techniques shown to be both effective and reliable.

- Prepare a report detailing results of the study and information needs.

2.0 BACKGROUND

2.1 Leaching Systems

The majority of produced salt spills are remediated passively, relying on the infiltration of natural precipitation to leach salts down through the soil profile and out of the root zone. Calcium-based amendments such as gypsum or $Ca(NO_3)_2$ are commonly applied to prevent soil dispersion, which is an adverse effect of sodium on soil structure. Some spills are actively flushed with additional water to speed up the leaching process.

Engineered systems are sometimes employed on larger produced water spills to enhance the leaching process. Tile drainage is the most common engineered technique. Tile drains can be placed above or within the groundwater table, depending on site and spill characteristics, to remove leached salts from the soil system and to help prevent resalinization of the root zone soil. Resalinization can occur if there is upward movement of salts by capillary action from a high water table, or if the spill occurred in a groundwater discharge area. Leachate from the system must be collected and disposed of regularly to maximize the effectiveness of the system. A variation of tile drainage system is a trench intercept system that intercepts salts in soil or groundwater with a trench, bellhole or culvert placed to collect and facilitate disposal of leacheate. A third type of system, soil washing, aims to flush salts out of impacted soil by mixing the soil with clean water that is drained and then disposed.

2.2 Requirements for Successful Leaching

For remediation of produced salt spills by leaching to be successful, the following conditions must be present:

- **Sufficient water available for leaching**

  If passive remedial leaching of a spill is attempted in areas where precipitation is too low to produce effective downward movement of soil water through the soil out of the rooting zone, leaching will not remediate the site effectively. In some situations, additional water can be applied through irrigation. Some spills may benefit from passive water trapping techniques such as the use of snow fences in the winter, or re-contouring the site to collect additional runoff water.

- **Net downward movement of water**

  If sodium chloride salts are to leach downward out of the root zone during passive remediation, soils must have a net downward soil water flow. Remediation using passive leaching is unlikely to be successful in the presence of groundwater discharge or a net upward evapotranspirative flux. Leaching of salts out of the soil rooting zone may not be possible in areas with a high or fluctuating water table. Salts flushed from the root zone can resalinize root zone soils if the capillary fringe falls within the soil rooting zone at any time during the year.

- **Sufficiently permeable soil**

  The dispersive effect of sodium ions on clay-sized particles in soils is well known (see for example Sposito, 1989 or Bohn et al., 1985). The loss of soil structure and resulting decrease in permeability in a dispersed soil is a further impediment to efficient leaching of salts. This can be counterbalanced to some extent with the application of calcium-based amendments (see Sumner (1993) for an overview of the effect of sodium ions on soil properties).

- **Deep water table**

  Flushing salts from the soil rooting zone has the potential to impact groundwater resources under some conditions of high salt mass together with high water table and/or permeable soils.

2.3 Methods

A total of 16 oil and gas companies were contacted with a request for information on salt-impacted sites that were remediated either with engineered leaching systems (engineered sites), or by passive remediation (passive sites). To be useful to the study, spills required comparable soil salinity data collected at a minimum of two points in time, ideally several years apart. Nine companies supplied spill information, and data from seven companies were considered useful for this study. In total, file or data reviews were carried out for over 80 spills. Data from 35 spills were included in the study. Lack of consistency of sampling location or sampling depth between years, was the most common reason for rejecting data.

2.4 Evaluating Remediation Success

Various jurisdictions have developed guidelines or criteria to evaluate remediation success of salt spills. British Columbia has developed proposed risk-based guidelines specifically for salt-impacted soils (Royal Roads University, 2002). Saskatchewan's salt spill remediation guidelines are land use based (SPIGEC, 2000). Alberta's Salt Contamination and Remediation Guidelines (AENV, 2001) provide generic guidelines and procedures to develop site-specific risk-based criteria.

Alberta's generic soil quality guidelines for salts in soils were originally developed by Alberta Agriculture to assess soil materials for suitability as reclamation materials (Alberta Agriculture, 1987). They are based on the capability of the soils for use as a plant growth medium, not on actual vegetation parameters. The guidelines place soil into one of four categories based on a number of soil parameters including pH, electrical conductivity (EC), sodium adsorption ratio (SAR), saturation %, stone content, texture, consistency, organic carbon % and calcium carbonate ($CaCO_3$) equivalent %. The four categories were:

Good — None to slight soil limitations that affect use as a plant growth medium

Fair — Moderate soil limitations that affect use, but which can be overcome by proper planning and good management

Poor — Severe soil limitation that make use questionable

Unsuitable — Chemical or physical properties of the soil are so severe that reclamation may not be feasible

For non-commercial/industrial land use, Alberta's generic guidelines for salt contaminated soil (AENV 2001) adapted these four categories, basing them on the soil parameters relating directly to salts i.e. EC and SAR. To meet guidelines, soils must fall into the same category (good, fair, poor and unsuitable) as background or pre-impact soils. Using these categories makes allowance for naturally saline and sodic background soils, which are common in many parts of Alberta. It is not realistic to assume all soils will be remediated to 'de minimus' criteria or in many cases to background conditions.

2.5 Data Considerations

Data used for this study required comparable soil analytical data collected at more than one point in time, preferably several years apart. Because of the requirement for soil monitoring over several years, sites made available to the study tended to be larger or more persistent spills; they are not necessarily a typical cross-section of spills in Alberta or Western Canada.

3.0 RESULTS AND DISCUSSION

Locations of spills used in this study are shown on Figure 1. Site and spill information is summarized in Appendix A for each spill. Of the five engineered sites, two are located in the Peace region of Alberta, one in east-central Alberta, one in central Alberta and one in southeast Saskatchewan. Of the 30 passive sites, four are located in central Alberta, five in southeast Saskatchewan, one in the Peace region of Alberta and 20 in east-central Alberta.

At spills with engineered systems, spill volumes ranged from about 30 to 720 m^3 of produced water with impacted areas of 0.4 to 1.3 ha. Soil EC values in the spills ranged from less than 10 dS/m to as high as 70 dS/m and SAR values were as high as 25. Spills remediated passively ranged in volume from 1 to 1,000 m^3 of produced water; impacted areas ranged from 0.01 to 5 ha in size. Of the 35 spills, eight can be considered large spills (>100 m^3 brine released and/or >1 ha impacted). Spill volumes and areas of impact were not available in all spill information files.

Calcium amendments, usually $Ca(NO_3)_2$ and gypsum, were used at most spills. In general, source material was removed at the more recent spills, but not necessarily from the older spills.

Fertilizer or straw additions were common. Unfortunately, details of rates, types and timing of amendments were often not completely documented in spill information files provided.

3.1 Engineered Sites

Of the five engineered systems reviewed, four were tile drainage systems and one was a soil washing system. A brief description of these engineered systems and results of soil monitoring follows.

3.1.1 Spill 6: Southeastern Saskatchewan Tile Drainage System

3.1.1.1 *Background*

Spill 6 with a tile drainage system located in an area under a cultivated crop rotation in southeastern Saskatchewan, had consistent soil salinity data that were collected over a period of 11 years. Of all the spill information reviewed for this project, this site had the most complete and consistent data set. Unfortunately, details of soil type, depth to groundwater and system installation details were not provided. The spill was the result of a pipeline break in 1993 on cultivated land. An estimated 720 m^3 of produced water was released, affecting approximately 1.5 ha. Weeping tiles were installed after the initial spill clean-up. Tile drains were installed below 1 m depth and above the water table. The system was regularly maintained and soil samples were collected yearly. Approximately 75 m^3 of source material was removed in 2000. The spill was irrigated with hauled-in water in dry years, and leachate was collected regularly; however, detailed information on volumes of water added or removed was not available for every year. Gypsum was applied as required; however, details of rates and timing were not available throughout the history of the spill.

The site was divided into three areas roughly equal in size and composite samples were taken from each area. Soils were sampled yearly to 1 m depth, and analyzed for salinity parameters including EC, SAR, chloride and sulphate anions. In 1998 and subsequent years, the three areas were subdivided, resulting in the collection of more composite samples for each area each year. Soil samples were collected at depths of 0-15, 15-50 and 50-100 cm at all sampling events. Table 1 provides a summary of the data used for this analysis.

3.1.1.2 *Results*

Immediately after the spill, some areas had EC values up to 171 dS/m and SAR values up to 181 in the upper 15 cm of the soil. The most dramatic reduction in salinity throughout the 1 m monitored soil zone occurred within the first 3 years. After 3 years, the decrease in salinity was less dramatic but EC values continued to decline steadily in most parts of the spill. Figures 2a and 2b illustrate the decrease in average EC and SAR over time. Both EC and SAR dropped by more than half in the first 2 years of leaching, and even after 8 years, EC and SAR continued to decrease slowly. After 11 years, EC values in the upper 50 cm of the soil were less than 5 dS/m and SAR less than 3 at half the locations monitored in the spill area. Chloride concentrations (Figure 2c), show similar trends over time as EC and SAR.

Gypsum was applied to the impacted area regularly. Calcium concentrations through the soil profile in a control, and on the spill site at 1 and 11 years (1994 and 2004) after initial amendment are illustrated on Figure 2d. The increase in calcium compared to controls, and the decrease in calcium between 1994 and 2004 indicate that the much of the surface applied gypsum amendments have moved down the soil profile to at least 1 m.

In 2003, crop growth was reported as “fair” to “good” over more than 75% of the spill area. In 2004, chlorides were still being removed from the tile system in leachate water, an indication that remediation is continuing.

Soil samples were not collected below 1 m depth, so the effectiveness of the tile system in intercepting salts could not be assessed with the data available.

3.1.1.3 *Conclusions*

- Surface applied gypsum amendments effectively moved through the soil profile to at least 1 m depth in a 10-year time period.

- Most of the leaching took place in the first 2 to 3 years, which emphasizes the need to recover spill fluids as soon as possible after the spill event to limit the depth of leaching of salts and the volume of soil impacted.

- With this well maintained tile drainage system, EC and SAR in surface soil decreased and good crop growth was restored over much of the site within 10 years.

3.1.2 Spills 15 and 16: Peace Region Flare Pit Tile Drainage Installations

3.1.2.1 *Background*

Spills 15 and 16 were both flare pit remediation projects on agricultural land. Both sites had fine-textured soils. In 1998, salt impacted soils were excavated from the flare pits. Tile drains and leachate collection systems were then installed in the excavation pits; the excavated soil was mixed with gypsum amendments and replaced. Leachate was collected and disposed of only sporadically. The sites were not irrigated.

3.1.2.2 *Results*

At Spill 15, two soil samples were collected from the excavated soil piles in 1998, prior to construction of the tile system. In 2003, after the system had been in operation for 5 years, soil samples were collected to a maximum depth of 1.5 m (Table 2). At Spill 16, two composite samples were collected in 1998; soils were sampled again in 2003 at eight points, also after 5 years of operation, to a depth of 1.5 m (Table 2).

After 5 years, EC was lower in the leached soils at both sites compared to initial sampling results (Figure 3a). The decrease in EC was more pronounced for Spill 15 compared to Spill 16, but both had substantially lower EC values after 5 years of leaching at all depths. The EC decrease was not constant at all depths; however, possibly indicating insufficient water moving through the soil to remove salts entirely from the system, and/or inadequate removal of leachate.

At Spill 15, SAR was substantially lower at all depths to 1.5 m (Figure 3b) after 5 years of leaching. At Spill 16 however, SAR was higher after 5 years of leaching compared to the initial SAR at all depths. Assuming SAR data accurately reflects soil conditions, the apparent increase in SAR after leaching may reflect the relocation of sodium in the profile during leaching coupled with insufficient calcium amendments.

From the information available, it was not possible to determine the volume of salts actually removed from the system. The system appears to have been attended only sporadically over the 5-year period, and the 2003 soil monitoring event does not appear to have reached the maximum depth of impact at either site.

3.1.2.3 *Conclusions*

- Tile drainage successfully decreased EC at both spills to 150 cm depth. SAR increased at one sampling location, likely due to insufficient calcium amendments applied during the leaching process.

- The data illustrate the importance of sufficient water leaching through the soil profile to remove salts completely from the system and to prevent salt accumulation within the profile.

3.1.3 Spill 7: East-Central Alberta Tile Drainage System

3.1.3.1 *Background*

Spill 7 was at a battery in an agricultural area that was decommissioned in 1999. At that time (1999), elevated levels of salts were found near the flare pit, which had been remediated by excavation and disposal. Soil and groundwater information indicated that produced water had impacted the aquifer.

Groundwater remediation and weeping tile systems were installed in 2000 to remediate remaining salts and to prevent offsite migration of the salt plume. The tile system covered an area of approximately 4,000 m^2.

In 2003, the spill was flood irrigated to more actively leach salts from the treatment area and an automated leachate and groundwater recovery system was installed. Two tons (1.8 tonnes) of $Ca(NO_3)_2$ and 10 tons (9.1 tonnes) of gypsum were applied and incorporated into the treatment area. Approximately 1,200 m^3 of fresh water was applied to the treatment area over a 3 month period. A total of 284 m^3 of leachate was collected and hauled offsite for disposal. Quantab testing indicated disposed water contained chloride ions at levels greater than 4,000 mg/L.

Soil samples were collected from seven locations within the impacted area in 1999 prior to tile installation; unfortunately, samples were not analyzed above 150 cm, limiting their usefulness to this study. The 1999 data were not included for that reason. Soils were sampled twice at two different locations within the tile-drained area in 2003, once before irrigating and once after irrigating, using similar depth increments (Table 3), providing an interesting comparison.

3.1.3.2 *Results*

Results of the 2003 leaching differed between locations 1 and 2 within the tile-drained area, shown on Figures 4a to 4d. Note that the lowest depth of each increment was graphed. The EC at both locations decreased in the 0-15 cm depth increment after irrigation (Figure 4a). At location 1, post-irrigation EC increases with depth below 15 cm, and exceeds pre-irrigation EC between approximately 30 and 150 cm depth. At 200 cm depth, post-irrigation EC is lower than the pre-irrigation value at location 1. At location 2, post-irrigation EC values decreased to about 60 cm, then began to increase with depth. Post-irrigation values remained lower than pre-irrigation to almost 150 cm depth.

A deeper EC “bulge” (increase in EC values) below 100 cm at location 2 compared to location 1 indicates more effective leaching than at location 1, where the EC “bulge” occurred between 50 and 100 cm. This difference could be due to a number of factors including differences in soil texture and micro topography between the locations, which could affect the volume of water moving through the soil.

Post-irrigation SAR values (Figure 4b) at location 1 were substantially higher than pre-irrigation below about 15 cm to the depth of assessment (200 cm), peaking at about 75 cm. The magnitude of the increase in SAR at location 1 is difficult to explain, but could be due in part to analytical differences since the location 1 pre-irrigation samples were analyzed by a different laboratory than post-irrigation location 1 samples and all location 2 samples. Alternatively, some unknown differences in sampling or handling may have had an effect. At location 2, post-irrigation SAR was lower than pre-irrigation values to about 75 cm; below 75 cm post-irrigation SAR values were higher than pre-irrigation values.

Data for sodium and chloride mirror the SAR results (Figures 4c and 4d). At location 1, both sodium and chloride concentrations increase substantially between about 15 and 175 cm depths, after irrigation compared to before,. At location 2, post-irrigation sodium and chloride concentrations are lower than pre-irrigation values to a depth of almost 100 cm.

This tile drainage system with a single irrigation event moved salts down the soil profile but was not particularly effective in removing salts from the system as a whole. The volume of leachate collected and disposed (284 m^3) was relatively small compared to the volume of water used to irrigate the spill (1,200 m^3), indicating that much of the water applied did not leach through the soil into the tile system. Post-irrigation data indicate that salts are accumulating at various depths within the soil profile.

3.1.3.3 *Conclusions*

- Salts move down the soil profile with the application of irrigation water, but the amount of salts and the depths to which they will leach can vary widely within a single, relatively homogeneous spill area.

- The depth at which salts will concentrate in a soil profile will depend on the volume of water available to move through the soil profile. If insufficient water is available to move salts through the profile and into the tile drainage system below, salts will accumulate higher in the soil profile. Differences in soil texture, structure, bulk density and even microtopography can affect the rate of salt leaching and the depth at which salts will accumulate in the soil at a given site.

3.1.4 Spill 2: Northeast of Edmonton Soil Washing Site

3.1.4.1 *Background*

At Spill 2, located northeast of Edmonton, soil washing was used to treat salt-impacted soils excavated from a flare pit as part of a remediation program. Approximately 3,500 m^3 impacted soil material was placed into two lined wash pits, one constructed in the former flare pit, and a second adjacent to the flare pit. A wash water collection system was constructed which drained to an interception trench.

Soils were washed using surface water pumped from a nearby slough; soils and water in the pits were mixed three times and allowed to settle. Fluids were then pumped off and disposed down hole. Washing took place twice, once in July 1999 and again in July 2000. The washing process was reported to be slow and labour intensive. Gypsum and $Ca(NO_3)_2$ amendments were added together and incorporated into the soil in the pits using a backhoe, after the second washing event in October 2000. In all, 11,000 kg gypsum and 1,150 kg $Ca(NO_3)_2$ were mixed into soils in the pits.

Spill delineation information provided for this site indicated that soils in the spill-impacted area likely had EC values between 10 and 36 dS/m and SAR values between 20 and 90 prior to remediation. Analytical data for the soils actually placed into the washing pits were not available. Soils in the pits were monitored for salinity parameters after each washing event and after the amendments were added.

3.1.4.2 *Results*

Assuming starting EC values between 10 and 36 dS/m, the bulk of the decrease in EC likely occurred with the first washing event; EC after the first wash averaged 4.5 dS/m (Figure 5a; Table 4). After the second wash, soil sample EC values decreased from the first wash average of 4.5 dS/m to an average of 3.3 dS/m. Soil washing apparently resulted in a substantial decrease in EC, with values less than 5 dS/m after two wash events. However, EC after the addition of amendments was higher than values after the two washing events, averaging 8.9 dS/m.

The first soil washing event lowered soil SAR values to 26.2 and 19.4 in Pits 1 and 2, respectively (Table 4), from assumed initial SAR values ranging between 20 and 90. After the second soil washing event, SAR decreased further, but values remained relatively high, an average of 23.6 in Pit 1 and 9.5 in Pit 2. Gypsum and $Ca(NO_3)_2$ amendments added after the second wash resulted in a further decrease in SAR to 9 in Pit 1 and 7.3 in Pit 2.

Amendments added after the second washing event resulted in a decrease in SAR as expected. However, from the data presented, amendment addition appears to have increased EC to levels higher than before washing, compromising remediation success. Changes in both sodium and chloride (Figure 5b) show the same trends as EC; a decrease between the two washing events but an increase after amendment additions close to or higher than levels measured after the first washing event. There is no clear explanation for the increase in sodium and chloride after amendment additions, since neither was reported as having been added. Theoretically, an increase in sodium could have occurred as added calcium replaced sodium on the soil exchange complex. However, the increase in chloride cannot be explained in this way. It is possible that the single samples collected from each pit after amendment addition did not adequately reflect variability in the amended soil.

3.1.4.3 *Conclusions*

- Soil washing effectively reduced EC to near guideline levels, with by far the biggest reduction occurring in the first washing.

- Soil washing was less effective at reducing SAR than EC. Calcium amendments added after washing effectively further lowered SAR values, but the effect of the amendments on soil EC is not clear from the data for this site.

3.1.5 Engineered Sites – Summary

Well maintained tile drainage systems with adequate calcium amendments and sufficient water for leaching are effective in remediating soil EC and SAR to levels at which good crop growth can be restored within 10 years. Without sufficient calcium amendments however, SAR remains high or may increase in some parts of the soil profile with leaching. If insufficient leaching water moves through the soil, salts can accumulate within the soil profile, never reaching the underlying tile drainage system. However, even within a relatively small area, leaching success can vary widely, depending on various soil factors and micro topography. The key to successful leaching with a tile system would appear to be careful maintenance, adequate volumes of water applied to the site as irrigation, rainfall or collected runoff, timely removal of leachate and judicious application of calcium amendments.

Soil washing effectively speeded up the leaching process, reducing EC values to near guideline levels within two wash events. SAR was reduced but remained high after leaching, requiring the addition of calcium amendments. The effects of calcium amendments on soil EC was not clear from the data presented.

3.2 Passive Sites

Data from 30 passively remediated spills were considered useful to this study. Of these, 20 spills were located in east-central Alberta, four were located in central Alberta, five were located in southeast Saskatchewan and one was located in the Peace region. Passively remediated spills ranged in age from 2 to 15 years from the spill date to the date of the most recent data available. Because not all spills were monitored immediately after the spill event, monitoring periods ranged from 2 to 9 years. Summary sheets with site and spill information as well as pertinent soil analytical data are presented in Appendix A. Data are summarized in Table 5.

Of the 30 passively remediated spills, most recent monitoring data indicated that:

- Topsoil EC decreased at 27 spills (90%) between the first and the last monitoring event; of those, 11 spills (41%) approached EC of 5 dS/m or less in the most recent monitoring event. Subsoil EC decreased at 17 of the 18 spills (94%) that had subsoil data; of those 6 spills (33%) approached EC of 5 dS/m or less in the most recent monitoring event.

- Topsoil SAR decreased at 28 of the 30 (93%) spills between the first and last monitoring event; of those, 11 spills (about 40%) approached SAR 8 or less in the most recent monitoring event. Subsoil SAR decreased at 15 of 18 spills (83%), with four of 18 (22%) approaching SAR 8 or less in the most recent monitoring event.

Spills which approached acceptable topsoil EC and SAR levels at the end of the monitoring period tended to be older spills, 5 to 11 years in age.

The EC and/or SAR increased over the monitoring period at seven of the 30 spills (23%). Net increases over time may have resulted from high or fluctuating water tables, or because the spill was located in a groundwater discharge area. Increases may also be a result of critical differences in sampling locations between years.

3.3 Influence of Climate

Passive leaching depends on water from precipitation (P) infiltrating through the soil. However, to estimate the amount of precipitation potentially available to leach salts through the soil profile, evapotranspiration (ET), defined as the amount of water estimated to move from the soil-plant surfaces to the atmosphere, must be taken into consideration along with precipitation. Based on information available from Alberta Environmental Protection, (Bothe and Abraham, 1987 and 1993) the average areal ET for the Alberta spills in this study are presented in the following table. No equivalent data were available for the Saskatchewan spill area.

Region	Average Areal Evapotranspiration (ET)	Average Precipitation (P)	P-ET	Station Used
East-Central Alberta	401 mm	401 mm	0 mm	Coronation
Central Alberta	419 mm	482 mm	63 mm	Edmonton International Airport
Peace Region	321 mm	471 mm	150 mm	Fairview

Subtracting ET from average precipitation (P) gives a theoretical estimate of the amount of precipitation in an area that might be available to leach salts through the soil in an average year. For the passive spills examined in this study, the amount of water theoretically available for leaching (P-ET) varied from 0 mm in east-central Alberta to 150 mm in the Peace region; this suggests that spills in the Peace region should remediate faster than spills in eastern Alberta, when non-irrigated systems are used. Unfortunately, the data set in this study did not provide sufficient information to determine if a difference does in fact exist.

Other factors will also influence water availability for leaching. Depending on the slope and microtopography of the spill site, a substantial proportion of water potentially available for leaching may be lost in spring runoff. In relatively level landscapes, microtopography becomes particularly important in determining how much water will runoff the site and how much will be available to leach into the soil. Vegetation transpiration rates will also affect the volume of water leaching through the soil. Any efforts to encourage leaching through the soil by trapping snow or holding water on a spill site will be beneficial to the passive remediation process.

3.4 Influence of Topography

Three spills (Spills 20, 21 and 22) all located in east-central Alberta, provided soil monitoring data for different slope positions (Table 6).

At Spill 20, soils were monitored at seven locations down a complex slope. Initial (2000) EC and SAR values varied widely between slope positions and depth increments, with no apparent relationships between the two. Four years after the spill, EC and SAR values and the variability between all slope positions were greatly reduced in the 0-15 cm depth increment (Figures 6a and 6b). After 4 years of leaching, EC values approached 5 dS/m in all slope positions. SAR remained over 10 after leaching at all upper to mid slope positions. Chloride concentrations in the 0-15 cm depth were less than about 200 mg/kg at all slope positions except the break site and upper slope position (Figure 6c) after 4 years of leaching.

In subsoil (60-100 cm) at Spill 20, EC decreased substantially after 4 years of leaching at all points assessed down the slope except at the break point and one mid slope point (Figure 6d). Subsoil SAR in the mid to lower slope positions was higher 4 years after the spill compared to before, possibly indicating inadequate calcium soil amendments at these location, or insufficient time for amendments to move through the soil (Figure 6e). Like EC, subsoil chloride concentrations remained elevated in 2004 at the break point and at one mid-slope location (Figure 6f).

At Spill 21, soils were monitored to a depth of 200 cm at mid-slope and lower slope positions in 2000 soon after the spill occurred, and again in 2004 (Figures 7a to 7c; Table 6). EC and chloride concentrations showed similar trends; 2004 values in topsoil are relatively low, indicating effective leaching of salts in surface soil at both slope positions. However, at the lower slope position, both EC levels and chloride concentrations have a “bulge” between 50 and 100 cm depth, indicating less effective leaching at the lower slope position compared to the mid-slope. SAR decreased in all slope positions after 4 years of leaching.

At Spill 22, soils were monitored to a depth of 100 cm, at upper, mid and lower slope positions in 2000 and again in 2004 (Figures 8a to 8c; Table 6). Trends were similar for EC, SAR and chloride concentrations. At the upper slope position (closest to the break point), EC, SAR and chloride concentration were lower after leaching in 2004 compared to 2000 to at least 100 cm depth. At the mid-slope position, these parameters were lower after leaching compared to before, to about 50 cm depth. At the lower slope position, EC, SAR and chloride concentrations at 100 cm depth were slightly higher after leaching in 2004 compared to before.

In summary, salts at lower slope positions tended to leach less deeply than those at upper and mid slopes after 4 years of leaching, resulting in increased EC and SAR values in the subsoil. The influence on leaching of higher water tables at lower slope positions may be a factor. In some cases, SAR remained relatively high after EC and chloride concentrations had been substantially reduced, possibly due to inadequate calcium amendment or insufficient time for amendments to move through the soil.

3.5 Effects of Soil Types

Very few of the spills included in this study had basic soils information such as soil texture or soil classification included with the salinity data. As a result, it was not possible to draw any conclusions regarding the effects of soil type on leaching from the data set.

3.6 Effects of Time

Few of the spill data sets included soil salinity monitoring data starting soon after the spill event. Where such data does exist (for example Spills 6 and 19; Figures 9a and 9b), it points to a rapid decrease in EC and SAR within the first 2 to 3 years of leaching after the spill event. At both spills, leaching proceeded after the first 2 years at a much slower pace, but continued for more than 10 years.

Data collected regularly over more than 10 years were available for two spills: Spill 19, a passively remediated spill and Spill 6 a spill remediated with a tile drainage system. A comparison of the two data sets shows very different trends over multiple years. Figure 9a shows changes in surface soil EC (0-15 cm depth) over time at both spills. Surface soil EC decreased much more rapidly in the first 10 years of leaching at the tile-drained site compared to the passively drained site. Even after 15 years of leaching, surface soil EC at the passive site remained much higher than at the tile-drained site. The best-fit trendline for the passively remediated spill was a logarithmic function; the best-fit trendline for the tile-drained spill proved to be a power function, both shown on Figure 9a. Both had R^2 values greater than 0.9.

Surface soil SAR at the passively remediated site decreased somewhat during the first 2 years of leaching, but remained relatively steady after that; even after 15 years or leaching the SAR value was not much lower than the SAR value after only 2 years of leaching. Surface soil SAR in the tile-drained system on the other hand, decreased very rapidly in the first 2 years of leaching, then continued to decrease at a slower but fairly consistent rate to 11 years.

It is difficult to determine exactly how much of the differences noted between these two spills are due to differences between the two leaching systems, passive-compared to tile-drained. Salts at the tile-drained spill leached faster than at the passive spill. The tile-drained spill was more closely managed over its 10 year history than the passively drained site, with additions of amendments as required, and occasional irrigation, which likely would have enhanced leaching rates with or without tile drainage. Other factors such as differences in climate, soil texture, precipitation and microtopography may also have affected rates of leaching at these two sites.

It is not possible to draw firm conclusions regarding salt leaching rates at tile-drained sites compared to passively drained sites from these two data sets alone. However, at these sites leaching is proceeding at a substantially faster rate at the tile-drained site compared to the passive site.

At Spill 42, soils were monitored to a depth of over 14 m, 10 years after the spill occurred. Information supplied identified soils at the site as silt and clay till from surface to approximately 5 m, and sand (or sandy) from approximately 5 m to the maximum depth of evaluation.

Results showed a dramatic decrease in surface soil EC and SAR after 10 years of leaching. A distinct “bulge” in EC, SAR, sodium and chloride occurred around the 0.75 m sample depth, decreasing rapidly by the 3.75 m sample depth (Figures 10a and 10b; Table 7). Deeper in the soil profile, chloride concentrations greater than 400 mg/L and sodium concentrations greater than 100 mg/L occurred to 10.5 m depth. EC values greater than 5 dS/m occurred to about 5 m depth, and SAR values greater than 8 occurred to about 4 m depth. At present, salts appear to be moving down the soil profile at a rate of between 0.5 and 1 m per year.

Sulphate apparently applied as gypsum to the surface shows no "bulge" after 10 years of leaching and approaches background levels by the 3.75 m sample. Differences between parameters in depth of leaching after 10 years likely relates to relative solubilities of the salts in question.

Trendlines applied to EC, SAR, sodium, chloride and sulphate data collected to nearly 15 m depth after 10 years of leaching, show very good fits to a logarithmic function, with R^2 values greater than 0.9 in both cases (Figures 10a and 10b). However, sulphate shows a relatively poor fit to a logarithmic function (R^2 = 0.37), but a much better fit to an exponential function (shown on Figure 10b) with an R^2 value of 0.86. The lower solubility of gypsum compared to sodium chloride likely accounts for this difference.

3.7 Effects of Remediation History

Most spills supplied for this study did not have complete remediation histories accompanying soil salinity monitoring data. Details of amendment application timing and rates were frequently missing, as were details of source removal. However, the review of available information indicates that calcium amendments, mainly gypsum and $Ca(NO_3)_2$, were very widely used for spill remediation. Some reports stated, for example, that amendments were applied "as required" or recommended specific rates and types of amendments, without indicating whether or not these rates were actually applied to the spill. As a result, it was not possible to gain any insight into optimal rates or timing of the application of amendments from this information.

The potential importance of calcium-based amendments to the leaching process, when added in sufficient quantities, was illustrated in data from several spills (for example Spills 7 and 16), where subsoil SAR was higher after leaching compared to before, but not subsoil EC. This was attributed to insufficient calcium amendments and/or lack of time for amendments to move through the soil profile.

At a number of spills, gypsum amendments were surprisingly effective in moving through the soil profile, despite gypsum's relatively low solubility. At Spill 6 for example, the decrease in calcium concentration 11 years after initial application relative to 1 year after initial application illustrates this point (Figure 2d). At Spill 21, after 4 years of remediation, sulphate concentration was highest in the 60-100 cm depth increment (Figure 11); below 1.0 m, sulphate levels decreased rapidly, but remain higher than pre-remediation levels to 2.0 m, indicating sulphate had moved through the soil profile at least to that depth. Because calcium can occur naturally in soils, especially at depth, it is difficult to track movement of applied calcium through the soil profile without sufficient comparable background data.

At Site 42, the lower solubility of gypsum compared to sodium chloride was apparent in the different data trends between sulphate and chloride concentrations with depth. The slower rate of movement of calcium from gypsum through the soil compared to sodium chloride can result in a situation where SAR can increase in subsoil as leaching of gypsum lags behind the leaching of sodium chloride salts.

3.8 Estimated Relative Costs

Detailed information on the costs of various leaching technologies was generally lacking in the files available to the study. Based on Matrix Solution's experience, approximate costs to remediate a spill passively and with a tile drainage system were estimated (2005 prices).

Approximate costs to passively remediate a 1 ha spill, excluding amendment delivery costs, equipment travel time and consulting fees:

- Gypsum (20 tonnes/ha) = 20 tonnes × $265/tonne = $5,300
- $Ca(NO_3)_2$ (400 kg/ha) = 400 kg × $0.6/kg = $240
- Spreading and incorporation of amendments by disc or rotospic = $3,300/ha
- Total: $8,850 for a one-time application of amendments not including amendment delivery costs, equipment travel time and consulting fees

Since passive remediation is frequently used in conjunction with source removal, costs involved in excavating, landfilling and replacing impacted soil would also need to be included. Ongoing costs for a passively remediated spill include soil and vegetation monitoring every few years to monitor remediation success and to determine if more amendments are required, additional amendment application costs if required, and ongoing lease payments to the landowner.

Approximate costs to install and maintain a 1 ha tile drainage system, excluding amendment delivery costs, equipment travel time and consulting fees:

- Installation of tiles - $25,000 for tiles ploughed in to a 1.5 m depth with a 5 m spacing. Installation costs could go up to $40,000/ha if tiles need to be installed in trenches below 1.5 m, or if the tile spacing must be reduced substantially.

- Cost for amendments is the same as for a passive spill (approximately $8,850/ha).

Ongoing expenses for the system include:

- Hauling of leachate $80 to $120/hour depending location and availability of trucks and truck capacity (10 to 12 m^3 capacity truck).

- Disposal of leachate $25 to $35/$m^3$ (downhole disposal).

Regular monitoring of soil and groundwater is recommended for tile drainage systems.

Passive remediation is less expensive than remediation with tile drains. However, tile drainage systems are appropriate for large spills where salts need to be removed from the system to prevent impact to groundwater quality, quality of nearby soils, or other receptors.

4.0 CONCLUSIONS

- Leaching can move salts downward very rapidly, particularly in the first several years after the spill, but this is not true for all spills. Many of the factors that appear to affect the rate of leaching are site specific, such as soil texture, topography, slope position and groundwater conditions. However, there is evidence that tile drainage may enhance the rate of salt leaching, particularly if the system is well maintained. Both engineered and passive systems can be effective in remediating salt spills and restoring good crop growth. However, passive leaching was not effective in removing salts from the topsoil at all spills. At about 10% of the passively remediated spills, EC and SAR increased between monitoring events. These spills may be located in groundwater discharge situations, have high water tables, or sampling may not have been consistent between monitoring events.

- Salts originating from produced water spills can move through the soil profile to a depth of 5 m or more within 10 years in permeable soil.

- Calcium amendments appear to be very important to the leaching process. Gypsum worked into the soil surface as an amendment can leach effectively through the soil profile to a depth of 1.0 m or more within 10 years, despite its low solubility. However, slower leaching of gypsum compared to much more soluble sodium chloride can result in an increase in subsoil SAR, at least in the short-term.

- Sufficient water is needed to flush salts out of the root zone or into tile drains. Otherwise salts can accumulate in subsoil as a "bulge" in EC and/or SAR values. If leaching water is insufficient, additional time may not help move the salt "bulge" deeper into the soil profile.

- Data were insufficient to determine the effectiveness of tile drainage systems in removing salt mass from the soil/groundwater system.

5.0 RECOMMENDATIONS FOR SPILL MONITORING

This study highlighted the need for soil monitoring of a complete and consistent set of parameters, in consistent locations and depths, extending the complete depth of impact, and conducted at regular time intervals throughout the spill remediation process. Of the spills used in the study, adequate historical spill and site information documentation, including documentation of amendments and other remedial efforts was often lacking. Records of volumes and salt content of water removed from tile drains were often incomplete, so that the salt mass balance could not be assessed. Soil salinity analytical data including chloride and sulphate anion concentrations were available for almost all of the spills, but other potentially useful parameters like cation exchange capacity, bulk density and soil texture were rarely available.

Sampling protocols and sampling locations frequently differed significantly between monitoring events, preventing meaningful comparisons. Very few of the data sets had accompanying vegetation data so that conclusions regarding the effects of salt levels on crop productivity could not be drawn. Similarly, few spills with soil monitoring data also had groundwater monitoring data so that the interactions between the two could not be examined. Data monitoring the salt levels in soils below tile drains were not available for any tile-drained site, so the effectiveness of tile drains at removing salts from the whole soil/groundwater system could not be evaluated.

The following guidelines for monitoring spills are recommended:

- Record spill information such as volume of spill, type of fluid spilled, whether the spill was surface or subsurface, and initial containment and recovery work completed. Record all initial clean-up and remediation measures implemented including dates, types and rates of amendment applications.

- Record spill site information such as the spill break point, its slope position, slope gradient, surface drainage direction, and vegetation types and quality, and location of any nearby surface water bodies.

- As soon as possible after completion of initial remediation measures, collect soil samples from the spill area and one or more background locations. Sample both surface soil and subsoil, since plant roots can extend to 1.5 m or deeper. Make sure that the same depths are sampled both on and off the spill to allow a valid comparison. At a minimum, analyze samples for pH, EC, SAR, cations, and chloride and sulphate anions all by the saturated paste method, and particle size analysis (soil texture) by the hydrometer method. Sample below the depth of impact to fully delineate the spill, followed by adequately sealing and grouting boreholes or wells to prevent migration of salts into previously unimpacted soil layers or groundwater.

- Ensure that sampling locations are accurately marked on a map drawn to scale, or with a GPS unit capable of ±1 m accuracy. Remember that the most common property of all soils is their variability; the effectiveness of any monitoring program will depend on the ability to collect soil samples from the same spot at each monitoring event and from the same depth increments. Normally background locations need to be sampled only once, unless monitoring has been carried out for more than 10+ years, since natural salts also can change over time.

- Collect vegetation data such as plant species, plant height, density, % cover or yield, from each sample location, including the background location, during each monitoring event. Vegetation data can be collected easily to provide a quick assessment of remediation progress.

- Soils do not normally need to be monitored each year. However, since the effectiveness of a remediation program depends on adequate and timely calcium amendments, it is wise to sample soils every 2 or 3 years, or if remediation problems become apparent in vegetation. Record dates, types and rates of any amendments applied.

- If a tile drainage system is being installed, ensure that tile drains can be located easily prior to soil sampling. Make sure soils are sampled periodically below the depth of tile installation to ascertain the potential salt concentration that is below the tile drain system and a potential source to groundwater. Salts below the tile drains may pre-exist the installation of the tile drain or/and be the result of salts bypassing the collection system. Keep a running record of water removed from the system and its chemical analysis.

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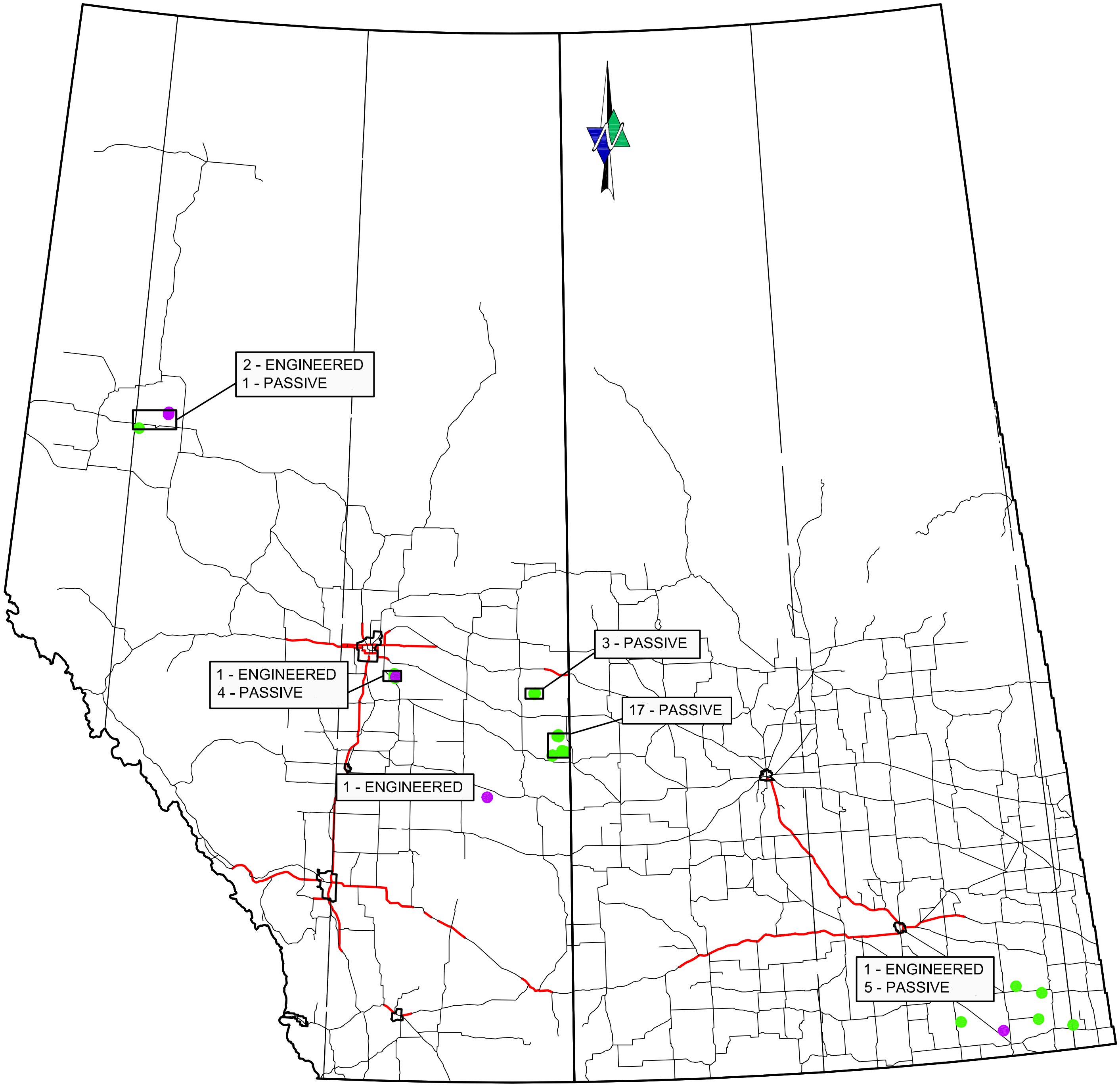
7.0 LIMITATIONS

Matrix Solutions Inc. has exercised reasonable skill, care and diligence to assess the information acquired during the preparation of this report. Matrix Solutions Inc. believes this information is accurate but cannot guarantee or warrant its accuracy or completeness. Information provided by others was believed to be accurate but cannot be guaranteed.

The information presented in this report was acquired, compiled and interpreted exclusively for the purposes described in this report. Matrix Solutions Inc. does not accept any responsibility for the use of this report or data used in it, in whole or in part, for any purpose other than intended or to any third party for use whatsoever.



LEGEND
- ENGINEERED SPILLS (5 TOTAL)
- PASSIVE SPILLS (30 TOTAL)

SCALE 1:7 000 000

DATE: NOVEMBER 2006	CLIENT: **PETROLEUM TECHNOLOGY ALLIANCE CANADA**
JOB NO: 3202-601	PROJECT: **REMEDIATION OF SALT AFFECTED SITES BY LEACHING**
CAD FILE: 3202-Sites-06.dwg	**SPILL LOCATION MAP**
DESIGN: NF / DRAWN: GE / CHECK: JF	FIGURE: **1**

Matrix Solutions Inc.
ENVIRONMENTAL CONSULTANTS

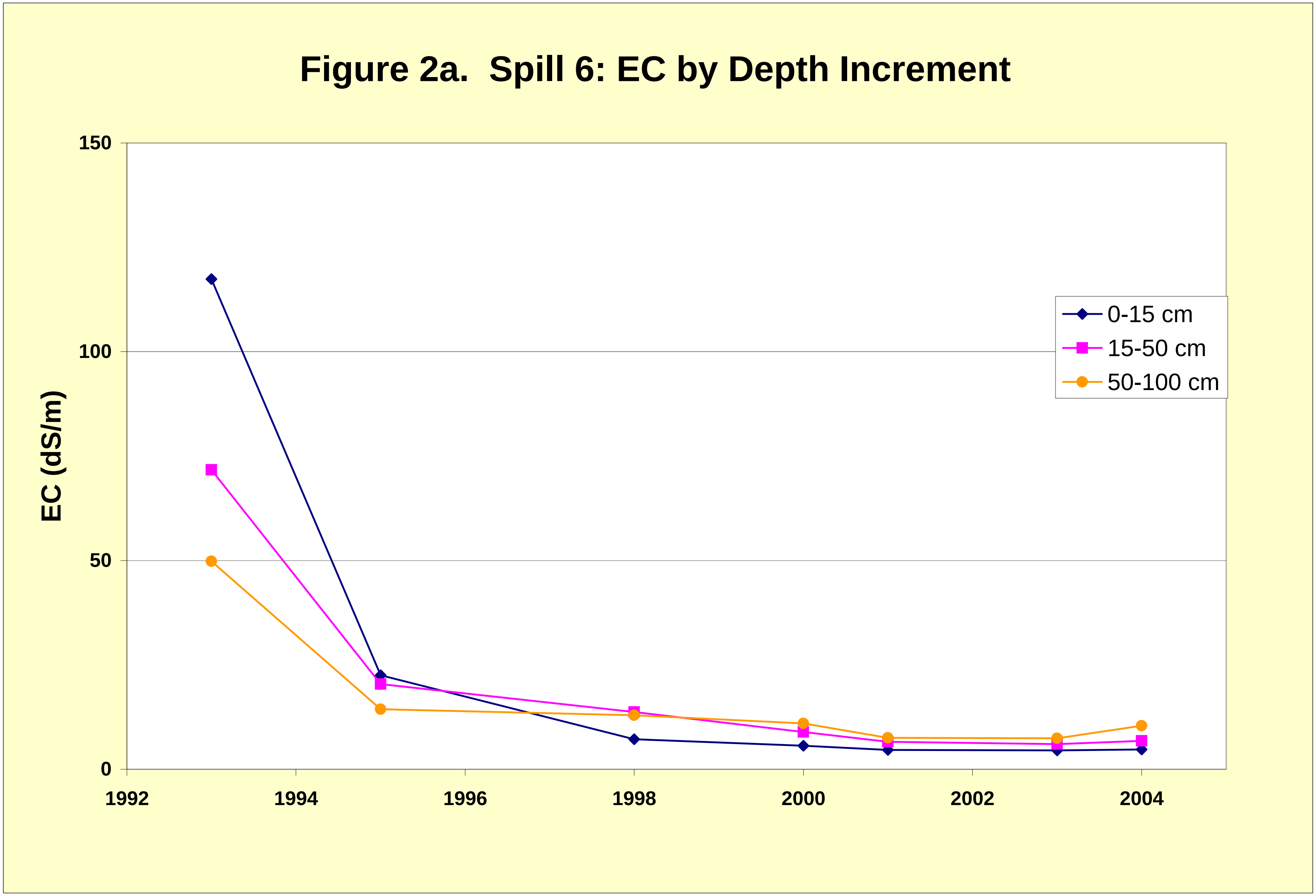


Figure 2a. Spill 6: EC by Depth Increment
EC (dS/m)
150
100
50
0
1992
1994
1996
1998
2000
2002
2004
0-15 cm
15-50 cm
50-100 cm

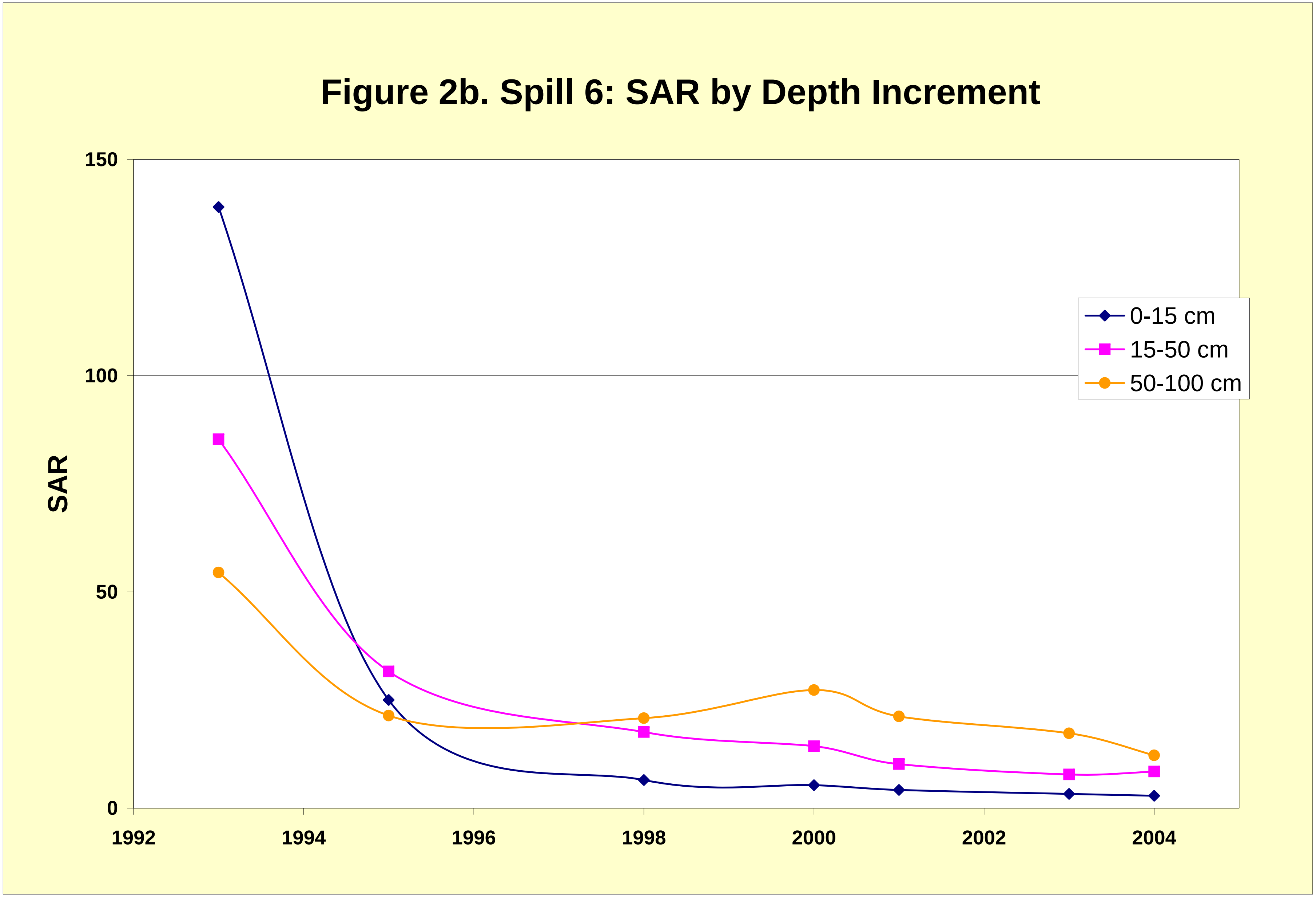


Figure 2b. Spill 6: SAR by Depth Increment
SAR
150
100
50
0
1992
1994
1996
1998
2000
2002
2004
0-15 cm
15-50 cm
50-100 cm

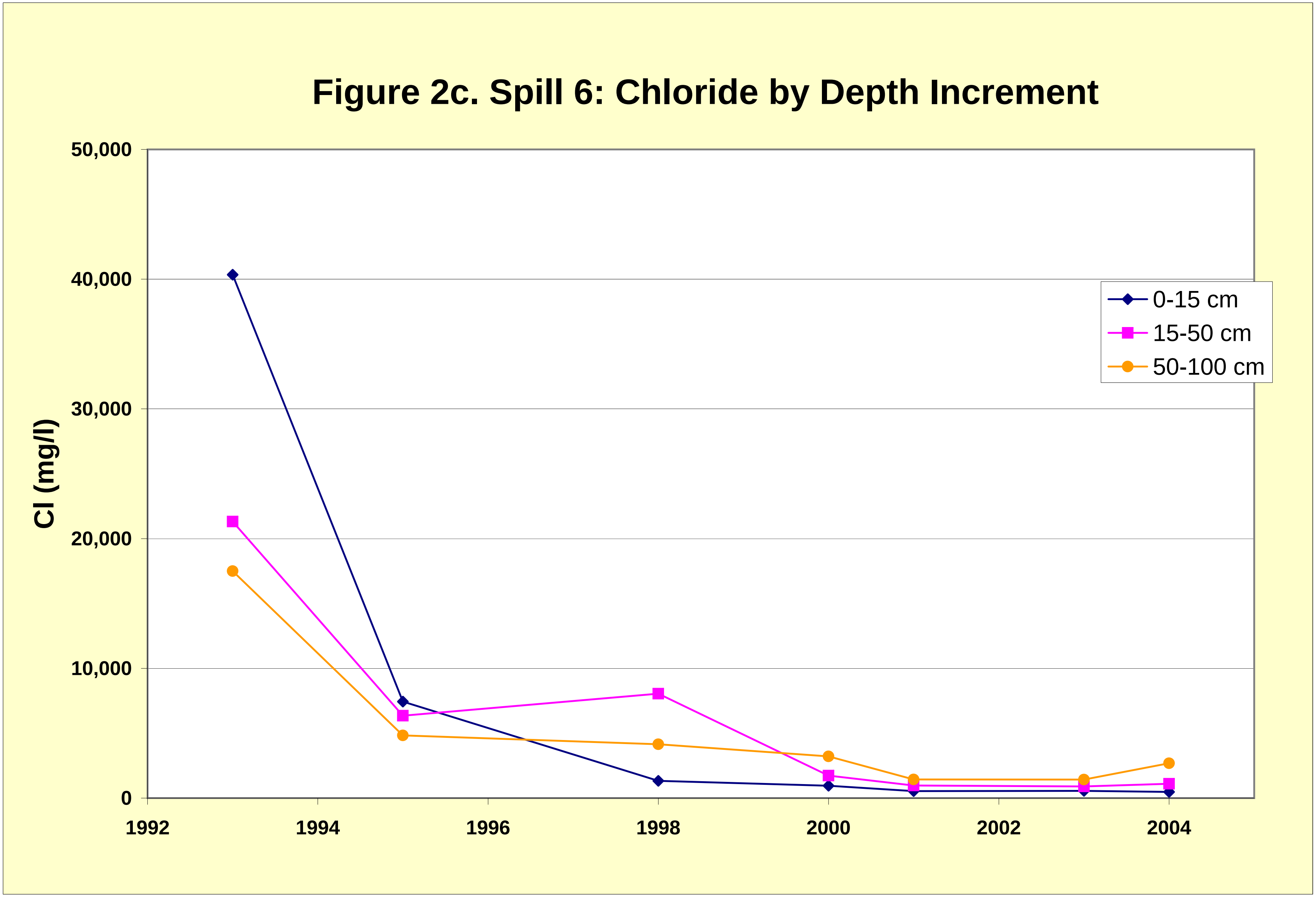


Figure 2c. Spill 6: Chloride by Depth Increment
Cl (mg/l)
50,000
40,000
30,000
20,000
10,000
0
1992
1994
1996
1998
2000
2002
2004
0-15 cm
15-50 cm
50-100 cm

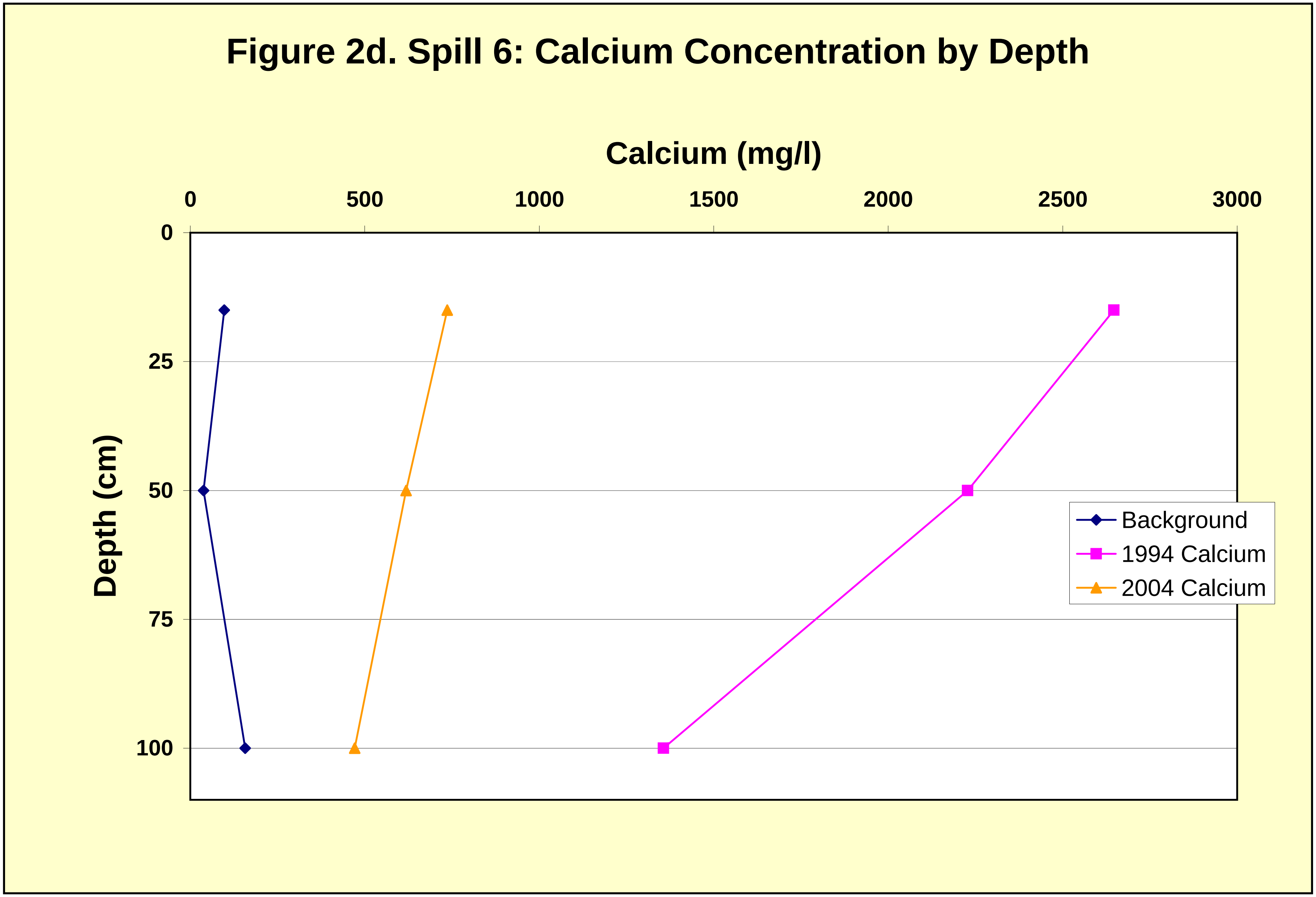


Figure 2d. Spill 6: Calcium Concentration by Depth
Calcium (mg/l)
0
500
1000
1500
2000
2500
3000
Depth (cm)
0
25
50
75
100
Background
1994 Calcium
2004 Calcium

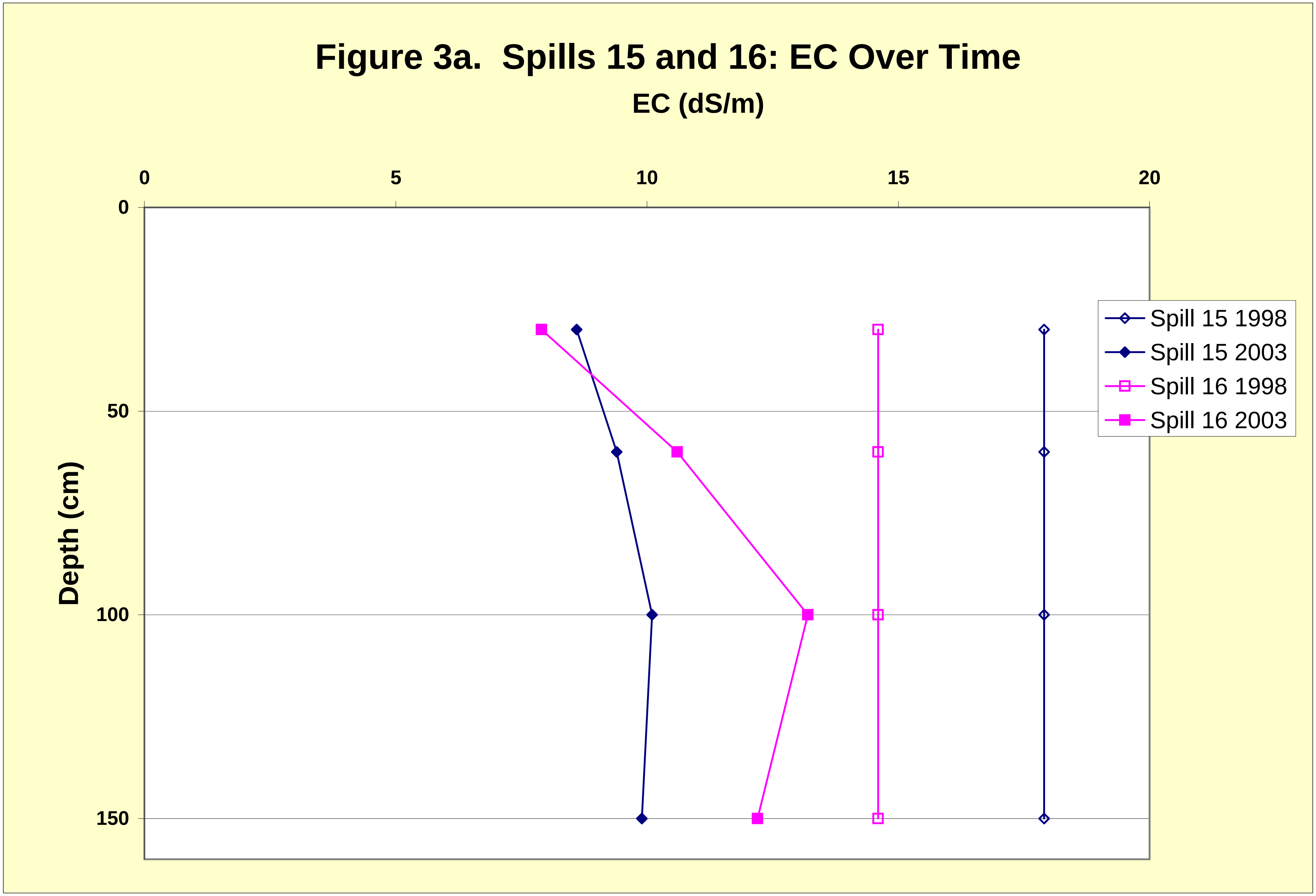


Figure 3a. Spills 15 and 16: EC Over Time
EC (dS/m)
0
5
10
15
20
0
50
100
150
Depth (cm)
Spill 15 1998
Spill 15 2003
Spill 16 1998
Spill 16 2003

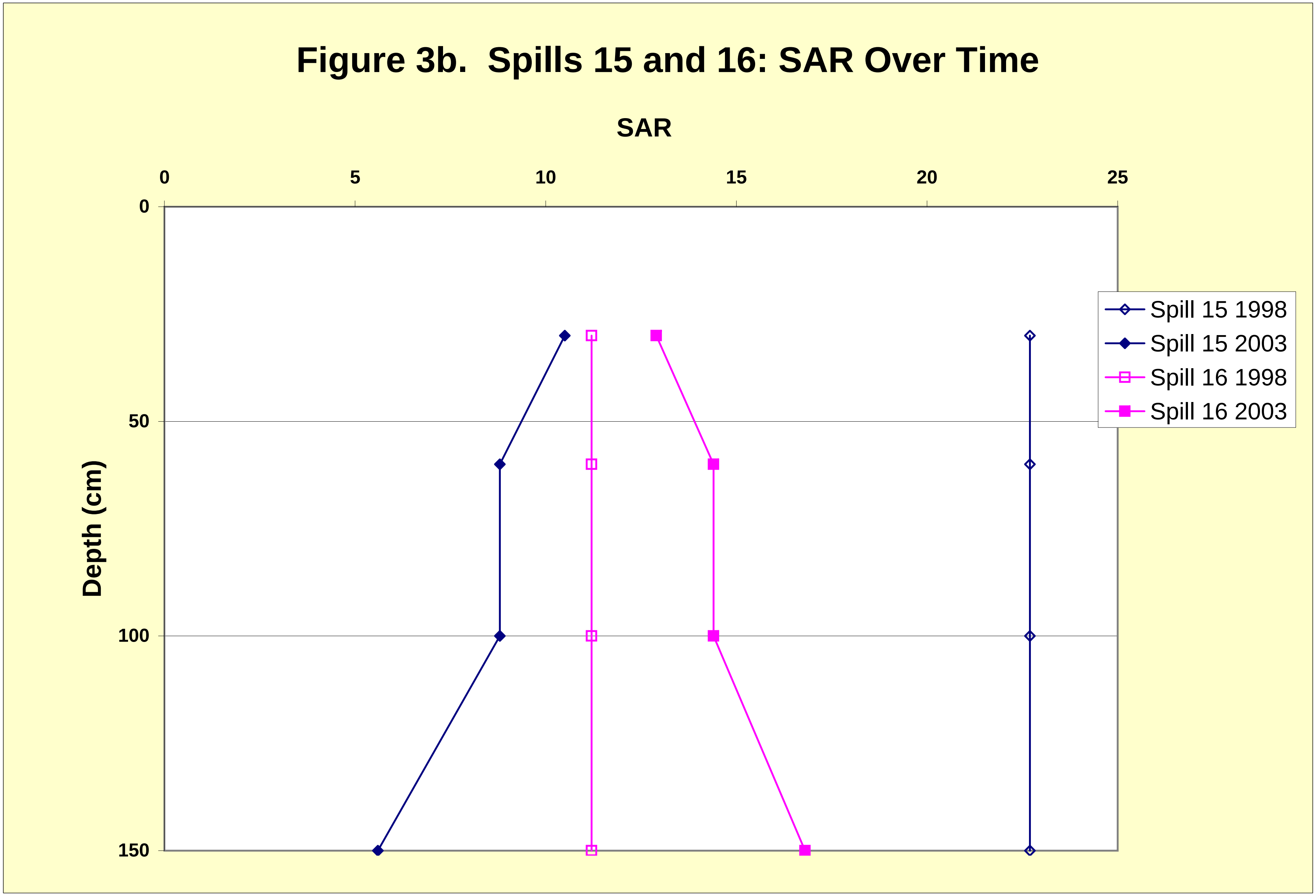


Figure 3b. Spills 15 and 16: SAR Over Time
SAR
0
5
10
15
20
25
Depth (cm)
0
50
100
150
Spill 15 1998
Spill 15 2003
Spill 16 1998
Spill 16 2003

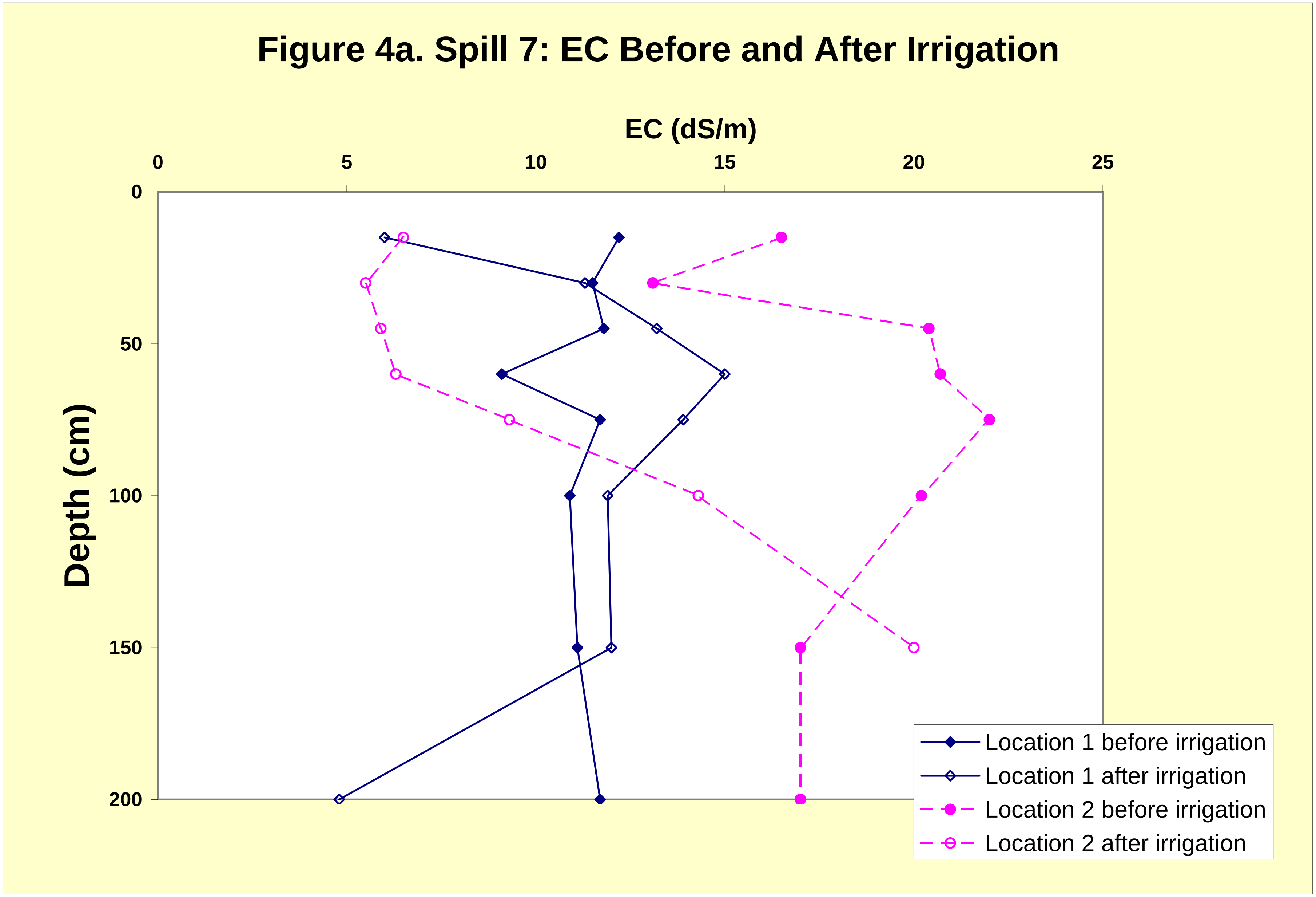


Figure 4a. Spill 7: EC Before and After Irrigation
EC (dS/m)
0
5
10
15
20
25
Depth (cm)
0
50
100
150
200
Location 1 before irrigation
Location 1 after irrigation
Location 2 before irrigation
Location 2 after irrigation

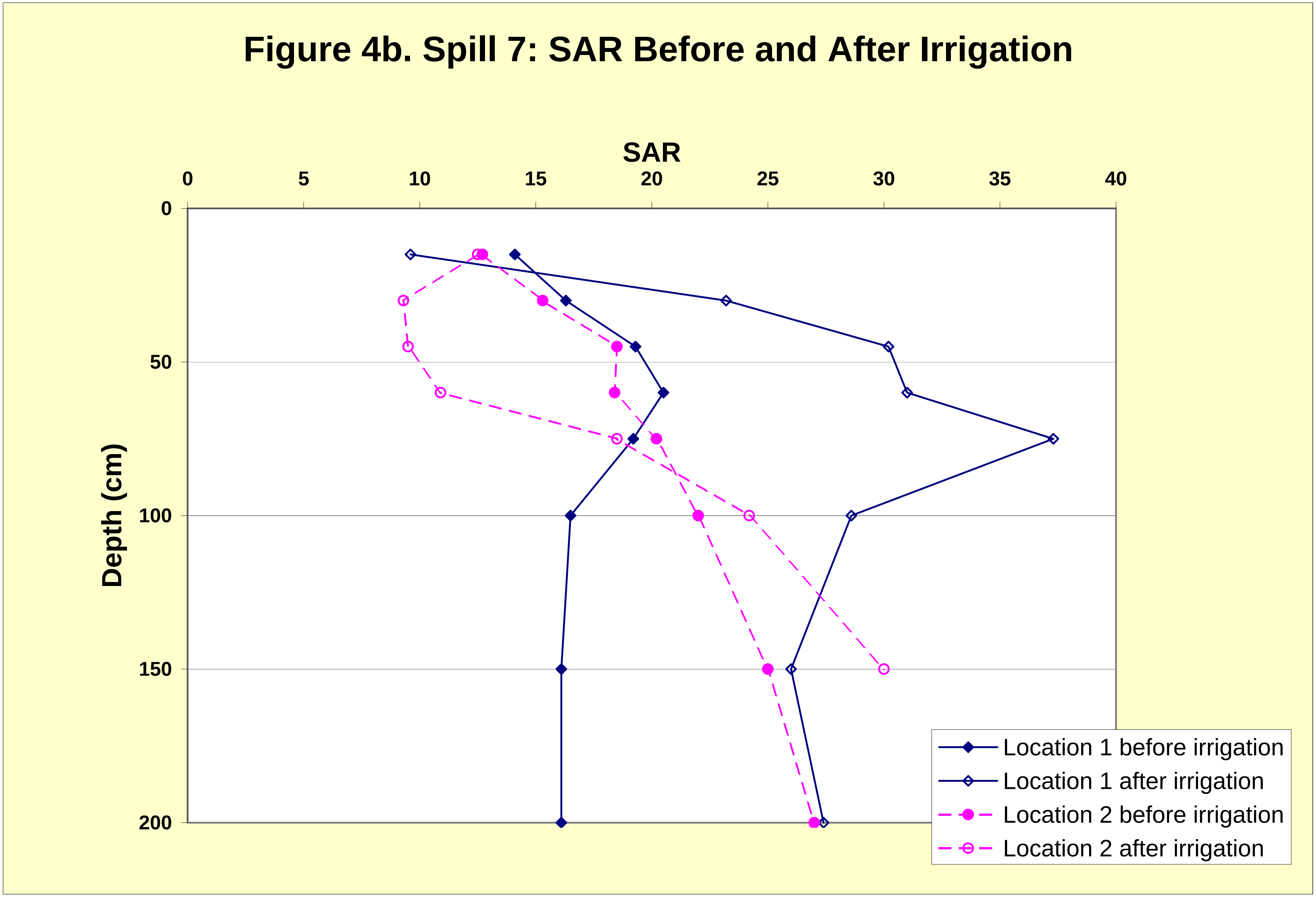


Figure 4b. Spill 7: SAR Before and After Irrigation
SAR
0
5
10
15
20
25
30
35
40
Depth (cm)
0
50
100
150
200
Location 1 before irrigation
Location 1 after irrigation
Location 2 before irrigation
Location 2 after irrigation

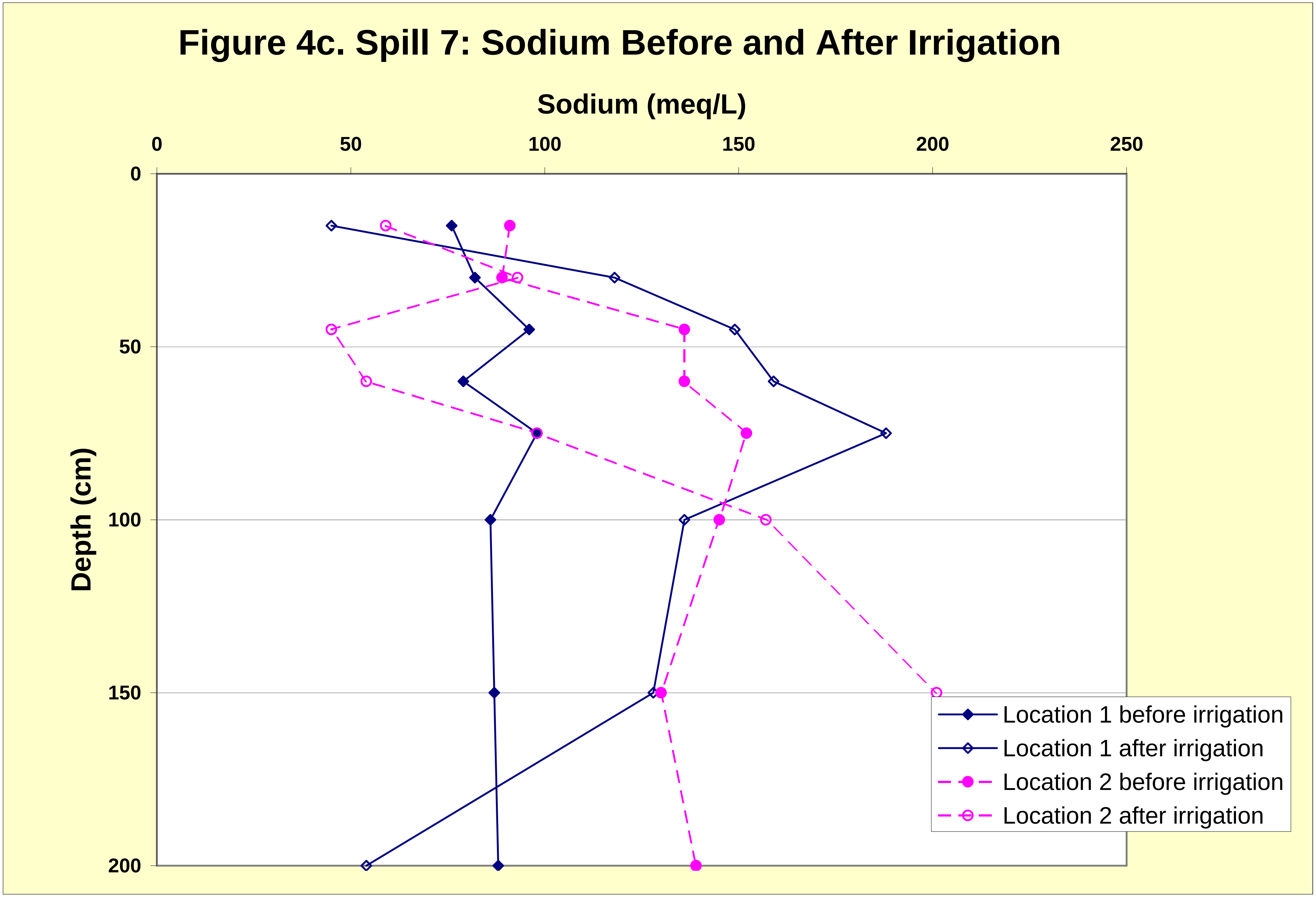


Figure 4c. Spill 7: Sodium Before and After Irrigation
Sodium (meq/L)
0
50
100
150
200
250
Depth (cm)
0
50
100
150
200
Location 1 before irrigation
Location 1 after irrigation
Location 2 before irrigation
Location 2 after irrigation

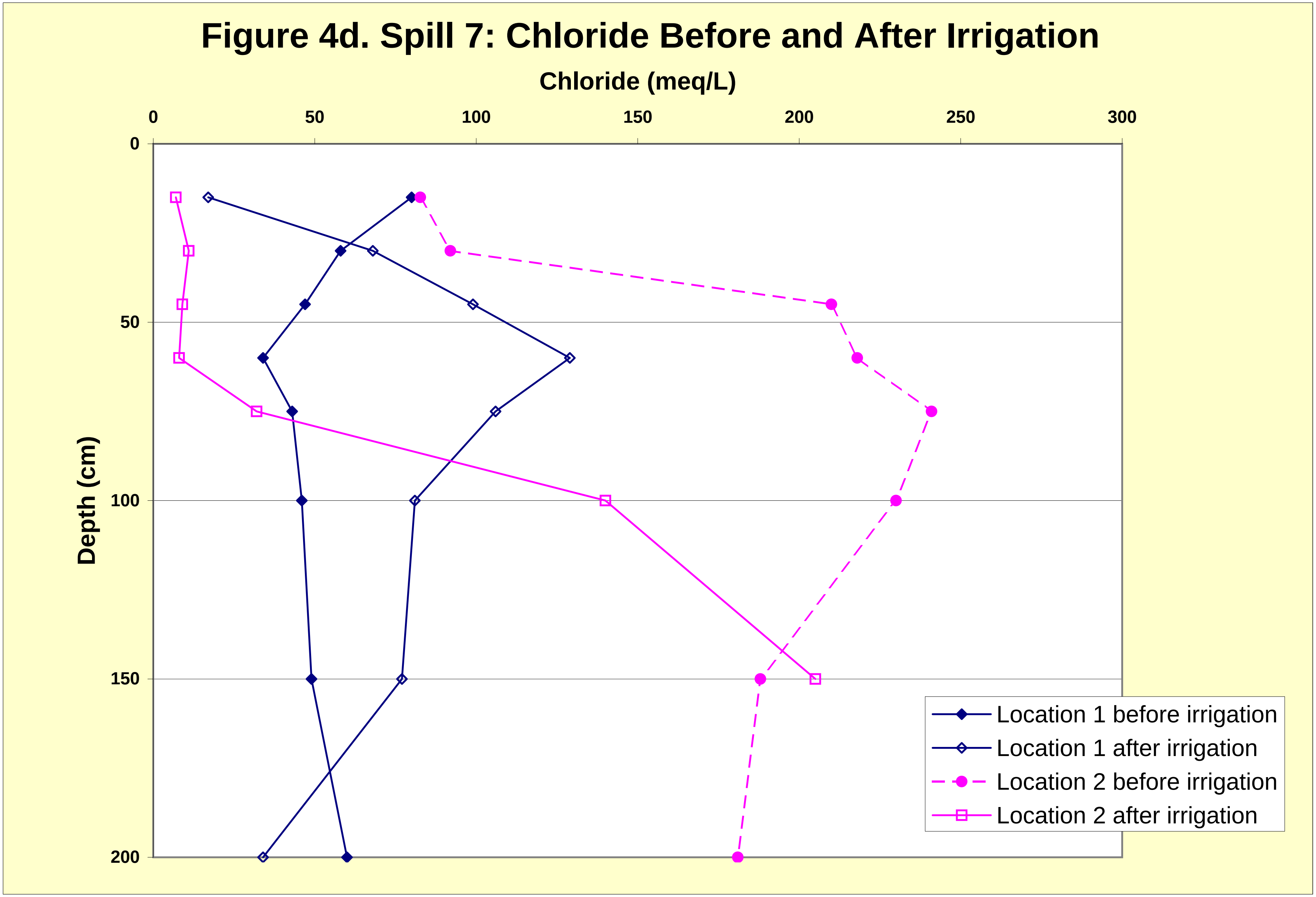


Figure 4d. Spill 7: Chloride Before and After Irrigation
Chloride (meq/L)
0
50
100
150
200
250
300
Depth (cm)
0
50
100
150
200
Location 1 before irrigation
Location 1 after irrigation
Location 2 before irrigation
Location 2 after irrigation

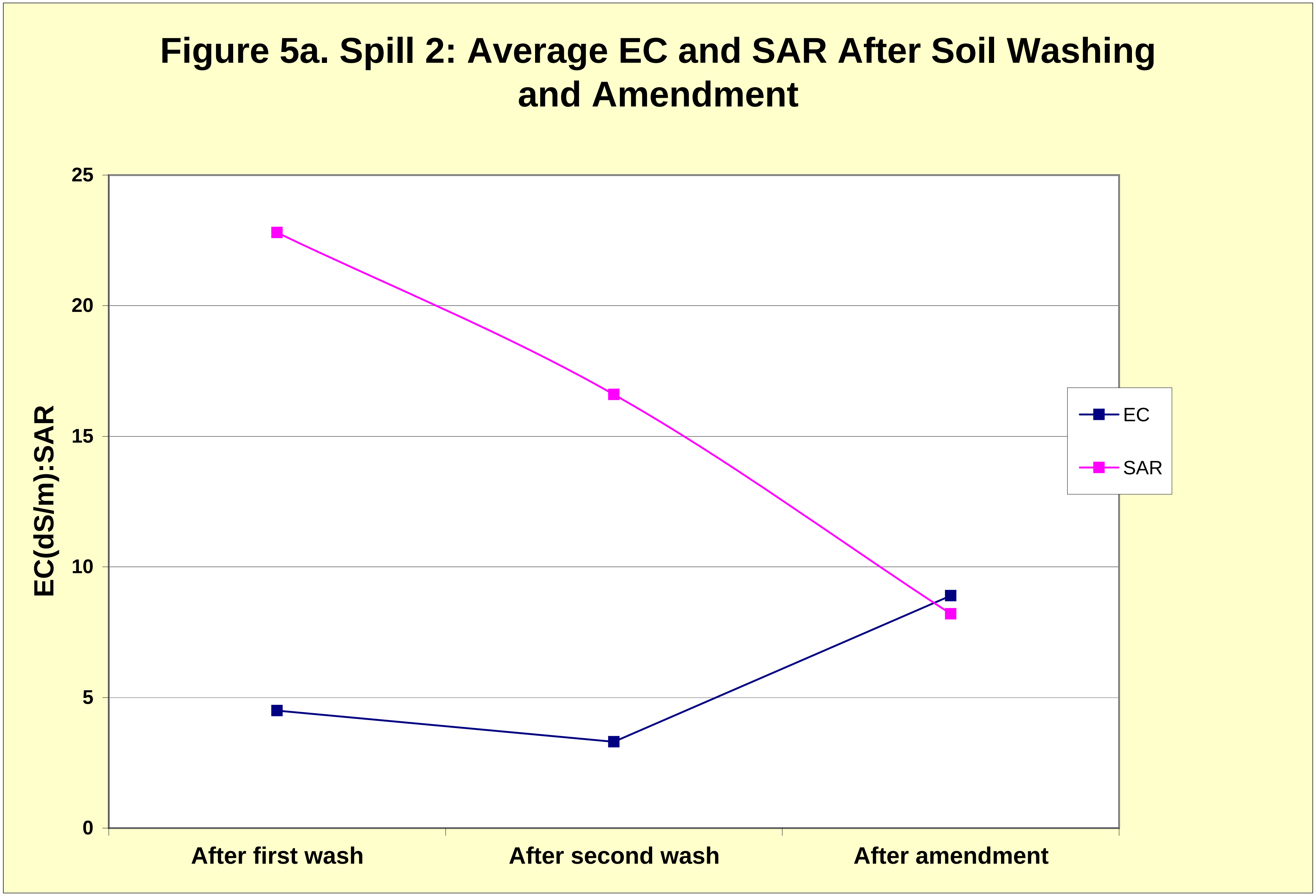


Figure 5a. Spill 2: Average EC and SAR After Soil Washing and Amendment
EC(dS/m):SAR
25
20
15
10
5
0
After first wash
After second wash
After amendment
EC
SAR

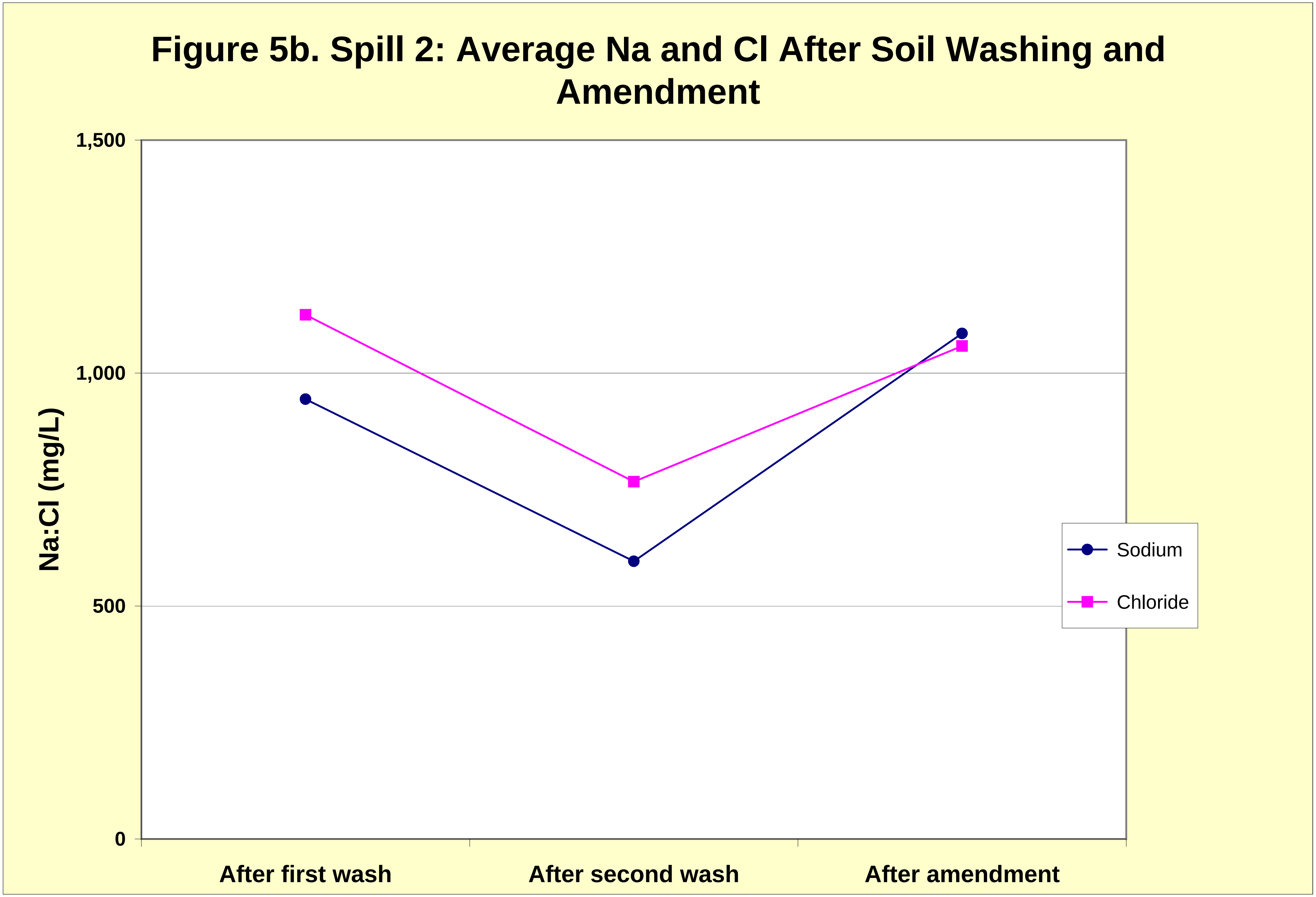


Figure 5b. Spill 2: Average Na and Cl After Soil Washing and Amendment
Na:Cl (mg/L)
1,500
1,000
500
0
After first wash
After second wash
After amendment
Sodium
Chloride

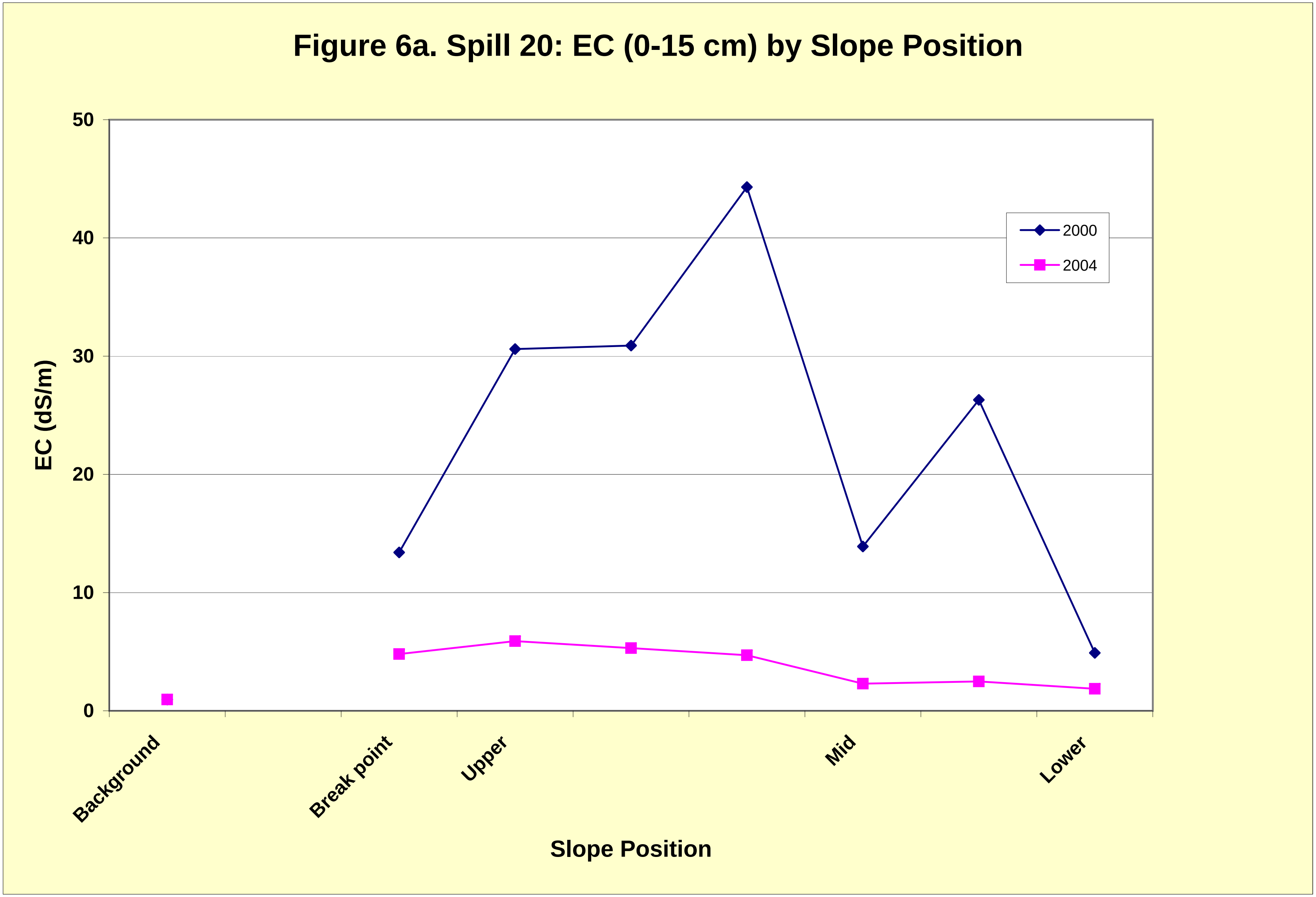


Figure 6a. Spill 20: EC (0-15 cm) by Slope Position
EC (dS/m)
50
40
30
20
10
0
2000
2004
Background
Break point
Upper
Mid
Lower
Slope Position

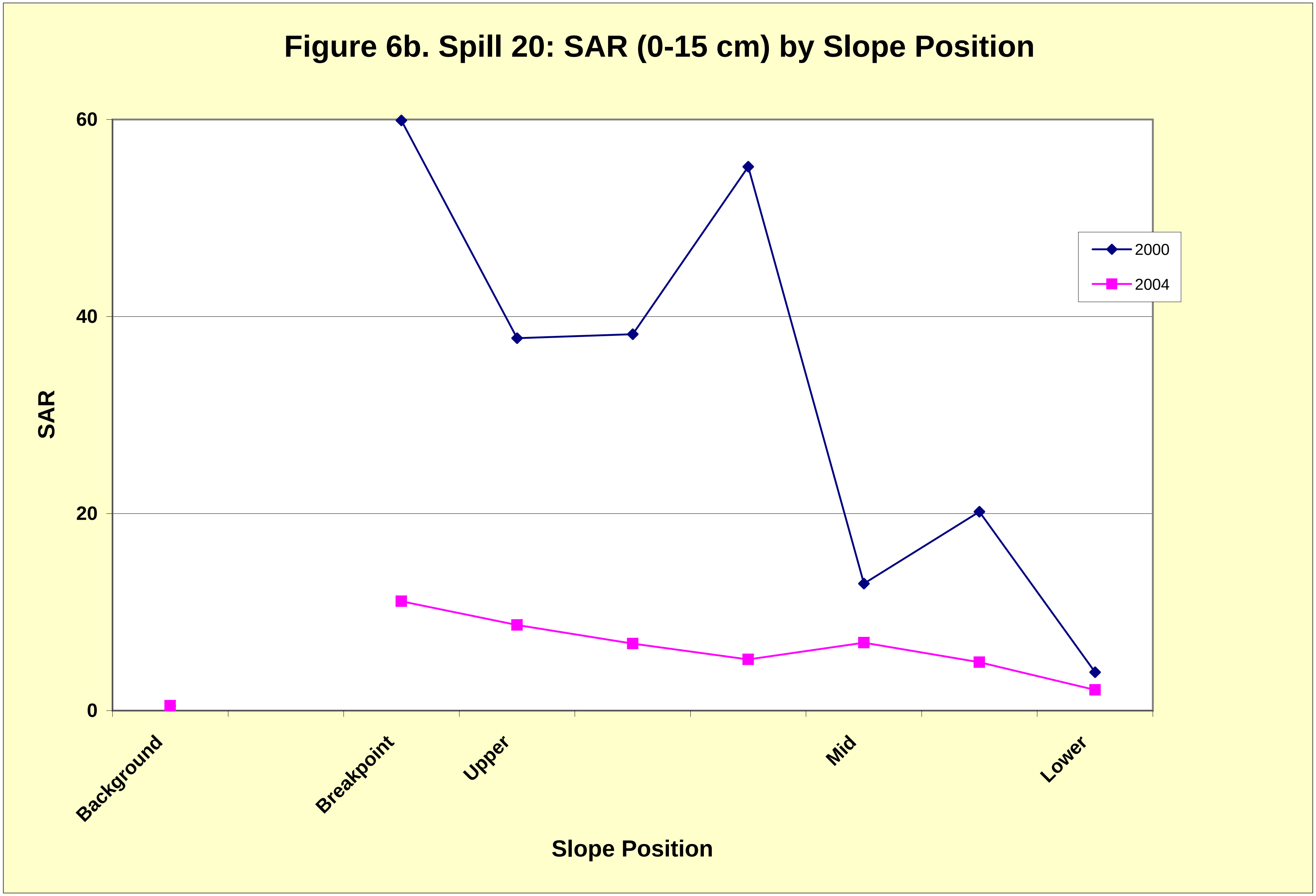


Figure 6b. Spill 20: SAR (0-15 cm) by Slope Position
60
40
20
0
SAR
2000
2004
Background
Breakpoint
Upper
Mid
Lower
Slope Position

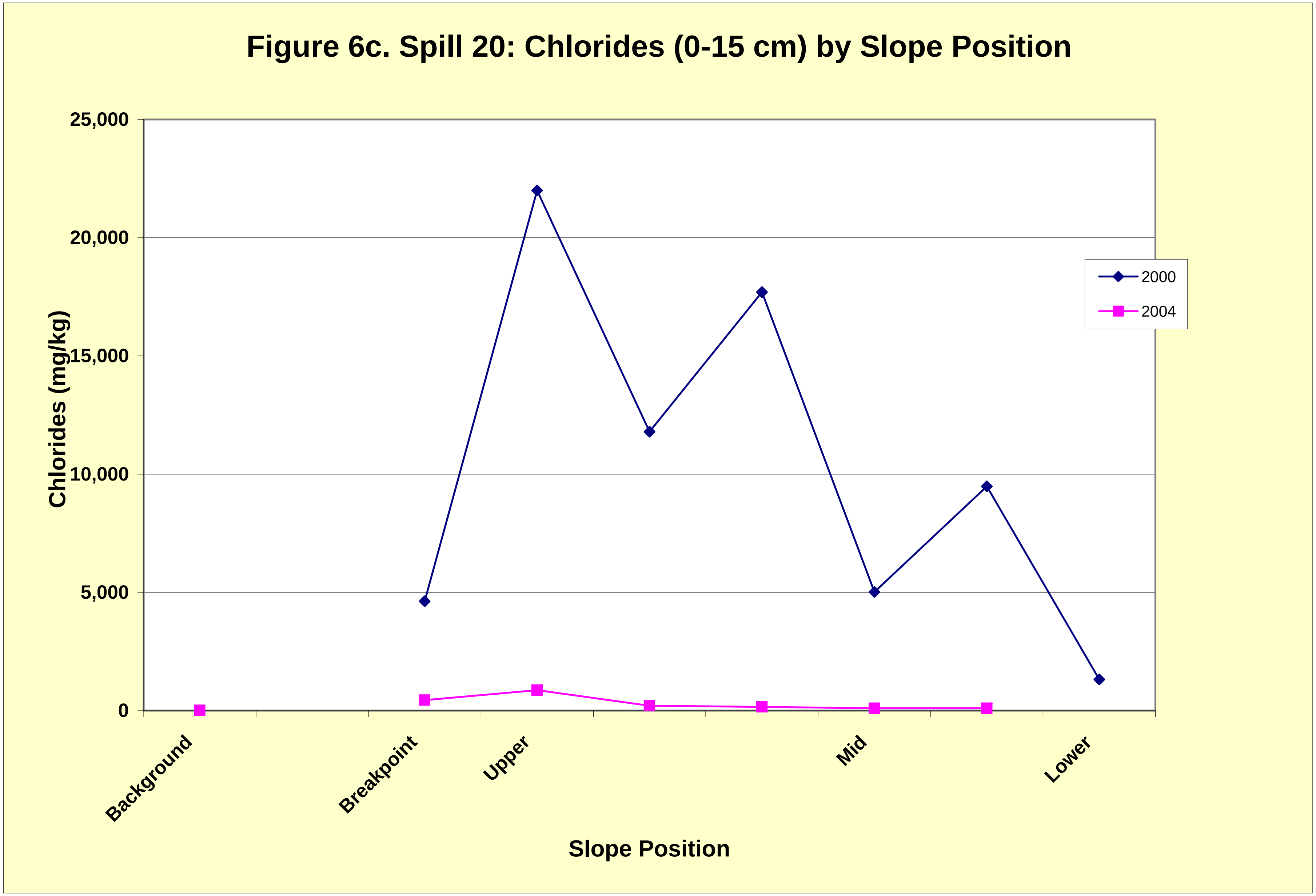


Figure 6c. Spill 20: Chlorides (0-15 cm) by Slope Position
Chlorides (mg/kg)
25,000
20,000
15,000
10,000
5,000
0
Background
Breakpoint
Upper
Mid
Lower
Slope Position
2000
2004

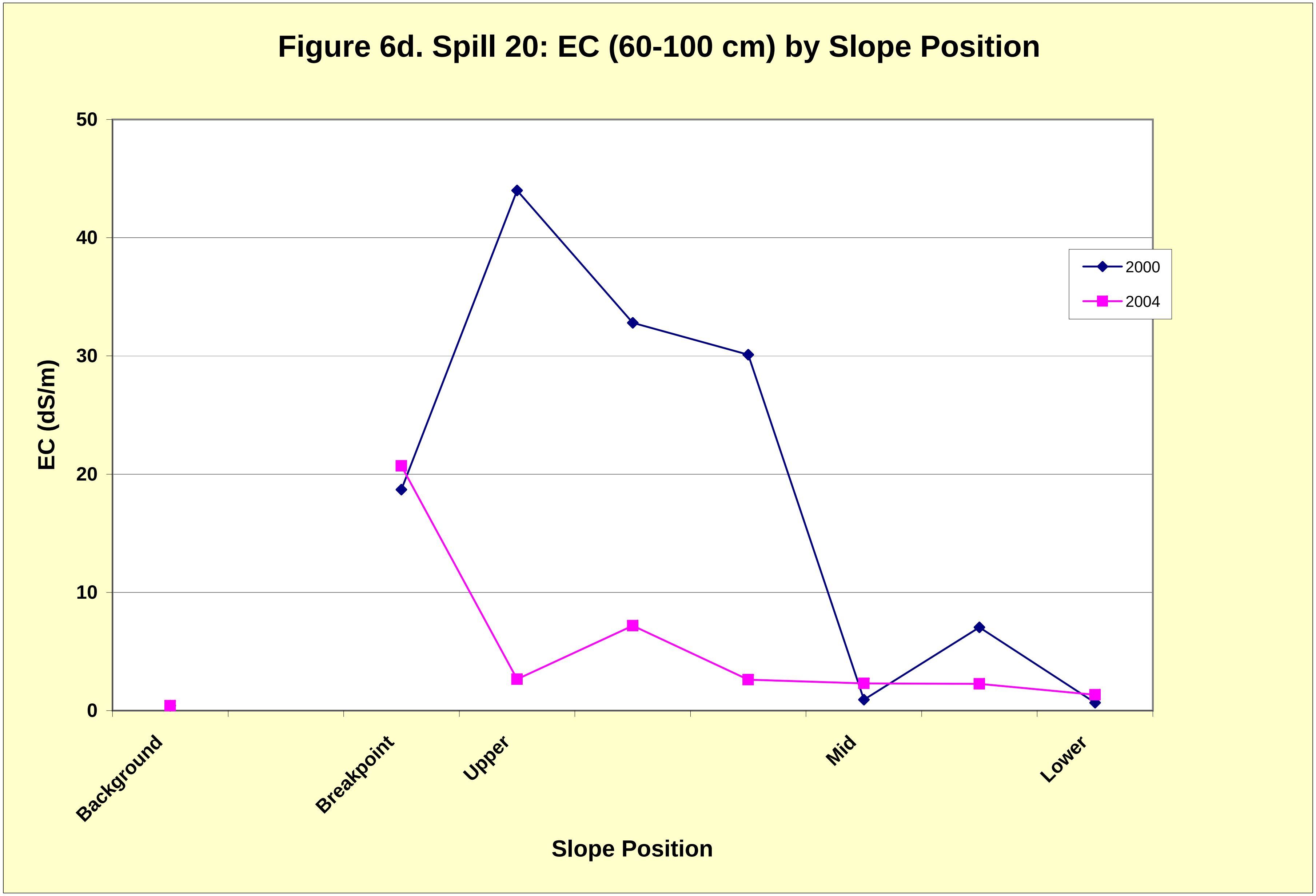


Figure 6d. Spill 20: EC (60-100 cm) by Slope Position
EC (dS/m)
0
10
20
30
40
50
2000
2004
Background
Breakpoint
Upper
Mid
Lower
Slope Position

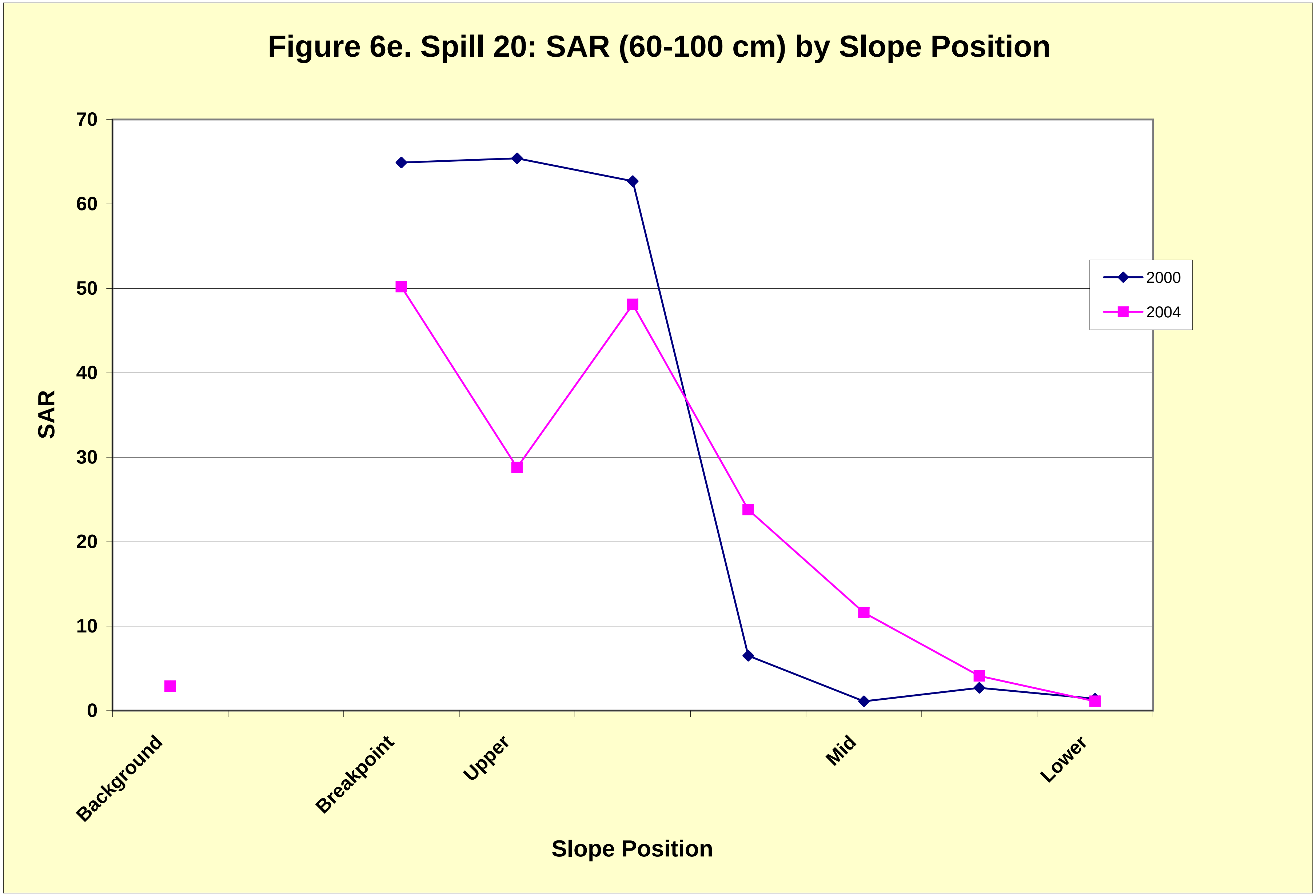


Figure 6e. Spill 20: SAR (60-100 cm) by Slope Position
SAR
70
60
50
40
30
20
10
0
Background
Breakpoint
Upper
Mid
Lower
Slope Position
2000
2004

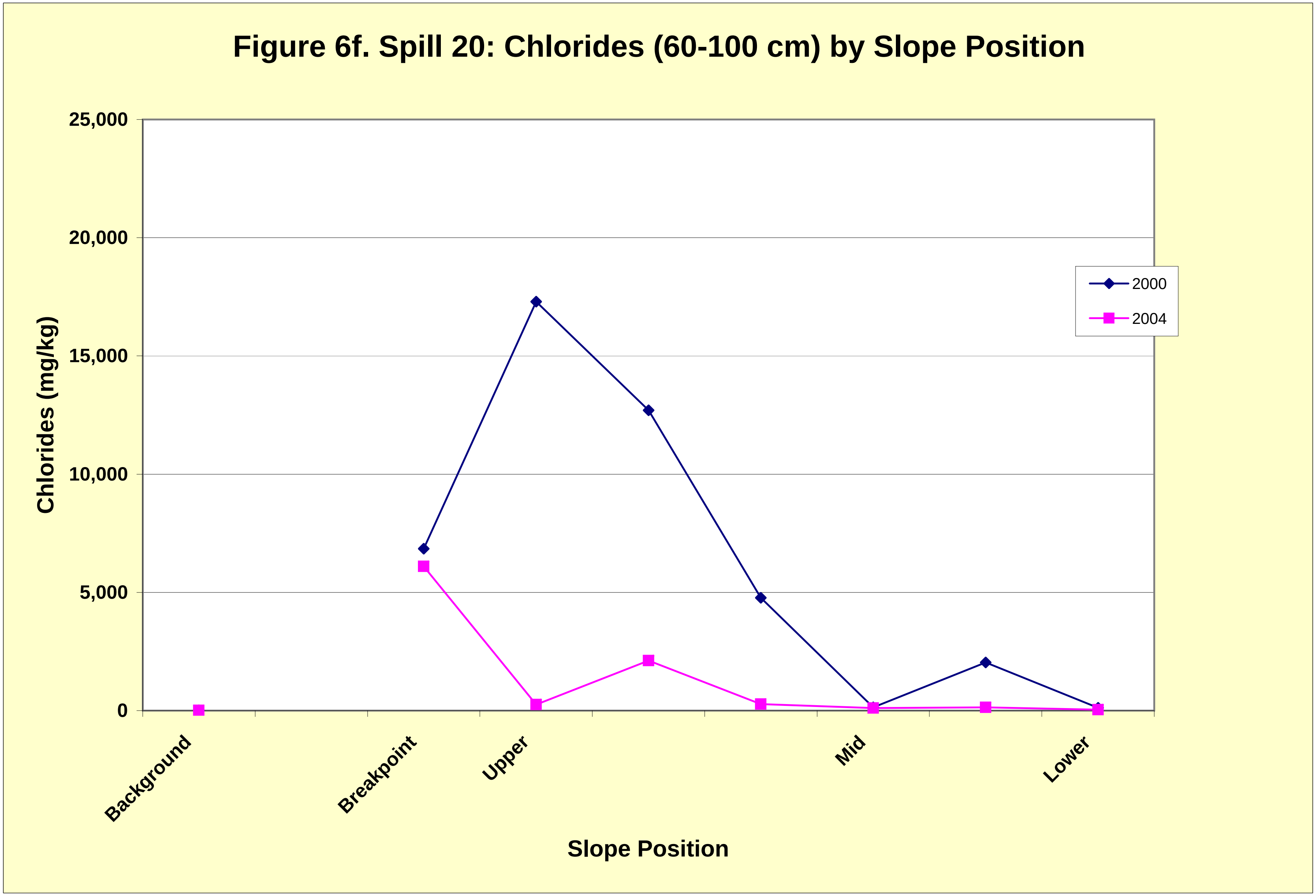


Figure 6f. Spill 20: Chlorides (60-100 cm) by Slope Position
25,000
20,000
15,000
10,000
5,000
0
Chlorides (mg/kg)
2000
2004
Background
Breakpoint
Upper
Mid
Lower
Slope Position

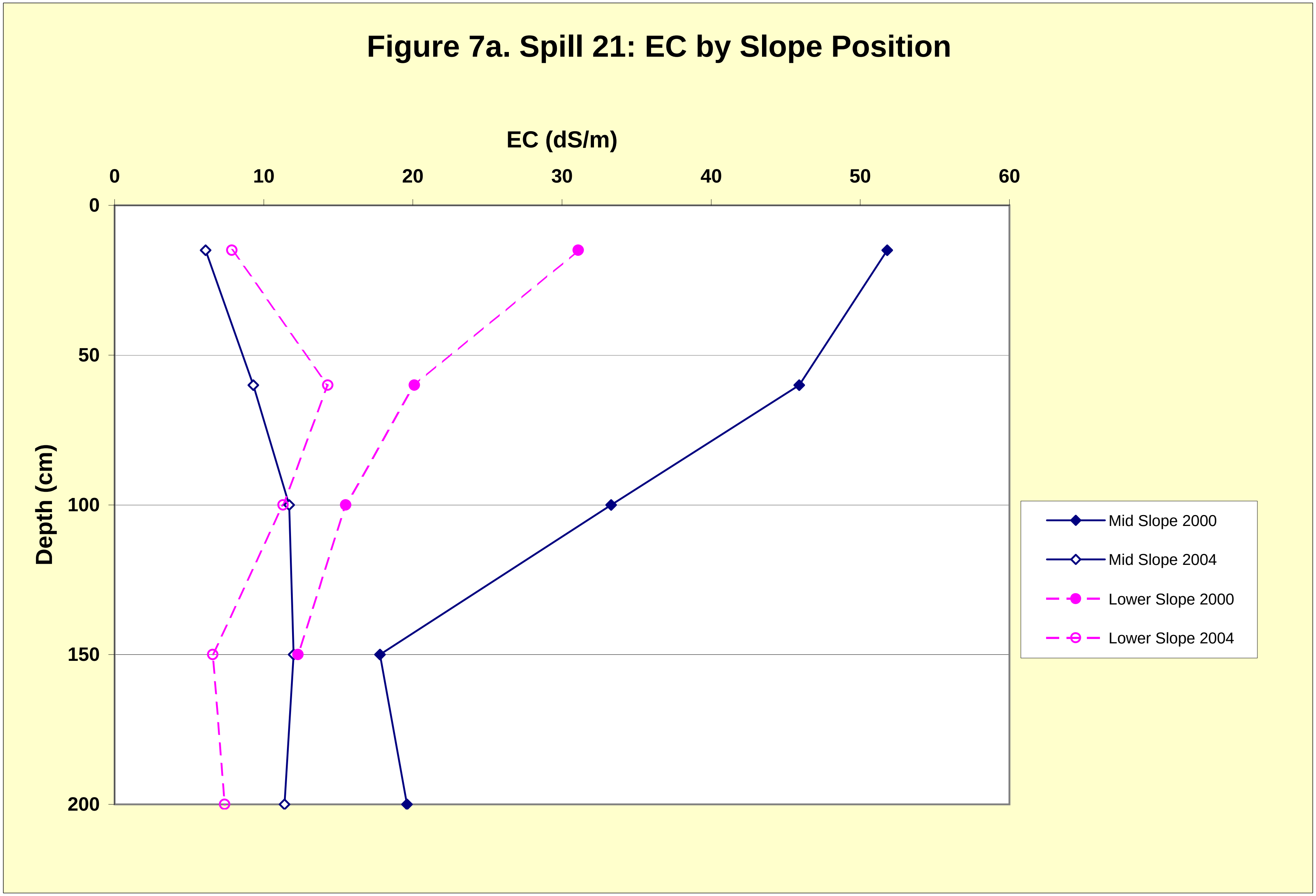


Figure 7a. Spill 21: EC by Slope Position
EC (dS/m)
0
10
20
30
40
50
60
Depth (cm)
0
50
100
150
200
Mid Slope 2000
Mid Slope 2004
Lower Slope 2000
Lower Slope 2004

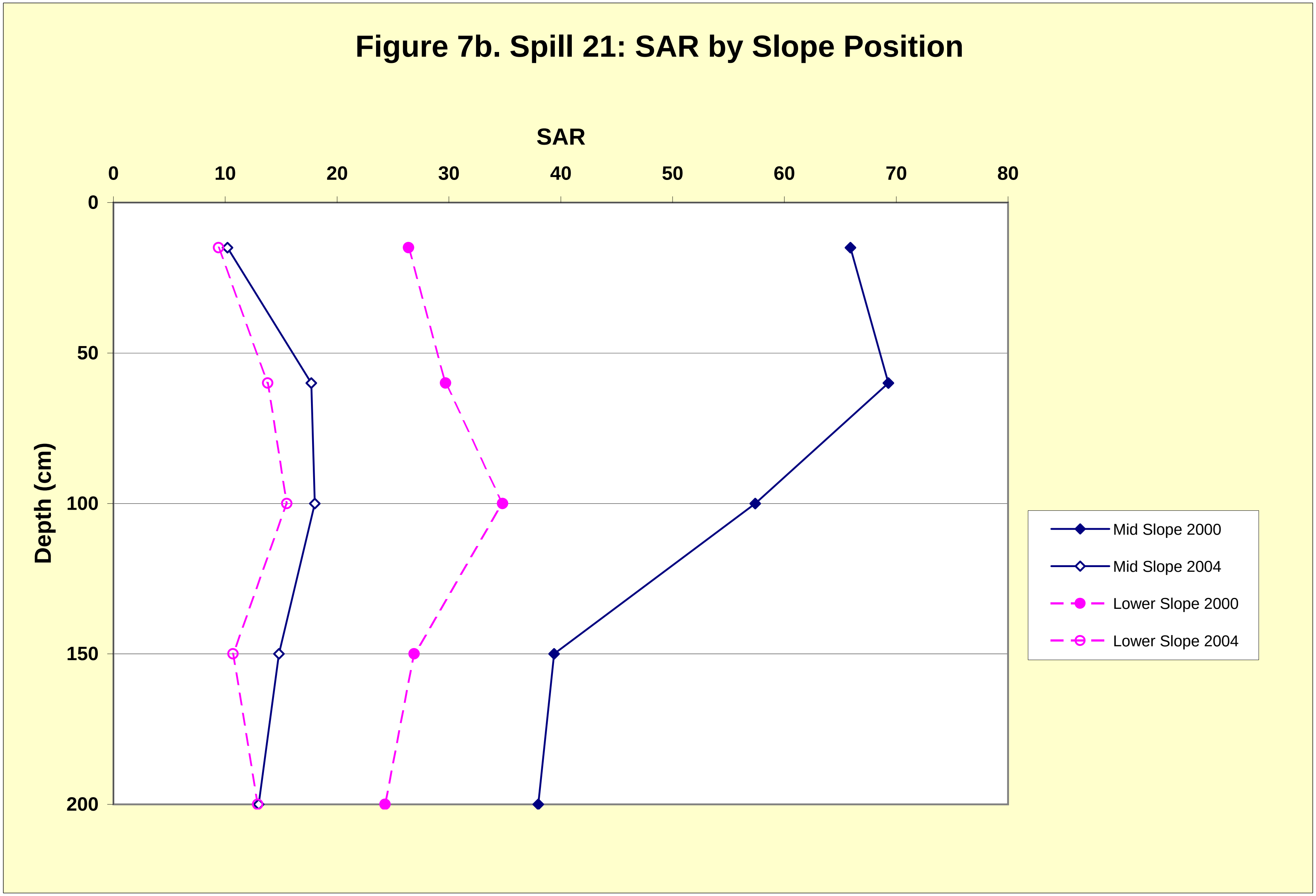
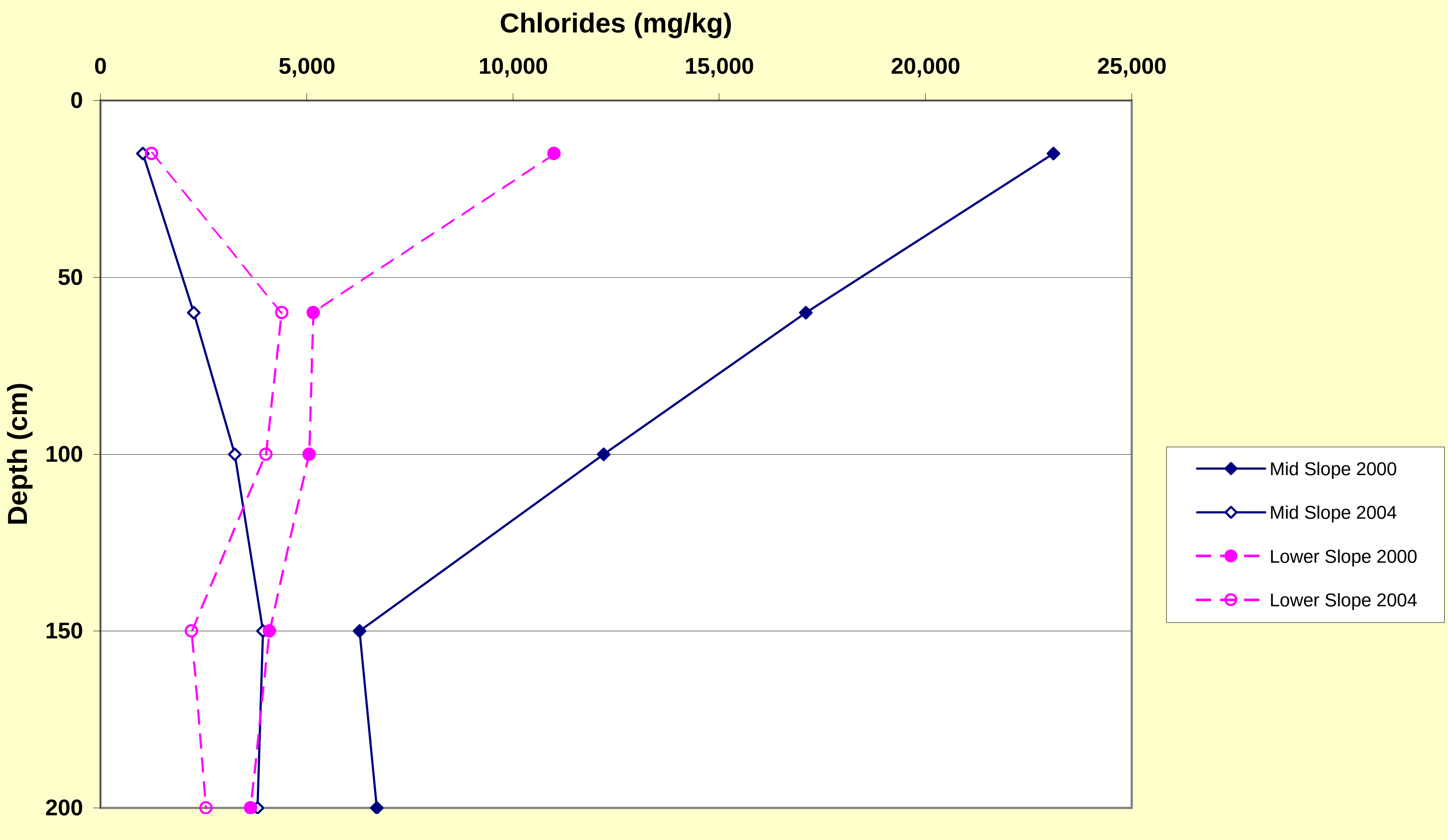


Figure 7b. Spill 21: SAR by Slope Position
SAR
0
10
20
30
40
50
60
70
80
Depth (cm)
0
50
100
150
200
Mid Slope 2000
Mid Slope 2004
Lower Slope 2000
Lower Slope 2004

Figure 7c. Spill 21: Chlorides by Slope Position



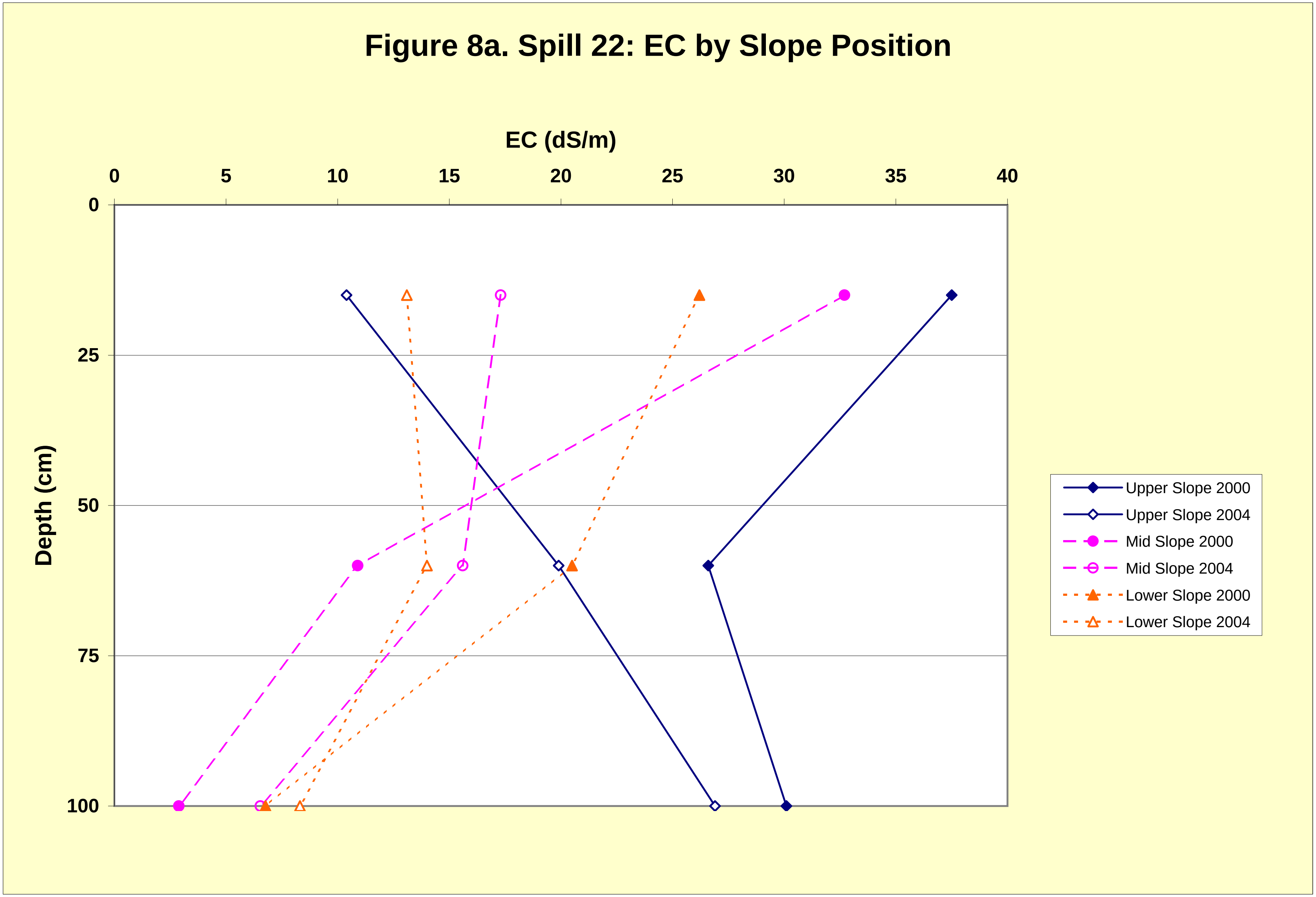


Figure 8a. Spill 22: EC by Slope Position
EC (dS/m)
0
5
10
15
20
25
30
35
40
Depth (cm)
0
25
50
75
100
Upper Slope 2000
Upper Slope 2004
Mid Slope 2000
Mid Slope 2004
Lower Slope 2000
Lower Slope 2004

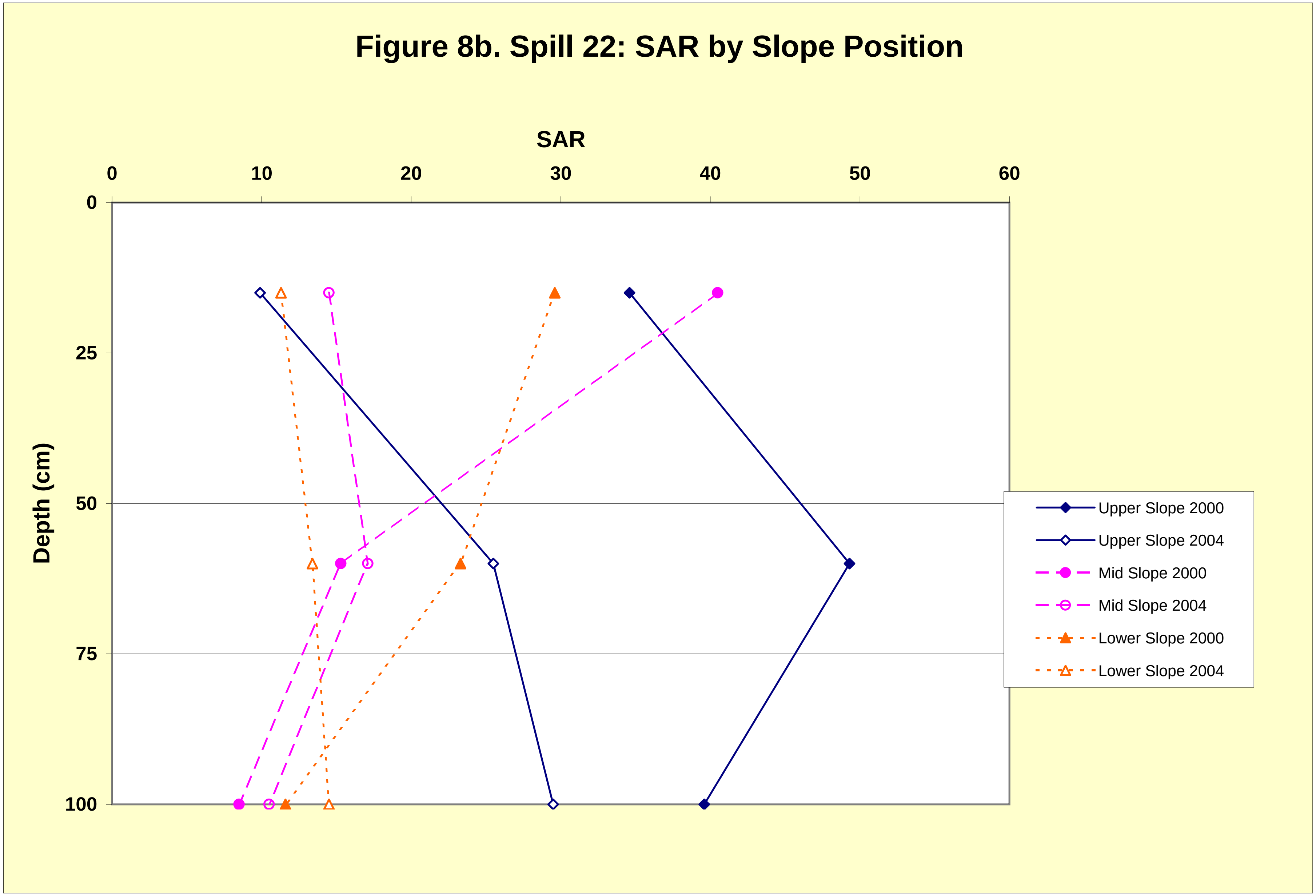


Figure 8b. Spill 22: SAR by Slope Position
SAR
0
10
20
30
40
50
60
0
25
50
75
100
Depth (cm)
Upper Slope 2000
Upper Slope 2004
Mid Slope 2000
Mid Slope 2004
Lower Slope 2000
Lower Slope 2004

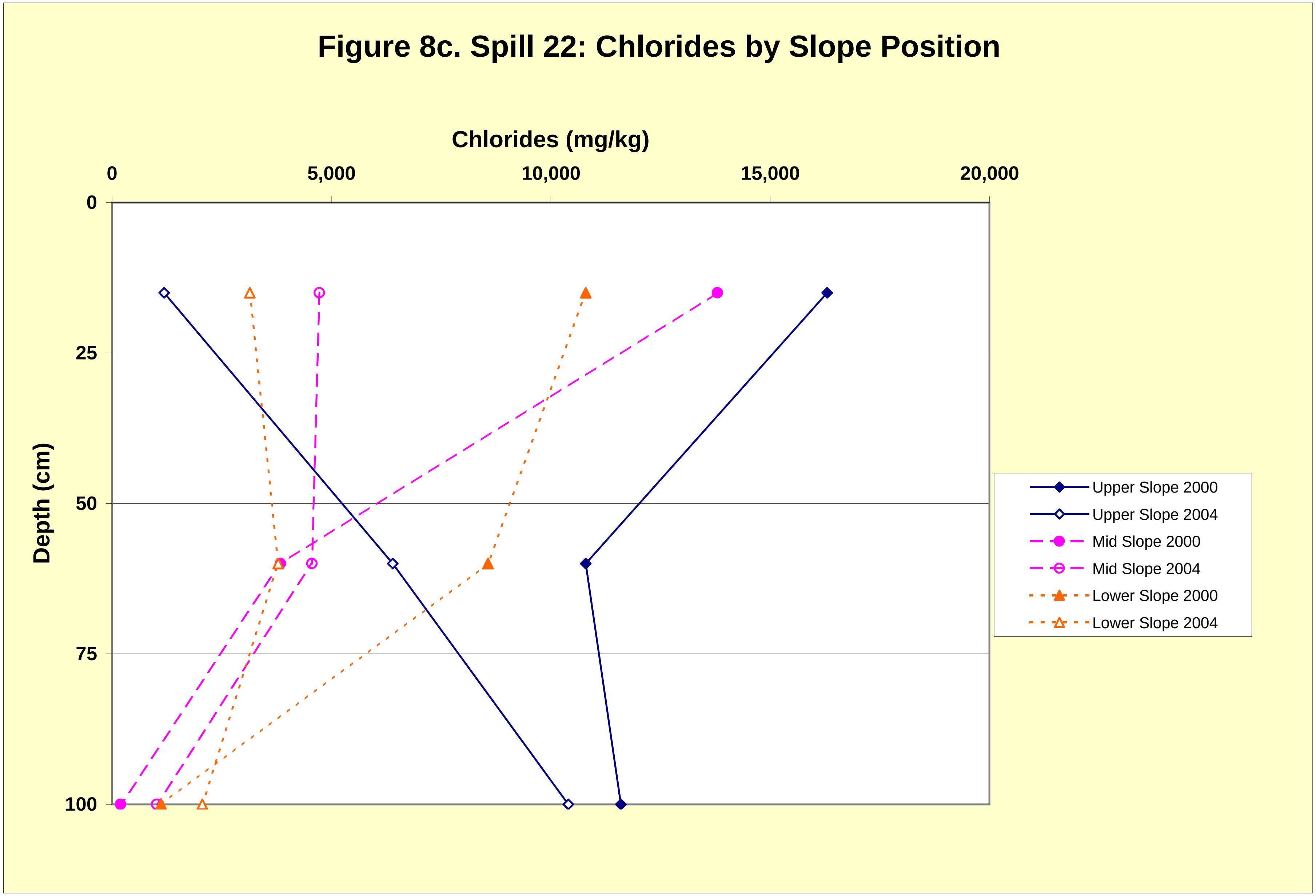


Figure 8c. Spill 22: Chlorides by Slope Position
Chlorides (mg/kg)
0
5,000
10,000
15,000
20,000
Depth (cm)
0
25
50
75
100
Upper Slope 2000
Upper Slope 2004
Mid Slope 2000
Mid Slope 2004
Lower Slope 2000
Lower Slope 2004

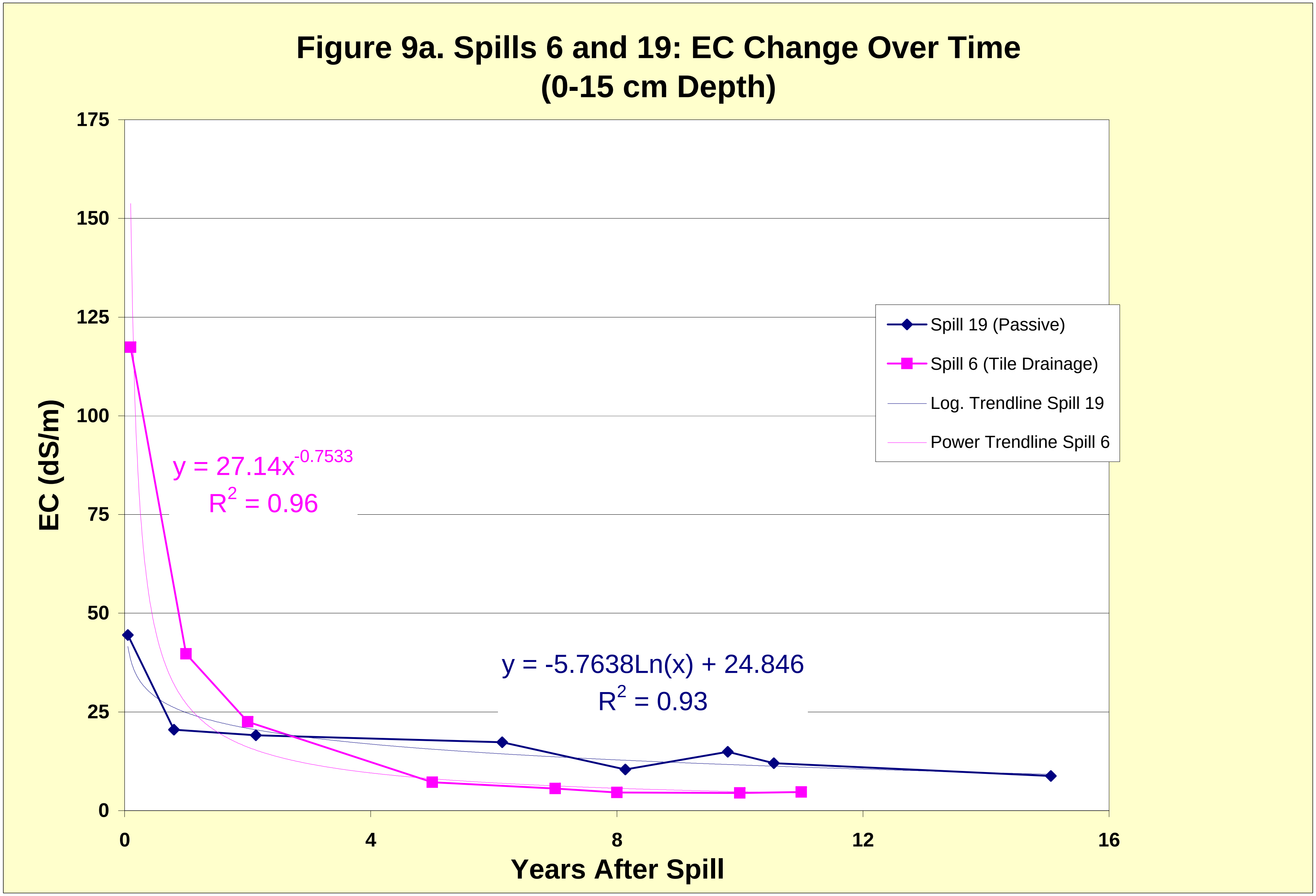


Figure 9a. Spills 6 and 19: EC Change Over Time
(0-15 cm Depth)
175
150
125
100
75
50
25
0
EC (dS/m)
0
4
8
12
16
Years After Spill
y = 27.14x-0.7533
R2 = 0.96
y = -5.7638Ln(x) + 24.846
R2 = 0.93
Spill 19 (Passive)
Spill 6 (Tile Drainage)
Log. Trendline Spill 19
Power Trendline Spill 6

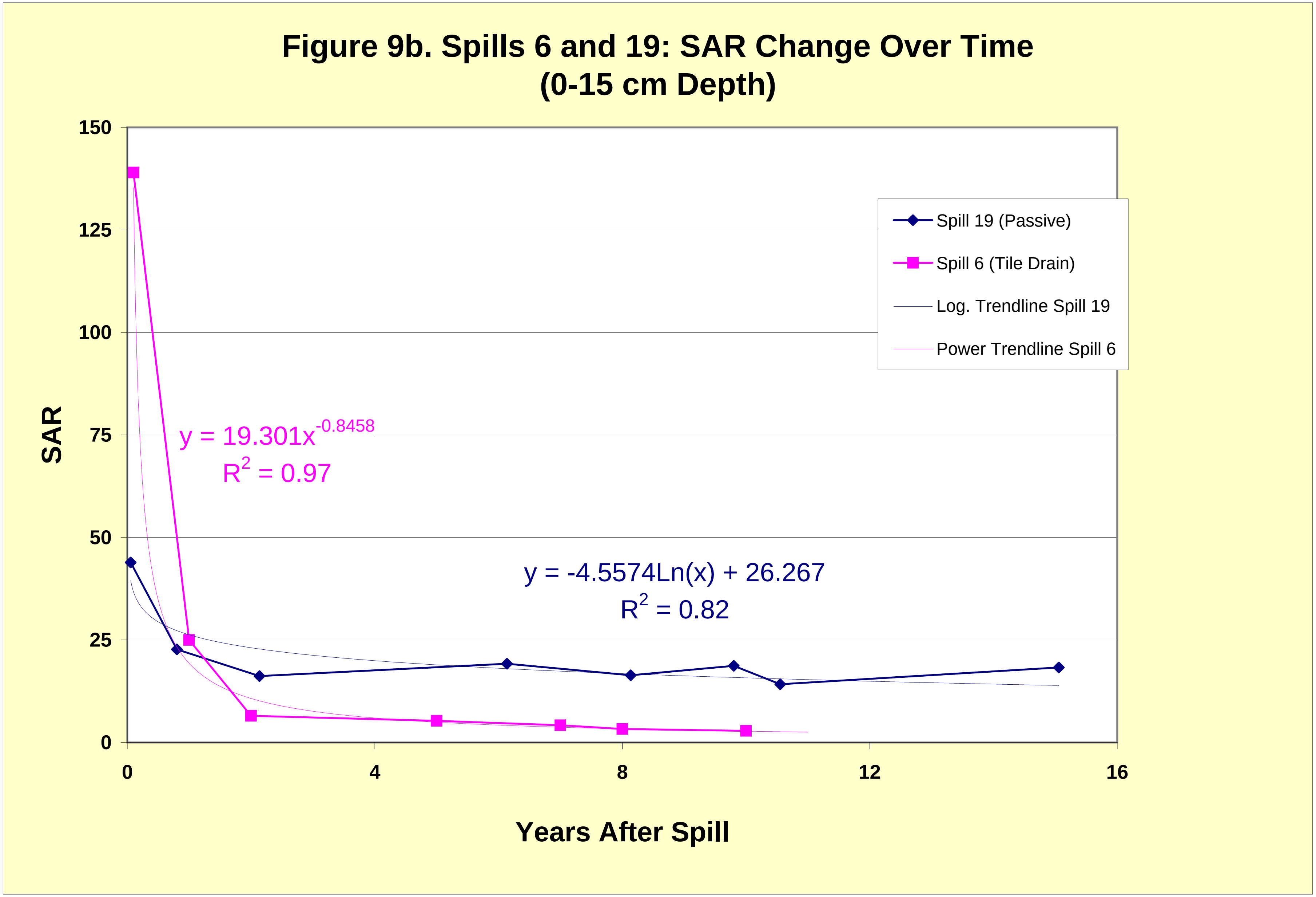


Figure 9b. Spills 6 and 19: SAR Change Over Time
(0-15 cm Depth)
SAR
150
125
100
75
50
25
0
0
4
8
12
16
Years After Spill
Spill 19 (Passive)
Spill 6 (Tile Drain)
Log. Trendline Spill 19
Power Trendline Spill 6
y = 19.301x^-0.8458
R2 = 0.97
y = -4.5574Ln(x) + 26.267
R2 = 0.82

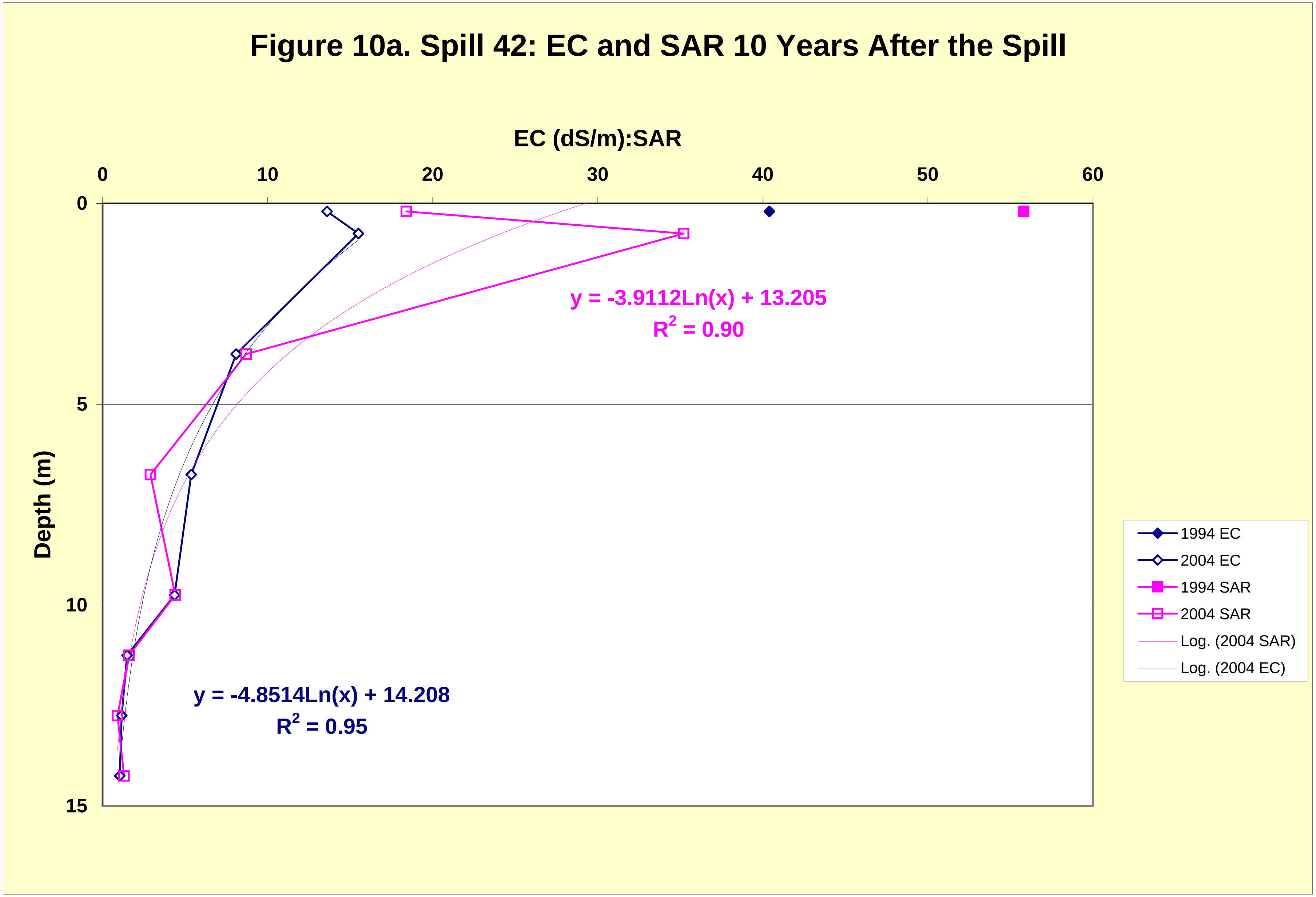


Figure 10a. Spill 42: EC and SAR 10 Years After the Spill
EC (dS/m):SAR
0
10
20
30
40
50
60
Depth (m)
0
5
10
15
y = -3.9112Ln(x) + 13.205
R2 = 0.90
y = -4.8514Ln(x) + 14.208
R2 = 0.95
1994 EC
2004 EC
1994 SAR
2004 SAR
Log. (2004 SAR)
Log. (2004 EC)

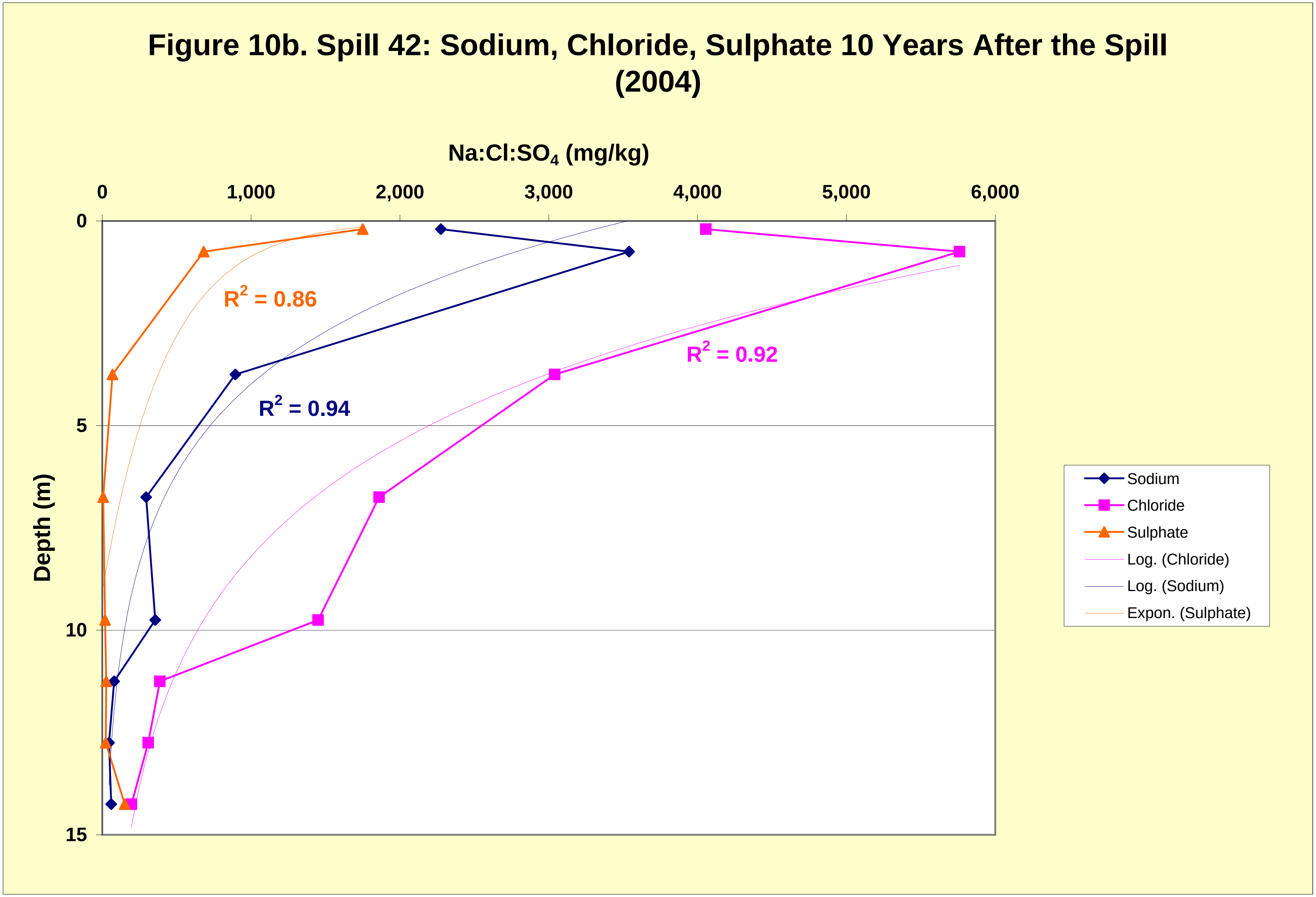


Figure 10b. Spill 42: Sodium, Chloride, Sulphate 10 Years After the Spill (2004)
Na:Cl:SO4 (mg/kg)
0
1,000
2,000
3,000
4,000
5,000
6,000
Depth (m)
0
5
10
15
R2 = 0.86
R2 = 0.94
R2 = 0.92
Sodium
Chloride
Sulphate
Log. (Chloride)
Log. (Sodium)
Expon. (Sulphate)

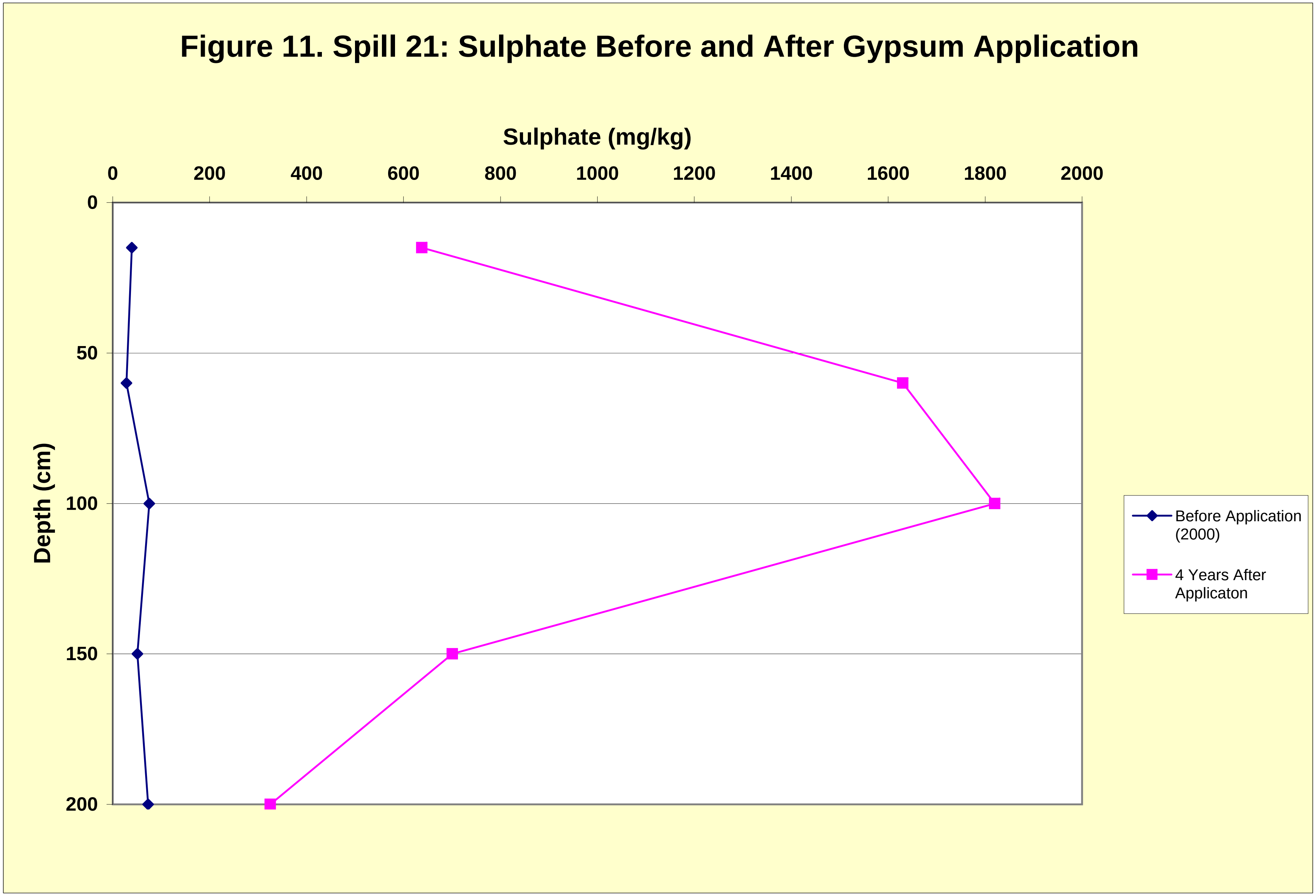


Figure 11. Spill 21: Sulphate Before and After Gypsum Application
Sulphate (mg/kg)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Depth (cm)
0
50
100
150
200
Before Application (2000)
4 Years After Applicaton

TABLE 1. SPILL 6: SOUTHEAST SASKATCHEWAN TILE DRAINAGE SYSTEM

EC (dS/m)		**1993**	**1994**	**1995**		**depth (cm)**	**1998**	**2000**	**2001**	**2003**	**2004**
Area 2	0-15	63.8	22	21	Area 2a	0-15	7.1	3	2.8	3	3.5
	15-50	70.3	10.6	23.3		15-50	6.6	4.7	2.9	3.1	3.3
	50-100	35.8	13.1	14.2		50-100	7.4	3.6	2	4.7	5.3
		--	--	--	Area 2b	0-15	5.3	4.5	3.4	3.3	4
		--	--	--		15-50	13	8.5	5.6	4.8	6.1
		--	--	--		50-100	22	12.8	8.1	6.4	12.3
Area 3	0-15	171	40.2	14.4	Area 3a	0-15	4.8	3.6	3.2	3.1	3.7
	15-50	73	55.1	9.4		15-50	6.1	4.8	4.6	3.7	3.5
	50-100	63.8	32	7.3		50-100	6.5	4.1	2.8	5	4.4
		--	--	--	Area 3b	0-15	8.5	5.8	6.8	4.4	8
		--	--	--		15-50	18	10.5	8.7	6.7	13.6
		--	--	--		50-100	19	14.9	12.2	7.9	16.5
Area 4	0-15	missing	56.6	34	Area 4a	0-15	3.2	4.8	3.2	3.2	3.9
	15-50		52.8	28.6		15-50	7.6	7.7	4	3.7	4.1
	50-100		24.2	21.6		50-100		10.2	6.4	5.4	3.3
		--	--	--	Area 4b	0-15	14	12	8.2	10	5.3
		--	--	--		15-50	31	17.2	14	14	10.3
		--	--	--		50-100	9.6	20.3	13.2	15	20.8
Control	0-15	--	--	--	Control	0-15	--	--	0.7	--	--
	15-50	--	--	--		15-50	--	--	5	--	--
	50-100	--	--	--		50-100	--	--	5.5	--	--
Control A	0-15	--	--	--	Control A	0-15	--	--	--	1	1.6
	15-50	--	--	--		15-50	--	--	--	0.8	0.6
	50-100	--	--	--		50-100	--	--	--	0.5	0.9
Control B	0-15	--	--	--	Control B	0-15	--	--	--	1.2	0.5
	15-50	--	--	--		15-50	--	--	--	1.7	0.5
	50-100	--	--	--		50-100	--	--	--	2.5	2.4
SAR		**1993**	**1994**	**1995**		**depth (cm)**	**1998**	**2000**	**2001**	**2003**	**2004**
Area 2	0-15	56.6	51.8	23.7	Area 2a	0-15	1.6	0.8	0.3	0.3	0.3
	15-50	59.4	42.9	22.8		15-50	5.5	6.4	0.7	0.6	0.9
	50-100	28.8	20	10.7		50-100	12	10	4	1.4	1.6
		--	--	--	Area 2b	0-15	5.2	3.5	1.9	1.7	2.1
		--	--	--		15-50	20	14	8.9	6.3	7.2
		--	--	--		50-100	32	31	19	21.7	16.5
Area 3	0-15	179.6	43	12.7	Area 3a	0-15	4.3	1.7	1.7	1.1	0.6
	15-50	66.1	54.3	31		15-50	9.1	6.4	7.5	4.1	1.6
	50-100	56.6	34.3	27.7		50-100	13	16	13	12.4	5.7
		--	--	--	Area 3b	0-15	10	6.4	8.6	4.9	9
		--	--	--		15-50	26	17	15	12.4	22.5
		--	--	--		50-100	32	33	38	22.8	9.1
Area 4	0-15	180.7	51.8	38.7	Area 4a	0-15	1.1	4.4	1.5	0.8	0.8
	15-50	129.9	42.9	40.9		15-50	11	12	4.2	2.3	2.7
	50-100	78.2	20	25.9		50-100		27	12	5.4	8.5
		--	--	--	Area 4b	0-15	17	15	11	11	4.3
		--	--	--		15-50	34	30	25	21.1	15.8
		--	--	--		50-100	15	47	41	27.2	31.8
Control	0-15	--	--	--	Control	0-15	--	1.2	--	--	--
	15-50	--	--	--		15-50	--	4	--	--	--
	50-100	--	--	--		50-100	--	6	--	--	--
Control A	0-15	--	--	--	Control A	0-15	--	--	--	0.3	0.5
	15-50	--	--	--		15-50	--	--	--	0.3	1
	50-100	--	--	--		50-100	--	--	--	0.4	0.5
Control B	0-15	--	--	--	Control B	0-15	--	--	--	0.6	0.5
	15-50	--	--	--		15-50	--	--	--	1.3	0.8

-- not analysed

TABLE 1 (continued)

Cl (mg/l)		1993	1994	1995		depth (cm)	1998	2000	2001	2003	2004
Area 2	0-15	27860	7650	6500	Area 2a	0-15	466	83	30	77	67
	15-50	30520	3808	7800		15-50	1300	207	26	73	216
	50-100	14560	5046	4800		50-100	1670	373	54	720	864
		--	--	--	Area 2b	0-15	708	530	127	146	214
		--	--	--		15-50	3030	1490	427	382	633
		--	--	--		50-100	8150	4380	776	1060	2940
Area 3	0-15	89900	15500	3120	Area 3a	0-15	448	127	57	107	43
	15-50	31520	24000	2500		15-50	623	191	62	199	45
	50-100	27800	13400	2060		50-100	1100	477	94	142	62
		--	--	--	Area 3b	0-15	1960	855	1200	447	1570
		--	--	--		15-50	6350	2400	1500	865	3330
		--	--	--		50-100	7150	5070	3330	1360	5000
Area 4	0-15	3277.6	23200	12700	Area 4a	0-15	116	627	73	103	149
	15-50	1909.6	22000	8750		15-50	1050	1040	157	61	105
	50-100	1012.6	7700	7650		50-100		1900	433	700	78
		--	--	--	Area 4b	0-15	4260	3480	1770	2450	824
		--	--	--		15-50	11800	5050	3630	3790	2310
		--	--	--		50-100	2680	7100	3960	4610	7180
Area 5	0-15	--	--	--	Area 5	0-15	--	--	--	--	--
	15-50	--	--	--		15-50	--	--	--	--	--
	50-100	--	--	--		50-100	--	--	--	--	--
Control	0-15	--	--	--	Control	0-15	--	15	--	--	--
	15-50	--	--	--		15-50	--	17	--	--	--
	50-100	--	--	--		50-100	--	20	--	--	--
Control A	0-15	--	--	--	Control A	0-15	--	--	--	53	23
	15-50	--	--	--		15-50	--	--	--	52	14
	50-100	--	--	--		50-100	--	--	--	41	25
Control B	0-15	--	--	--	Control B	0-15	--	--	--	19	10
	15-50	--	--	--		15-50	--	--	--	155	12
	50-100	--	--	--		50-100	--	--	--	111	9

SO_4 (mg/l)		1993	1994	1995		depth (cm)	1998	2000	2001	2003	2004
Area 2	0-15	200	2195	2095	Area 2a	0-15	1650	1660	1430	1480	1770
	15-50	200	198	900		15-50	2240	2570	1620	1360	1890
	50-100	100	105	327		50-100	1660	1330	872	1730	1900
		--	--	--	Area 2b	0-15	1950	1770	1590	1770	1750
		--	--	--		15-50	2560	2600	2350	2310	2220
		--	--	--		50-100	1270	795	3320	2350	1790
Area 3	0-15	500	2640	1737	Area 3a	0-15	2020	2000	1730	1680	1700
	15-50	200	290	626		15-50	2710	2620	2500	1890	2170
	50-100	280	119	296		50-100	2190	1240		2270	2730
		--	--	--	Area 3b	0-15	2120	1840	1830	1980	1970
		--	--	--		15-50	2510	2420	2340	2660	2640
		--	--	--		50-100	520	897	816	169	2240
Area 4	0-15	208	2020	2590	Area 4a	0-15	1600	1730	1550	1580	1900
	15-50	10.4	544	945		15-50	2600	3020	1870	2230	2380
	50-100	4.2	0.1	515		50-100		2660	2600	1590	2130
		--	--	--	Area 4b	0-15	2410	1840	1820	1760	1850
		--	--	--		15-50	1910	2030	2390	2400	2390
		--	--	--		50-100	1090	1000	846	1800	1400
Area 5	0-15	--	--	--	Area 5	0-15	--	--	--	--	--
	15-50	--	--	--		15-50	--	--	--	--	--
	50-100	--	--	--		50-100	--	--	--	--	--
Control	0-15	--	--	--	Control	0-15	--	126	--	--	--
	15-50	--	--	--		15-50	--	3120	--	--	--
	50-100	--	--	--		50-100	--	3520	--	--	--
Control A	0-15	--	--	--	Control A	0-15	--	--	--	177	83.9
	15-50	--	--	--		15-50	--	--	--	118	99.7
	50-100	--	--	--		50-100	--	--	--	67	183
Control B	0-15	--	--	--	Control B	0-15	--	--	--	144	35
	15-50	--	--	--		15-50	--	--	--	454	35.5
	50-100	--	--	--		50-100	--	--	--	1210	1330

-- not analysed

TABLE 2. PEACE REGION TILE SYSTEMS

Spill 15 Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl meq/L	SO_4-S meq/L
Control	0-30	1997	0.97	1.8	2.82	5.32
Control	30-60	1997	0.67	1.5	2.33	2.77
Control	60-100	1997	0.91	1.4	3.10	6.13
Pile 1	comp	1998	14.5	21.2	134	17.4
Pile 2	comp	1998	21.2	24.2	210	54.2
03-B1	0-30	2003	10.5	12.7	66.5	57.0
03-B1	30-60	2003	10.0	9.7	62.7	51.6
03-B1	60-100	2003	8.1	6.1	60.2	29.9
03-B2	0-30	2003	11.7	10.6	78.8	49.0
03-B2	30-100	2003	12.7	15.3	90.9	58.8
03-B2	60-100	2003	14.3	13.0	104	51.0
03-B2	100-140	2003	8.50	4.3	66.0	39.8
03-B3	0-30	2003	9.71	7.7	58.9	48.1
03-B3	30-60	2003	7.80	6.4	36.8	56.2
03-B3	60-100	2003	7.94	4.4	55.3	34.6
03-B3	100-130	2003	9.27	6.2	62.6	50.6
03-B4	0-30	2003	6.39	7.2	20.3	58.9
03-B4	30-60	2003	11.8	15.2	76.3	61.7
03-B4	60-100	2003	14.6	13.5	117	53.7
03-B4	100-150	2003	12.0	6.4	99.9	45.7
03-B5	0-30	2003	7.41	6.8	39.3	52.2
03-B5	30-60	2003	8.45	11.7	41.9	62.4
03-B5	60-100	2003	9.37	12.0	50.3	62.3
03-B6	0-30	2003	6.03	5.4	20.0	52.0
03-B6	30-60	2003	5.77	4.9	35.9	24.3
03-B6	60-100	2003	6.59	3.9	37.8	40.1

TABLE 2 (continued)

Spill 16 Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Na meq/L	Ca meq/L
Control	0-30	1997	0.62	1.5	--	--
Control	60-100	1997	0.58	1.9	--	--
Composite	--	1998	21.2	15.6	12.9	54.7
Composite	--	1998	7.94	6.8	42.8	37.9
03-B1	0-30	2003	5.83	6.4	32.6	31.8
03-B1	30-60	2003	7.64	10.3	54.4	32.1
03-B1	60-100	2003	10.5	14.7	81.4	37.9
03-B1	100-150	2003	13.0	12.5	84.7	54.6
03-B2	0-30	2003	9.07	10.6	62.1	36.4
03-B2	30-60	2003	12.8	18.6	109	40.9
03-B2	60-100	2003	13.2	14.1	94.3	53.9
03-B2	100-150	2003	7.02	7.6	39.8	25.5
03-B3	0-30	2003	9.34	11.0	66	40.8
03-B3	30-60	2003	12.6	16.3	102	43.7
03-B3	60-100	2003	14.9	15.8	111	59
03-B3	100-150	2003	11.9	12.4	82.4	52.8
03-B4	0-30	2003	11.1	14.1	88.4	45.6
03-B4	30-60	2003	14.4	18.0	119	49
03-B4	60-100	2003	29.3	38.5	298	82
03-B4	100-150	2003	32.1	64.2	388	49.4
03-B5	0-30	2003	7.46	7.6	44	38.6
03-B5	30-60	2003	9.29	10.1	60.6	39
03-B5	60-100	2003	7.53	6.0	35.7	30.8
03-B6	0-30	2003	6.68	7.3	37.8	30.7
03-B6	30-60	2003	9.39	11.2	62.5	32.2
03-B6	60-100	2003	15.0	12.0	56.6	53
03-B6	100-150	2003	10.1	7.4	47.6	39.9
03-B7	0-30	2003	7.38	7.7	40.9	32.2
03-B7	30-60	2003	10.5	11.0	65.1	36.2
03-B7	60-100	2003	10.8	11.2	67.1	44
03-B7	100-150	2003	8.42	11.3	55.3	26.3
03-B8	0-30	2003	6.16	6.1	32.8	35.2
03-B8	30-60	2003	8.53	7.9	45	42.7
03-B8	60-100	2003	4.58	3.10	14.5	24.9
03-B8	100-150	2003	2.73	1.90	6.46	12.8

TABLE 3. SPILL 7: EAST-CENTRAL ALBERTA TILE SYSTEM (2003)

		EC (dS/m)		SAR		Calcium (meq/L)		Sodium (meq/L)		Sulphate (meq/L)		Chloride (meq/L)	
Sample Point	Depth (cm)	Before Irrigation	After Irrigation	Before Irrigation	After Irrigation	Before Irrigation	After Irrigation	Before Irrigation	After Irrigation	Before Irrigation	After Irrigation	Before Irrigation	After Irrigation
1	0-15	12.2	6	14.1	9.6	35	32	76	45	59	51	80	17
	15-30	11.5	11.3	16.3	23.2	29	34	82	118	75	73	58	68
	30-45	11.8	13.2	19.3	30.2	25	31	96	149	87	81	47	99
	45-60	9.1	15	20.5	31	14	34	79	159	74	80	34	129
	60-75	11.7	13.9	19.2	37.3	25	32	98	188	11	79	43	106
	75-100	10.9	11.9	16.5	28.6	26	29	86	136	89	89	46	81
	100-150	11.1	12	16.1	26	27	30	87	128	91	86	49	77
	150-200	11.7	4.8	16.1	27.4	27	5	88	54	88	86	60	34
2	0-15	16.5	6.5	12.7	12.5	65	32	91	59	53	32	82.7	7
	15-30	13.1	5.5	15.3	9.3	37	28	89	93	74	60	92	11
	30-45	20.4	5.9	18.5	9.5	51	26	136	45	74	71	210	9
	45-60	20.7	6.3	18.4	10.9	50	29	136	54	74	79	218	8
	60-75	22	9.3	20.2	18.5	52	28	152	98	75	89	241	32
	75-100	20.2	14.3	22	24.2	38	39	145	157	50	71	230	140
	100-125		20		18		16		79		35		217
	125-150	17	20	25	30	22	39	130	201	34	44	188	205
	150-200	17		27		26		139		41		181	

TABLE 4. SPILL 2: SOIL WASHING SITE

Sample Point	Sample Date	pH	EC dS/m	SAR	Na mg/L	Cl mg/L
First Wash						
Pit 1	July 1999	7.6	4.5	26.2	948	1130
Pit 2	July 1999	7.5	4.55	19.4	940	1120
Second Wash						
Pit 1	July 2000	8.3	3.36	25	718	559
	July 2000	8.3	3.16	23.5	652	827
	July 2000	7.4	3.08	17.5	618	665
	July 2000	8.5	2.49	28.2	573	661
Pit 2	July 2000	6.8	3.57	9.4	549	926
	July 2000	6.8	3.45	9.5	543	848
	July 2000	6.9	3.44	9.8	580	817
	July 2000	6.8	3.44	9.5	539	838
	July 2000	6.8	3.41	9.5	546	848
Amendment Addition						
Pit 1	Oct. 2000	7.6	7.2	9	1040	755
Pit 2	Oct. 2000	7	10.6	7.3	1130	1360

TABLE 5. PASSIVE SPILLS SUMMARY

Site	Age of spill (to most recent data)	Monitoring Period (yrs)	Average Topsoil EC (dS/m)			Average Subsoil* EC			Average Topsoil SAR			Average Subsoil* SAR		
			starting	ending	Background	starting	ending	Background	starting	ending	Background	starting	ending	Background
1	2	2	11.7	8.3	2.3	4.7	5.5	7.7	20.7	14	10	6.6	7.4	12.8
4	3	3	23.2	7.3	2.5	7.6	7.4	5.3	40.5	8.1	1.8	12.5	7.2	6.8
8	9	2	3.9	1.4	0.4	--	--	--	18.1	8	0.4	--	--	--
9	5	2	13	12.3	0.79	--	--	--	57.2	24.6	0.5	--	--	--
10	4	2	13	2.8	--	8.9	3.7	--	11.8	3	--	9.3	4.6	--
11	6	2	11.6	14.8	--	--	--	--	23.6	21.1	--	--	--	--
12b	11	2	2.5	1	--	--	--	--	12.8	6.8	--	--	--	--
12c	10	2	9.4	6.3	--	--	--	--	57.9	25.4	--	--	--	--
12d	9	2	6.4	0.5	--	--	--	--	10.5	0.6	--	--	--	--
12e	9	2	17.4	15.3	--	--	--	--	56	23.9	--	--	--	--
12f	9	2	7.8	3.5	--	--	--	--	33.7	10.6	--	--	--	--
13	4	3	18.6	14.3	--	20.9	10.1	--	21.1	22.9	--	21.8	19.4	--
14	13	2	2.7	5.6	--	--	--	--	111.3	34.2	--	--	--	--
19	15	7	20.5	12	--	16.3	14.2	--	22.7	14.2	--	18.9	14.3	--
20	4	4	22	3.9	1	15.3	4	0.6	32.6	6.5	0.5	21.7	13.4	1.6
21	4	4	41.5	7	0.3	33	11.8	0.2	46.2	9.8	0.3	49.5	15.8	0.4
22	4	4	32.1	13.6	0.5	19.3	16.5	0.5	34.9	11.9	6.4	29.3	18.7	6.6
23	4	4	10.8	6.3	0.4	5.9	4.7	0.3	21.1	6.6	0.5	9.9	11.1	3.1
24	5	3	7.1	1.1	0.4	5.7	**2.3**	0.2	33.6	**2.3**	2.1	39.5	7.2	2.2
28	3	3	2.2	6.7	0.7	10.1	9.6	4.7	18	15.1	0.3	25.3	14.4	0.9
29	4	4	10.8	12.3	5.2	29.7	8.6	7	27.7	15	3.2	37.5	15	6
30	6	2	8.7	2.3	1.2	--	--	--	6	12.7	0.6	--	--	--
31	4	3	124	36.3	1.7	85.2	43.2	2	126	36.3	3	94.8	43.2	21.3
32	2	2	8.5	5.8	1.2	10.1	6.4	--	14	8.9	0.3	16.8	9.9	--
35	10	9	16.9	14.2	0.4	19.6	13.7	0.4	19	15.1	0.5	25.8	24.8	0.2
36	5	5	14.9	1	0.5	14	1.5	0.3	21.6	4.9	0.6	16.3	21.5	0.7
37	6	6	39.3	2.4	--	25.2	5	--	66.1	6.6	--	28.5	21.9	--
38	6	6	14.5	4.4	--	19.2	6.7	--	58.4	7.3	--	64.1	48	--
40	5	3	4.8	1.2	--	--	--	--	15.1	5.6	--	--	--	--
42	10	10	40.4	14.2	--	--	18.7	--	55.8	24.2	--	--	33.4	--

-- no data

* Depth increment immediately below topsoil

TABLE 6. SPILLS 20, 21 and 22

Spill 20

Sample Point	Depth (cm)	Sample Date	EC (dS/m)	SAR	Cl (mg/kg)	SO^4-S (mg/kg)
Breaksite	0-15	2000	13.4	59.9	4620	53
Breaksite	15-60	2000	31.8	69.4	11900	30
Breaksite	60-100	2000	18.7	64.9	6850	36
Breaksite	0-15	2004	4.81	11.1	439	1640
Breaksite	15-60	2004	10.1	25.6	1770	2420
Breaksite	60-100	2004	20.7	50.2	6100	4400
2	0-15	2000	30.6	37.8	22000	80
2	15-60	2000	32.3	17.2	12900	30
2	60-100	2000	44	65.4	17300	30
2	0-15	2004	5.85	8.7	869	327
2	15-60	2004	3.18	19.1	193	861
2	60-100	2004	2.65	28.8	251	965
3	0-15	2000	30.9	38.2	11800	60
3	15-60	2000	11.9	54.1	4040	78
3	60-100	2000	32.8	62.7	12700	30
3	0-15	2004	5.3	6.8	209	2560
3	15-60	2004	6.05	19.8	627	2100
3	60-100	2004	7.18	48.1	2120	453
4	0-15	2000	44.3	55.2	17700	40
4	15-60	2000	26.6	7.7	3990	14
4	60-100	2000	30.1	6.5	4770	22
4	0-15	2004	4.68	5.2	158	2320
4	15-60	2004	2.75	13.0	167	898
4	60-100	2004	2.62	23.8	279	559
5	0-15	2000	13.9	12.9	5020	23
5	15-60	2000	1.1	0.7	182	23.5
5	60-100	2000	0.92	1.1	133	21.7
5	0-15	2004	2.26	6.9	95	565
5	15-60	2004	2.06	9.8	78	553
5	60-100	2004	2.3	11.6	113	602
6	0-15	2000	26.3	20.2	9480	60
6	15-60	2000	2.28	0.9	465	42
6	60-100	2000	7.05	2.7	2040	49
6	0-15	2004	2.48	4.9	94	785
6	15-60	2004	2.44	5.0	115	890
6	60-100	2004	2.06	4.1	138	660
lower	0-15	2000	4.92	3.9	1320	45.1
lower	15-60	2000	1.4	1.7	367	12.6
lower	60-100	2000	0.67	1.4	119	13.7
lower	0-15	2004	1.86	2.1	76	230
lower	15-60	2004	1.43	1.8	46	175
lower	60-100	2004	1.34	1.1	38	124
Background	0-15	2000	0.96	0.5	13	31.6
Background	15-60	2000	0.59	1.6	16	50.9
Background	60-100	2000	0.41	2.9	10	30.8

TABLE 6 (continued)

Spill 21

Sample Point	Depth (cm)	Sample Date	EC (dS/m)	SAR	Cl (mg/kg)	SO^4-S (mg/kg)
Midslope	0-15	2000	51.8	65.9	23100	39.3
Midslope	15-60	2000	45.9	69.3	17100	28.1
Midslope	60-100	2000	33.3	57.4	12200	75.4
Midslope	100-150	2000	17.8	39.4	6280	50.9
Midslope	150-200	2000	19.6	38	6700	73.1
Midslope	0-15	2004	6.11	10.2	1030	638
Midslope	15-60	2004	9.31	17.7	2260	1630
Midslope	60-100	2004	11.7	18.0	3260	1820
Midslope	100-150	2004	12	14.8	3940	701
Midslope	150-200	2004	11.4	13.0	3810	325
Downslope	0-15	2000	31.1	26.4	11000	1470
Downslope	15-60	2000	20.1	29.7	5160	496
Downslope	60-100	2000	15.5	34.8	5060	118
Downslope	100-150	2000	12.3	26.9	4100	126
Downslope	150-200	2000	10.9	24.3	3640	149
Downslope	0-15	2004	7.86	9.4	1240	1380
Downslope	15-60	2004	14.3	13.8	4400	2060
Downslope	60-100	2004	11.3	15.5	4010	332
Downslope	100-150	2004	6.59	10.7	2210	53.3
Downslope	150-200	2004	7.38	12.9	2560	42.5
Control	0-15	2000	0.26	0.3	28	11.5
Control	15-60	2000	0.21	0.4	10	26.8
Control	60-100	2000	0.12	0.6	15	8.9

Spill 22

Sample Point	Depth (cm)	Sample Date	EC (dS/m)	SAR	Cl (mg/kg)	SO^4-S (mg/kg)
Upslope	0-15	2000	37.5	34.6	16300	205
Upslope	15-60	2000	26.6	49.3	10800	296
Upslope	60-100	2000	30.1	39.6	11600	2400
Upslope	0-15	2004	10.4	9.9	1190	1880
Upslope	15-60	2004	19.9	25.5	6400	2330
Upslope	60-100	2004	26.9	29.5	10400	2420
Midslope	0-15	2000	32.7	40.5	13800	97.3
Midslope	15-60	2000	10.9	15.3	3840	872
Midslope	60-100	2000	2.89	8.5	196	1280
Midslope	0-15	2004	17.3	14.5	4730	2010
Midslope	15-60	2004	15.6	17.1	4560	1930
Midslope	60-100	2004	6.54	10.5	1020	1870
Downslope	0-15	2000	26.2	29.6	10800	99.7
Downslope	15-60	2000	20.5	23.3	8570	346
Downslope	60-100	2000	6.77	11.6	1120	2740
Downslope	0-15	2004	13.1	11.3	3140	1850
Downslope	15-60	2004	14	13.4	3790	1970
Downslope	60-100	2004	8.31	14.5	2060	1280
Control	0-15	2000	0.53	6.4	91	74.2
Control	15-60	2000	0.49	6.6	45	77
Control	60-100	2000	3.22	17.4	523	762

TABLE 7. SPILL 42: EAST-CENTRAL ALBERTA

Sample point		Depth cm	Sample Date	EC dS/m	SAR	Na mg/L	Cl mg/L	SO_4- mg/L
After Similar Spill (average of 4 points)		Surface	2003	40.4	55.8	--	--	--
1994 spill area								
	Site 1	0-20	2003	13.6	18.8	2300	4150	1630
		20-100	2003	18.8	32.6	3650	6530	800
	Site 2	0-20	2003	13.6	17.9	2250	3960	1870
		40-100	2003	18.7	34.1	3640	6470	704
	Site 3	0-75	2003	15.5	35.2	3540	5760	681
		300-375	2003	8.09	8.7	894	3040	69.1
		600-675	2003	5.37	2.9	295	1860	6.6
		900-975	2003	4.36	4.4	356	1450	18.7
		1050-1125	2003	1.48	1.6	80	387	26.8
		1200-1275	2003	1.16	0.9	45	309	23.7
		1350-1425	2003	1.04	1.3	60	196	151

-- no data

APPENDIX A

SITE SUMMARIES FOR

Spill 1
Spill 2
Spill 4
Spill 6
Spill 7
Spill 8
Spill 9
Spill 10
Spill 11
Spill 12b
Spill 12c
Spill 12d
Spill 12e
Spill 12f
Spill 13f
Spill 14
Spill 15
Spill 16
Spill 19
Spill 20
Spill 21
Spill 22
Spill 23
Spill 24
Spill 28
Spill 29
Spill 30
Spill 31
Spill 32
Spill 35
Spill 36
Spill 37
Spill 38
Spill 40
Spill 42

Site Summary

Spill 1

Site Description		Remediation Efforts	
Location:	Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Source removed, details unknown
Soil texture:	Unknown	Amendment details:	
Soil Classification:	Unknown	Site was initially flushed with 2800 bbls water amended with 29.5 bags calcium nitrate. During remediation 118 bags calcium nitrate, 96 bags gypsum, 68 bags lime, and 56 bales straw worked in.	
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	2001 and 2002
Year of release:	2001	Control data?	yes
Brine origin (formation):	Nisku Devonian	Parameters analysed:	detailed salinity
Spill volume:	225 m^3	Sample points:	9 including 2 controls
Size of impacted area:	0.73 ha	Groundwater monitoring?	No
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	> 1 m		

Overview:

Site was a large spill, located on what appears to be naturally saline Solonetzic soils. The spill was remediated by flushing and amending with calcium products. Controls appear to be poorly chosen to represent pre-spill conditions since EC, SAR and sulphate values of control subsoil are higher than averages in the spill area. Topsoil EC, SAR and chlorides have decreased dramatically between the first and second years.

Spill 1

The Data

EC (dS/m)	Depth (cm)	2001	2002
Profile 1	0-15	12.3	10.2
	15-50	7.6	3.8
	50-100	6.8	5.4
Profile 2	0-15	16.2	12.8
	15-50	8.1	8.5
	50-100	6.3	5.8
Profile 3	0-15	13	8.9
	15-50	2.9	4.3
	50-100	3.2	2.4
Profile 4	0-15	15.7	7.9
	15-50	3.3	5.9
	50-100	2.2	2.8
Profile 5	0-15	13.2	6.8
	15-50	3.6	6.1
	50-100	4.3	4.8
Profile 6	0-15	9.2	4.4
	15-50	5.5	7.1
	50-100	4.5	5.6
Profile 7	0-15	2.3	7.2
	15-50	2	2.6
	50-100	1.1	4.6
Control 1	0-15	1.9	---
	15-50	7.7	---
	50-100	9.2	---
Control 2	0-15	2.7	---
	15-50	7.7	---
	50-100	8.7	---

SAR	Depth (cm)	2001	2002
Profile 1	0-15	18.4	13.2
	15-50	13.1	10.3
	50-100	14.9	7.3
Profile 2	0-15	40.9	20.2
	15-50	9	9.4
	50-100	8.2	7.3
Profile 3	0-15	22.3	14.2
	15-50	4.4	5.5
	50-100	3.3	3.5
Profile 4	0-15	27.2	12.9
	15-50	5.2	8.4
	50-100	5.2	6.1
Profile 5	0-15	22.1	14.2
	15-50	5.1	6.7
	50-100	3.5	4
Profile 6	0-15	12.4	14.4
	15-50	7	8.6
	50-100	3.1	6.7
Profile 7	0-15	1.8	8.8
	15-50	2.1	3.1
	50-100	2.3	3.9
Control 1	0-15	8.1	---
	15-50	11.6	---
	50-100	14.1	---
Control 2	0-15	11.9	---
	15-50	13.9	---
	50-100	15.4	---

Cl (mg/kg)	Depth (cm)	2001	2002
Profile 1	0-15	4410	2410
	15-50	1440	1240
	50-100	346	113
Profile 2	0-15	5860	3500
	15-50	1600	1600
	50-100	712	296
Profile 3	0-15	4650	2130
	15-50	578	1010
	50-100	107	264
Profile 4	0-15	5890	2220
	15-50	907	1810
	50-100	569	691
Profile 5	0-15	5240	1510
	15-50	1100	1350
	50-100	337	652
Profile 6	0-15	2710	1050
	15-50	557	1290
	50-100	194	561
Profile 7	0-15	---	---
	15-50	---	---
	50-100	---	---
Control 1	0-15	40	---
	15-50	20	---
	50-100	93	---
Control 2	0-15	16	---
	15-50	5	---
	50-100	8	---

SO_4-S (mg/kg)	Depth (cm)	2001	2002
Profile 1	0-15	647	1200
	15-50	2270	1070
	50-100	3930	3060
Profile 2	0-15	300	1830
	15-50	2440	2330
	50-100	2810	2770
Profile 3	0-15	432	1290
	15-50	579	313
	50-100	2210	791
Profile 4	0-15	100	624
	15-50	285	194
	50-100	270	268
Profile 5	0-15	76.4	825
	15-50	213	543
	50-100	2310	1720
Profile 6	0-15	1410	178
	15-50	2710	2470
	50-100	2860	2440
Profile 7	0-15	---	---
	15-50	---	---
	50-100	---	---
Control 1	0-15	734	---
	15-50	5180	---
	50-100	5800	---
Control 2	0-15	1220	---
	15-50	5190	---
	50-100	6060	---

--- no data

Site Summary

Spill 2

Site Description		Remediation Efforts	
Location:	Central Alberta	Remediation system:	Soil washing system with leachate collection
Natural region:	Dry Mixedwood	Source removal details:	175 m^3 removed in 1999
Soil texture:	Unknown	Amendment details:	11,000 kg gypsum and 1150 kg calcium nitrate added after soil washing treatment
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		

Spill Description		Monitoring	
Brine source:	Flare pit	Sampling events (dates):	1999 and 2000 after washing events
Year of release:	Unknown, first investigated in 1994	Control data?	No
Brine origin (formation):	Nisku Devonian	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	References to Piezometers installed, but no data available
Size of impacted area:	Unknown	Sample points:	4 to 5 samples
Max investigation depth:	not applicable	Details of EM surveys:	Done in 1994; no information available
Maximum impact depth:	Unknown		

Overview:

Soil washing was used to remediate salt affected soils at this flare pit. Soil was washed twice, once in 1999 and once in 2000. Report indicates first washing removed 72% of chlorides and 63% of sodium. EC was reduced by a factor of 2.9. Initial EC and SAR of the soil going into the soil washing pits are not given, but data from the initial flare pit investigation (1994) shows EC up to 36 and SAR up to 90. In September 2000, after the second wash, 4000 kg of gypsum and 460 kg of calcium nitrate was added to Pit 1 and 7000 kg of gypsum and 690 dm of calcium nitrate was added to Pit 2.

The Data

Event	Sample Point	Sample Date	pH	EC dS/m	SAR	Na mg/L	Cl mg/L
First wash	Pit 1	1999	7.6	4.5	26.2	948	1130
	Pit 2	1999	7.5	4.6	19.4	940	1120
Second wash	Pit 1	Jul-00	8.3	3.4	25	718	559
		Jul-00	8.3	3.2	23.5	652	827
		Jul-00	7.4	3.1	17.5	618	665
		Jul-00	8.5	2.5	28.2	573	661
	Pit 2	Aug-00	6.8	3.6	9.4	549	926
		Aug-00	6.8	3.5	9.5	543	848
		Aug-00	6.9	3.4	9.8	580	817
		Aug-00	6.8	3.4	9.5	539	838
		Aug-00	6.8	3.4	9.5	546	848
Amendment Addition	Pit 1	Oct-00	7.6	7.2	9	---	---
	Pit 2	Oct-00	7	10.6	9.3	---	---

Site Summary

Spill 4

Site Description		Remediation Efforts	
Location:	Central Alberta	Remediation system:	Passive
Natural region:	Dry Mixedwood	Source removal details:	None
Soil texture:	Unknown	Amendment details: Applied 6 barrels of calcium amendment with initial flushing plus 76 bags calcium nitrate, 122 bags gypsum, 180 bags line and 80 bales of straw	
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	2001, 2002, 2003
Year of release:	2000	Control data?	Yes
Brine origin (formation):	Nisku Devonian	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	No
Size of impacted area:	0.31 ha	Sample points:	5 including control
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	> 1.0 m		
Overview:			
Soil remediation in this hayland/pasture site was effected in 2001 and 2002. Reports note a substantial decrease in salt concentrations after the 2002 remediation efforts. Soil quality in the area is also impacted by natural salinity. Vegetation growth remained poor in the spill area.			

Spill 4

The Data

EC (dS/m)	Depth (cm)	2001	2002	2003
Profile 1	0-15	24.1	13.9	5.9
	15-50	13.2	13.7	4
	50-100	11	11.4	4.7
Profile 2	0-15	33.8	10.5	5.6
	15-50	4.5	7.4	6.2
	50-100	2.4	5.7	5.8
Profile 3	0-15	18.4	17.2	10.3
	15-50	8	8.3	12.6
	50-100	5.6	3.4	5.11
Profile 4	0-15	16.6	6.5	7.2
	15-50	4.8	5.2	6.7
	50-100	11.5	4.7	4.6
Control 1	0-15	2.5	---	---
	15-50	5.3	---	---
	50-100	5.3	---	---

SAR	Depth (cm)	2001	2002	2003
Profile 1	0-15	43	27.3	8.5
	15-50	32.4	14.2	6.2
	50-100	24.8	10.7	3.2
Profile 2	0-15	55.5	12.5	6.9
	15-50	5	8.5	7.1
	50-100	5.2	6.6	6.6
Profile 3	0-15	34.9	31	16.4
	15-50	9.7	10.3	15.4
	50-100	7	4.9	5.1
Profile 4	0-15	28.4	7.8	0.4
	15-50	3	0.1	0.1
	50-100	8.7	3.8	0.2
Control 1	0-15	1.8	---	---
	15-50	6.8	---	---
	50-100	8.1	---	---

Cl (mg/kg)	Depth (cm)	2001	2002	2003
Profile 1	0-15	11700	3900	843
	15-50	5350	4770	307
	50-100	4190	3420	630
Profile 2	0-15	19200	2560	929
	15-50	1300	1500	982
	50-100	507	608	570
Profile 3	0-15	8810	5510	2660
	15-50	1160	2090	4560
	50-100	720	469	696
Profile 4	0-15	7830	1280	1640
	15-50	1040	650	2060
	50-100	4750	172	2720
Control 1	0-15	47	---	---
	15-50	168	---	---
	50-100	47	---	---

SO_4-S (mg/kg)	Depth (cm)	2001	2002	2003
Profile 1	0-15	2000	2170	2220
	15-50	866	1480	1910
	50-100	720	1590	1820
Profile 2	0-15	540	1770	1910
	15-50	738	2350	2450
	50-100	596	2780	2910
Profile 3	0-15	369	1210	2130
	15-50	2360	1040	1990
	50-100	3560	2180	2490
Profile 4	0-15	435	1640	1850
	15-50	1950	2060	2670
	50-100	1810	2720	2790
Control 1	0-15	1680	---	---
	15-50	3600	---	---
	50-100	3710	---	---

--- no data

Site Summary

Spill 6

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Tile drainage system installed in 1993
Natural region:	Unknown	Source removal details:	75 m^3 removed in 2000
Soil texture:	Unknown	Amendment details:	Amendments applied regularly
Soil Classification:	Unknown		
Depth to groundwater:	> 1m		
Discharge or recharge?	Recharge		
Spill Description		**Monitoring**	
Brine source:	Pipeline break	Sampling events (dates):	Yearly 1993 to 2004
Year of release:	1993	Control data?	Yes
Brine origin (formation):	Winnipegosis	Parameters analysed:	Detailed salinity
Spill volume:	720 m^3	Groundwater monitoring?	No
Size of impacted area:	1.3 ha	Sample points:	7 including control (composite sampling)
Max investigation depth:	1.0 m	Details of EM surveys:	No survey
Maximum impact depth:	< 1.0 m		

Overview:

Tiles and a collection system were installed and soils monitored to 1 m yearly. Most dramatic reduction in salinity occurred within the first 3 years. After that the decrease was slower but steady. After 10 years salts in parts of the spill area approach guidelines but not everywhere. No information below 1 m was collected, so it is not known how much salt was actually removed from the system with the tile drainage system. Slow leaching of gypsum amendments down the soil profile is clear in sulphate data.

The Data

See Table 1

Site Summary

Spill 7

Site Description

Location:	East Central Alberta
Natural region:	Northern Fescue
Soil texture:	Fine, some sandy lenses
Soil Classification:	Unknown
Depth to groundwater:	1.5 to 2.5 m
Discharge or recharge?	Unknown

Remediation Efforts

Remediation system:	Tile drainage system installed in 2000
Source removal details:	Hydrocarbon impacted materials landfilled
Amendment details:	Two tons calcium nitrate and 10 tons gypsum

Spill Description

Brine source:	Flare pit
Year of release:	Site decommissioned in 1999
Brine origin (formation):	Viking
Spill volume:	Unknown
Size of impacted area:	4,000 m^2
Max investigation depth:	6 m
Maximum impact depth:	< 2.0 m

Monitoring

Sampling events (dates):	1999 and 2003
Control data?	Yes
Parameters analysed:	Detailed salinity
Groundwater monitoring?	Yes
Sample points:	Numerous, not all directly comparable
Details of EM surveys:	EM 38 and EM 31 surveys completed

Overview:

Elevated salinity was noted in the flare pit area of this site after excavation of hydrocarbon impacted materials. A detailed groundwater and soil investigation was carried out to delineate the extent of residu salt impact. Assessment included EM surveys. Once constructed, the tile area was irrigated and leacheate recovered. As the soil data was collected for delineation purposes and not impact monitoring, little of the information was directly comparable. However, data before and after irrigation is interesting in that EC and SAR were lower in subsoil at Sample Point 2, but higher in subsoil at Sample Point 1 after irrigation compared to before.

The Data

See Table 3

Site Summary

Spill 8

Site Description		Remediation Efforts	
Location:	East-Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	No source removal
Soil texture:	Moderately fine textured	Amendment details: 1 ton gypsum and sixteen 23 kg bags of calcium nitrate applied in 2001. Fertilized at a ratio of 20-100-120-0 lbs/acre including 73 kg of phosphate and 73 kg of potash. The area was paratilled to a depth of 50 cm and then lightly worked with a rotospic.	
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		

Spill Description		Monitoring	
Brine source:	Surface rupture	Sampling events (dates):	2001 and 2003
Year of release:	1994	Control data?	Yes
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	50 m^3	Groundwater monitoring?	None
Size of impacted area:	209 m^2	Sample points:	2 including control
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	0.7 m		

Overview:

A surface spill occurred in 1994. Soil was amended with gypsum, calcium nitrate, and fertilizer in 2001. Sampling occurred in 2001 and 2003. Background data was also collected and vertical delineation was completed. EC has decreased to near background levels, but SAR remains elevated.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl meq/L	SO_4-S meq/L
Spill area	0-30	2001	3.89	18.1	19.0	2.40
Spill area	0-15	2003	0.86	6.9	1.14	4.31
	15-30	2003	1.95	9.1	6.11	9.39
	70-100	2003	0.83	1.7	2.66	2.64
Control	0-15	2003	0.39	0.3	0.29	0.72
	15-30	2003	0.46	0.5	0.33	0.80
	70-100	2003	0.58	0.8	0.22	3.61

Site Summary

Spill 9

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	No source removal
Soil texture:	Sandy clay loam	Amendment details: 3 tonnes of gypsum and two 23 kg bags of calcium nitrate applied in 2001. Fertilized at a ratio of 20-100-120-0, including 18 kg of phosphate and 18 kg of potash.	
Soil Classification:	Unknown		
Depth to groundwater:	unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Surface rupture	Sampling events (dates):	2001 and2003
Year of release:	1998	Control data?	Yes
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	10 m^3	Groundwater monitoring?	None
Size of impacted area:	1090 m^2	Sample points:	2 including control
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Vertical and horizontal extent was not determined. Salinity impact still in place.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl meq/L	SO_4-S meq/L
Spill area	0-30	2001	12.98	57.2	111	31.3
Spill area	0-15	2003	11.5	15.2	89.8	60.8
	15-30	2003	13.1	33.9	124	15.1
	30-50	2003	13.0	23.3	115	38.2
	50-100	2003	14.9	27.1	146	23.6
Control	0-15	2003	0.67	0.5	0.89	1.59
	15-30	2003	0.91	0.5	0.42	1.79
	70-100	2003	0.82	3.5	0.63	2.56

Site Summary

Spill 10

Site Description		Remediation Efforts	
Location:	East-Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Unknown
Soil texture:	Clay loam	Amendment details:	480 lbs of calcium nitrate and 1120 lbs of gypsum added in 2000.
Soil Classification:	Unknown		
Depth to groundwater:	unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Pipeline break	Sampling events (dates):	2000 and 2003
Year of release:	1999	Control data?	none
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	1000 m^3	Groundwater monitoring?	None
Size of impacted area:	4400 m^2	Sample points:	One
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Vertical and horizontal extent was not determined. Salinity impact still in place. Movement of salts down the soil profile over time is evident from the data.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl meq/L
Spill area	0-15	2000	13	11.8	3477
	15-30	2000	8.9	9.3	2258
Spill area	0-15	2003	2.80	3.0	4.44
	15-30	2003	3.67	4.6	3.10
	50-100	2003	6.36	5.5	13.5

Site Summary

Spill 11

Site Description		Remediation Efforts	
Location:	East-Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	None
Soil texture:	Moderately fine	Amendment details: 0.75 tons of gypsum, 80 lbs of calcium nitrate and 2 straw bales added in 2001. The area was paratilled to a depth of 40 cm and rotospiced to 10 cm.	
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Subsurface line failure	Sampling events (dates):	2001 and 2003
Year of release:	1997	Control data?	none
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	30 m^3	Groundwater monitoring?	None
Size of impacted area:	182 m^2	Sample points:	One
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Vertical and horizontal delineation was not completed. The salt impacted soil is still in place.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl meq/L	SO_4-S meq/L
Spill area	0-30	2001	11.6	23.6	92	25.7
Spill area	0-15	2003	13.50	18.5	106.00	52.6
	15-30	2003	16.1	23.7	138.00	70.6
	50-100	2003	23.9	41.7	241.0	51.2

Site Summary

Spill 12b

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Unknown
Soil texture:	Moderately fine	Amendment details:	
Soil Classification:	Unknown	In 2001, the spill was treated with 300 lbs of calcium nitrated, 5 lbs of phosphate and 5 lbs of potash. Straw bales were spread across the site.	
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Subsurface line failure	Sampling events (dates):	2001 and 2003
Year of release:	1992	Control data?	None
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	6 m^3	Groundwater monitoring?	None
Size of impacted area:	339 m^2	Sample points:	1
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Spill not fully delineated. No background samples collected. Subsoil SAR impact remains after leaching.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl mg/kg
Spill area	0-30	2001	2.5	12.8	220
Spill area	0-15	2003	0.73	3.6	24.8
	15-30	2003	1.28	10.0	75.5
	50-100	2003	1.46	11.0	135.4

Site Summary

Spill 12c

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Unknown
Soil texture:	Moderately fine	Amendment details: In 2001 the impacted area was treated with 5 tons of gypsum, 350 lbs of calcium nitrate, 70 lbs of phosphate and 70 lbs of potash. Straw bales were incorporated into the spill area. In 2003 (or 04?) 5 tons/ac of gypsum was incorporated.	
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		

Spill Description		Monitoring	
Brine source:	Subsurface line failure	Sampling events (dates):	2001 and 2003
Year of release:	1993	Control data?	None
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	52 m^3	Groundwater monitoring?	None
Size of impacted area:	1912 m^2	Sample points:	1
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Spill not fully delineated. Movement of salts through the profile evident from the data.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl mg/kg
Spill area	0-30	2001	9.4	57.9	1270
Spill area	0-15	2003	6.60	13.7	279.3
	15-30	2003	5.9	37.0	872.1
	50-100	2003	11.8	13.4	3935.0

Site Summary

Spill 12d

Site Description		Remediation Efforts	
Location:	East-Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Unknown
Soil texture:	Moderately fine	Amendment details: The spill area was treated with 5 tons of gypsum, 150 lbs of calcium nitrate, 40 lbs of phosphate, and 40 lbs of potash. Straw bales were incorporated into the spill impacted area.	
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		

Spill Description		Monitoring	
Brine source:	Subsurface line failure	Sampling events (dates):	2001 and 2003
Year of release:	1994	Control data?	None
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	1 m^3	Groundwater monitoring?	None
Size of impacted area:	274 m^2	Sample points:	1
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Remediation on this small spill appears to be successful.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl mg/kg
Spill area	0-30	2001	6.4	10.5	469.0
Spill area	0-15	2003	0.5	0.5	16.6
	15-30	2003	0.4	0.6	3.9
	50-100	2003	0.6	1.5	26.3

Site Summary

Spill 12e

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Unknown
Soil texture:	Moderately fine	Amendment details:	
Soil Classification:	Unknown	Manure was spread 5 to 10 cm thick across the spill area. The soil was worked 40 cm deep with a paratill. Straw was incorporated. 20 tons/ac of gypsum was incorporated in 2003 or 2004.	
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Subsurface line failure	Sampling events (dates):	2001 and 2003
Year of release:	1994	Control data?	None
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	1.5 m^3	Groundwater monitoring?	None
Size of impacted area:	144 m^3	Sample points:	1
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Unlike 12d, this small spill has not remediated well. There was little change in EC between sampling events, although SAR has decreased.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl mg/kg
Spill area	0-30	2001	17.4	56.0	4120
Spill area	0-15	2003	16.2	18.4	3899
	15-30	2003	14.4	29.4	3793
	50-100	2003	23.5	26.1	8083

Site Summary

Spill 12f

Site Description		Remediation Efforts	
Location:	East-Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Unknown
Soil texture:	Moderately fine	Amendment details: The soil was amended with 3.5 tons of gypsum, 300 lbs of calcium nitrate, 80 lbs of phosphate, 80 lbs of potash and straw. 1 ton/ac of gypsum was incorporated in 2003 or 2004.	
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Subsurface line failure	Sampling events (dates):	2001 and 2003
Year of release:	1994	Control data?	None
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	5 m^3	Groundwater monitoring?	None
Size of impacted area:	786 m^2	Sample points:	1
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Small spill appears to be remediating well, but some impacts remain.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl mg/kg
Spill area	0-30	2001	7.8	33.7	1210
Spill area	0-15	2003	4.0	9.1	126
	15-30	2003	3.0	12.0	168
	50-100	2003	3.1	1.9	121

Site Summary

Spill 13

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Unknown
Soil texture:	Clay loam to clay	Amendment details: In 2000, 7000 lbs of gypsum and 440 lbs of calcium nitrate added to the upper area and 11 tons gypsum and 1720 lbs calcium nitrate added to the lower area. In 2004, 19.8 tons/acre gypsum and 400 lbs of calcium nitrate were applied.	
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		

Spill Description		Monitoring	
Brine source:	Subsurface line failure	Sampling events (dates):	2000 and 2003
Year of release:	1999	Control data?	None
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	300 m^3	Groundwater monitoring?	None
Size of impacted area:	5450 m^2	Sample points:	1
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Complete horizontal and vertical delineation not achieved. Spill impact has persisted.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl mg/kg
Spill area	0-15	2000	18.6	21.1	4400
	15-30	2000	20.9	21.8	5720
Spill area	0-15	2003	14.3	22.9	4112
	15-30	2003	10.1	19.4	2765
	50-100	2003	22.4	22.4	3534

Site Summary

Spill 14

Site Description		Remediation Efforts	
Location:	East-Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	None
Soil texture:	Clay loam to clay	Amendment details: 0.5 tons/acre of gypsum and two 80 pound bags of calcium nitrate applied in 2001. The area was paratilled to a depth of 45 cm and was rotospiced to a depth of 10 cm.	
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		

Spill Description		Monitoring	
Brine source:	Surface spill	Sampling events (dates):	2001 and 2003
Year of release:	1990	Control data?	None
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	6 m^3	Groundwater monitoring?	None
Size of impacted area:	600 m^2	Sample points:	1
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

Complete horizontal and vertical delineation not achieved. Some impact has persisted.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl meq/L
Spill area	0-30	2001	2.7	111.3	6.8
Spill area	0-15	2003	5.6	16.3	14.9
	15-30	2003	5.7	52.0	30.2
	50-100	2003	8.1	60.0	68.4

Site Summary

Spill 15

Site Description		Remediation Efforts	
Location:	Peace Region	Remediation system:	Tile drainage system
Natural region:	Dry Mixedwood	Source removal details:	Flare pit soils
Soil texture:	Clay loam	Amendment details:	Gypsum applied during construction.
Soil Classification:	Unknown		
Depth to groundwater:	2 to 3 m		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Flare pit	Sampling events (dates):	1998 and 2003
Year of release:	Unknown	Control data?	Yes
Brine origin (formation):	Debolt	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	Yes
Size of impacted area:	Unknown	Sample points:	6 in 2003
Max investigation depth:	1.4 m	Details of EM surveys:	Completed in 1997
Maximum impact depth:	Unknown		

Overview:

Flare pit soils were excavated and placed into an LTA between 1991 and 1995. A tile drainage system was installed in the LTA to address soil salinity issues in 1998. By 2003, soils had not reached guidelines, and soils were excavated in 2004. Maintenance of the system while operating was sporadic.

The Data

See Table 2

Site Summary

Spill16

Site Description		Remediation Efforts	
Location:	Peace Region	Remediation system:	Tile drainage system
Natural region:	Dry Mixedwood	Source removal details:	Flare pit soils
Soil texture:	Clay loam	Amendment details:	Gypsum applied during construction.
Soil Classification:	Unknown		
Depth to groundwater:	2 to 3 m		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Flare pit	Sampling events (dates):	1998 and 2003
Year of release:	Unknown	Control data?	Yes
Brine origin (formation):	Debolt	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	Yes
Size of impacted area:	Unknown	Sample points:	8 in 2003
Max investigation depth:	1.5 m	Details of EM surveys:	
Maximum impact depth:	Unknown		

Overview:

Soil were excavated from a flare pit, tiles installed, and soil replaced over the tile system. Site was constructed in 1998, sampled in 2003 and removed in 2004. Maintenance of the system while operational was sporadic.

The Data

See Table 2

Site Summary

Spill 19

Site Description		Remediation Efforts	
Location:	Peace Region	Remediation system:	Passive, leachate collected in a drainage ditch
Natural region:	Dry Mixedwood	Source removal details:	None
Soil texture:	Sandy loam to silt loam	Amendment details:	86 T Gypsum and 1.6 T calcium nitrate added in 1989.
Soil Classification:	Orthic and Dark Grey Chernozems		8.3 T/ha gypsum added in 1990. Calcium nitrate added in 1991.
Depth to groundwater:	0.3 to 2.7 m		
Discharge or recharge?	Recharge, but local site groundwater discharge to nearby creek.		
Spill Description		**Monitoring**	
Brine source:	Well blowout	Sampling events (dates):	1997, 1998, 1999, 2000, 2004, not all comparable
Year of release:	1989	Control data?	Yes
Brine origin (formation):	Unknown	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	Yes -- See Table 7b
Size of impacted area:	50,000 m^2	Sample points:	Various, but not all directly comparable between years
Max investigation depth:	9 m	Details of EM surveys:	1997 and 2004
Maximum impact depth:	Around 7.5 m		
Overview:			
Large area of impact, has been remediating since 1989. Known impact to groundwater. Site drains towards a creek.			

The Data

Spill 19

Soil

Year	Depth (cm)	EC	STDEV	SAR	STDEV	n
1989	0-12	44.5	12	46.1	24.7	5
	12-25	28.6	15.1	16.2	20.4	3
1990	0-15	20.5	11.8	22.7	11	9
	15-30	16.3	8.2	18.9	4.9	3
	30-45	9.4	2.2	11.8	6.1	3
	45-60	22.6	20.2	20.8	16.7	3
	60-100	14	9.3	13.8	14	3
1991	0-15	19.1	15.7	16.2	12.2	9
	15-30	12.1	5.1	10.1	3.6	3
	30-45	6	2	5.5	2.1	3
	45-60	5.6	3.4	4.8	3.8	3
	60-100	5.8	3.6	4.5	4.6	3
1999	0-15	14.9	12.2	14.9	16.5	5
	15-30	22.7	21	22.7	19.8	4
	30-60	21.6	13.6	21.6	22.7	3
	60-100	16.7	9	16.7	15.7	2
2000	0-15	12	7	14.2	7.9	9
	15-30	14.2	8.2	14.3	9.3	9
	30-60	13.6	7.8	14.3	9.4	10
	60-100	12.2	6.6	12.1	6.2	11

Groundwater

Monitoring Well	Sample Date	Lab EC µS/cm	Cl mg/L
97-2	1997	47000	18100
97-2	1998	31300	15000
97-2	1999	36700	13000
97-2	2000	9770	2220
97-2	2004	28100	10600
97-2d	1997	29500	10000
97-2d	1999	15300	4200
97-2d	2000	35800	14900
97-2d	2004	6200	846
99-5	1999	6300	1010
99-5	2000	8080	1410
99-5d	1999	4700	20.6
99-5d	2000	4520	19.7
99-5d	2004	7100	1210
99-7	1999	27900	9870
99-7	2000	26800	11300
99-7	2004	14400	5900
99-8	1999	11600	3300
99-8	2000	10600	3450
99-8	2004	7690	2210
99-12	1999	20700	7070
99-12	2000	20000	7720
99-12	2004	12700	4910
00-13	2000	5950	998
00-13	2004	4430	559
00-13d	2000	6960	1450
00-13d	2004	6260	1580

Site Summary

Spill 20

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	None reported
Soil texture:	Unknown	Amendment details:	Calcium nitrate and fertilizer
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Pipeline break	Sampling events (dates):	2000 and 2004
Year of release:	2000	Control data?	Yes
Brine origin (formation):	Lloyd/Sparky	Parameters analysed:	Detailed salinity
Spill volume:	150 m^3	Groundwater monitoring?	None
Size of impacted area:	1.9 ha	Sample points:	7 plus 1 control
Max investigation depth:	1 m	Details of EM surveys:	None
Maximum impact depth:	< 1 m		
Overview:			
Oil is being remediated with salts. Salt remediation is progressing.			

The Data

See Table 6

Site Summary

Spill 21

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	None reported
Soil texture:	Unknown	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Pipeline break	Sampling events (dates):	2000 and 2004
Year of release:	2000	Control data?	Yes
Brine origin (formation):	Lloyd/Sparky	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	None
Size of impacted area:	Unknown	Sample points:	2 plus 1 control
Max investigation depth:	2.0 m	Details of EM surveys:	None
Maximum impact depth:	< 2 m		
Overview:			
Remediation is progressing			

The Data

See Table 6

Site Summary

Spill 22

Site Description		Remediation Efforts	
Location:	East-Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	None reported
Soil texture:	Unknown	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Pipeline break	Sampling events (dates):	2000 and 2004
Year of release:	2000	Control data?	Yes
Brine origin (formation):	Lloyd/Sparky	Parameters analysed:	Detailed salinity
Spill volume:	30 m^3	Groundwater monitoring?	None
Size of impacted area:	3300 m^2	Sample points:	3 plus 1 control
Max investigation depth:	1 m	Details of EM surveys:	None
Maximum impact depth:	> 1 m		
Overview:			
Remediation is progressing			

The Data

See Table 6

Site Summary

Spill 23

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	None reported
Soil texture:	Unknown	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Pipeline break	Sampling events (dates):	2001, 2002 and 2003
Year of release:	2000	Control data?	Yes
Brine origin (formation):	Viking	Parameters analysed:	Detailed salinity
Spill volume:	30 m^3	Groundwater monitoring?	None
Size of impacted area:	150 m^2	Sample points:	2 plus 1 control
Max investigation depth:	1 m	Details of EM surveys:	None
Maximum impact depth:	> 1 m		
Overview:			
Remediation is progressing; impacts remain 3 years after spill occurrence.			

Spill 23

The Data

EC (dS/m)	Depth (cm)	2001	2002	2003
Profile 1	0-15	6.3	5.6	5.1
	15-50	3.4	4.2	4.8
	50-100	1	2.3	3.9
Profile 2	0-15	15.3	8.4	7.5
	15-50	8.4	6.8	4.6
	50-100	7.6	9.4	7.7
Control 1	0-15	0.4	---	---
	15-50	0.3	---	---
	50-100	1	---	---

SAR	Depth (cm)	2001	2002	2003
Profile 1	0-15	12.1	6.8	4.5
	15-50	4.4	7.3	6.7
	50-100	2.5	9.3	8.3
Profile 2	0-15	30	17	8.6
	15-50	15.3	15.4	15.5
	50-100	13	13.2	9
Control 1	0-15	0.5	---	---
	15-50	3.1	---	---
	50-100	5.7	---	---

Cl (mg/kg)	Depth (cm)	2001	2002	2003
Profile 1	0-15	2330	626	482
	15-50	1060	644	638
	50-100	252	986	682
Profile 2	0-15	6730	1410	2980
	15-50	3490	1840	736
	50-100	2730	3030	2480
Control 1	0-15	14	---	---
	15-50	6	---	---
	50-100	29	---	---

SO_4-S (mg/kg)	Depth (cm)	2001	2002	2003
Profile 1	0-15	42.5	1730	1610
	15-50	157	574	897
	50-100	25.3	127	524
Profile 2	0-15	69.6	2280	1750
	15-50	101	562	1030
	50-100	411	461	732
Control 1	0-15	30	---	---
	15-50	28	---	---
	50-100	306	---	---

--- no data

Site Summary

Spill 24

Site Description		Remediation Efforts	
Location:	East-Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	None reported
Soil texture:	Unknown	Amendment details:	Gypsum, calcium nitrate and peat moss added
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Pipeline break	Sampling events (dates):	2001, 2002 and 2003
Year of release:	1999	Control data?	Yes
Brine origin (formation):	Viking	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	None
Size of impacted area:	70 m^2	Sample points:	1 plus 1 control
Max investigation depth:	1 m	Details of EM surveys:	None
Maximum impact depth:	> 1 m		
Overview:			
Remediation is progressing			

Spill 24

The Data

EC (dS/m)	Depth (cm)	2001	2002	2003
Profile 1	0-15	7.1	6	1.1
	15-50	5.7	7.9	2.3
	50-100	6.7	6.7	3.4
Control 1	0-15	0.4	---	---
	15-50	0.2	---	---
	50-100	0.5	---	---

SAR	Depth (cm)	2001	2002	2003
Profile 1	0-15	33.6	14.9	2.3
	15-50	39.5	43	7.2
	50-100	29.2	40.4	5.2
Control 1	0-15	2.1	---	---
	15-50	2.2	---	---
	50-100	2.3	---	---

Cl (mg/kg)	Depth (cm)	2001	2002	2003
Profile 1	0-15	2240	560	45
	15-50	1900	2420	108
	50-100	1890	2790	440
Control 1	0-15	27	---	---
	15-50	7	---	---
	50-100	9	---	---

SO_4-S (mg/kg)	Depth (cm)	2001	2002	2003
Profile 1	0-15	800	3070	405
	15-50	195	1530	642
	50-100	39	254	534
Control 1	0-15	31.5	---	---
	15-50	25	---	---
	50-100	33.4	---	---

--- no data

Site Summary

Spill 28

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Passive
Natural region:	Unknown	Source removal details:	Not reported
Soil texture:	Unknown	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	1999, 2000 and 2001
Year of release:	1999	Control data?	Yes
Brine origin (formation):	Frobauda	Parameters analysed:	Detailed salinity
Spill volume:	2 m^3	Groundwater monitoring?	None
Size of impacted area:	540 m^2	Sample points:	1 plus 1 control
Max investigation depth:	0.75 m	Details of EM surveys:	None
Maximum impact depth:	> 0.75 m		

Overview:

The Data

EC (dS/m)	Depth (cm)	1999	2000	2001
Profile 1	0-15	2.2	9.6	6.7
	30-45	10.1	11.9	9.6
	60-75	18.9	16	8.5
Control 1	0-15	0.7	---	---
	30-45	4.7	---	---

SAR	Depth (cm)	1999	2000	2001
Profile 1	0-15	18	19.2	15.1
	30-45	25.3	16.8	14.4
	60-75	51	16.9	7.4
Control 1	0-15	0.3	---	---
	30-45	0.9	---	---

Cl (meq/L)	Depth (cm)	1999	2000	2001
Profile 1	0-15	8.2	31.8	14
	30-45	88.9	69.2	59.9
	60-75	193	111	56.7
Control 1	0-15	1.4	---	---
	30-45	0.4	---	---

SO_4-S (meq/L)	Depth (cm)	1999	2000	2001
Profile 1	0-15	2.7	78.1	73.5
	30-45	4.2	59.9	5.7
	60-75	4.5	26.6	13.3
Control 1	0-15	0.7	---	---
	30-45	78.9	---	---

--- no data

Site Summary

Spill 29

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Passive
Natural region:	Unknown	Source removal details:	None reported
Soil texture:	Unknown	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	1997, 1998 and 2001
Year of release:	1997	Control data?	Yes
Brine origin (formation):	Frobauda	Parameters analysed:	Detailed salinity
Spill volume:	3 m^3	Groundwater monitoring?	None
Size of impacted area:	295 m^2	Sample points:	1 plus 1 control
Max investigation depth:	0.75 m	Details of EM surveys:	None
Maximum impact depth:	> 0.75 m		

Overview:

Have 2003 data but samples collected from different depth increments than earlier samples making comparison difficult.

The Data

EC (dS/m)	Depth (cm)	1997	1998	2001	SAR	Depth (cm)	1997	1998	2001
Profile 1	0-15	10.8	22.5	12.3	Profile 1	0-15	27.7	28.7	15
	30-45	29.7	16.8	8.6		30-45	37.5	15.4	7.9
	60-75	16.9	21.7	10.6		60-75	21.2	17.4	7.5
Control 1	0-15	5.2	---	---	Control 1	0-15	3.2	---	---
	30-45	7	---	---		30-45	6	---	---
	60-75	7	---	---		60-75	7.3	---	---

Cl (meq/L)	Depth (cm)	1997	1998	2001	SO_4-S (meq/L)	Depth (cm)	1997	1998	2001
Profile 1	0-15	43.7	204	88.3	Profile 1	0-15	60.5	66.6	62.3
	30-45	246	152	55.5		30-45	60.7	50.8	43.7
	60-75	122	225	72.4		60-75	39.1	48.5	68.4
Control 1	0-15	2.8	---	---	Control 1	0-15	62.5	---	---
	30-45	2.2	---	---		30-45	107	---	---
	60-75	1.9	---	---		60-75	105	---	---

--- no data

Site Summary

Spill 30

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Passive
Natural region:	Unknown	Source removal details:	None reported
Soil texture:	Unknown	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	2001 and 2003
Year of release:	1997	Control data?	Yes
Brine origin (formation):	Frobauda	Parameters analysed:	Detailed salinity
Spill volume:	34 m^3	Groundwater monitoring?	None
Size of impacted area:	1200 m^2	Sample points:	2 plus 1 control
Max investigation depth:	0.75 m	Details of EM surveys:	None
Maximum impact depth:	> 0.75 m		

Overview:

Only 0-15 depth increment comparable between years at this site due to inconsistencies in sampling depths between years.

The Data

EC (dS/m)	Depth (cm)	2001	2003	SAR	Depth (cm)	2001	2003
Profile 1	0-15	6.1	2.3	Profile 1	0-15	5	12.7
Profile 2	0-15	11.2	---	Profile 2	0-15	6.9	---
Control 1	0-15	1.2	---	Control 1	0-15	0.6	---

Cl (meq/L)	Depth (cm)	2001	2003	SO_4-S (meq/L)	Depth (cm)	2001	2003
Profile 1	0-15	25.9	---	Profile 1	0-15	7.1	---
Profile 2	0-15	78.1	---	Profile 2	0-15	41.6	---
Control 1	0-15	1.2	---	Control 1	0-15	2.8	---

--- no data

Site Summary

Spill 31

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Passive
Natural region:	Unknown	Source removal details:	Not reported
Soil texture:	Unknown	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	1998, 2000 and 2001
Year of release:	1997	Control data?	Yes
Brine origin (formation):	Frobauda	Parameters analysed:	Detailed salinity
Spill volume:	5 m^3	Groundwater monitoring?	None
Size of impacted area:	50 m^2	Sample points:	1 plus 1 control
Max investigation depth:	0.75 m	Details of EM surveys:	None
Maximum impact depth:	> 0.75 m		

Overview:

Remediation is progressing.

The Data

EC (dS/m)	Depth (cm)	1998	2000	2001	SAR	Depth (cm)	1998	2000	2001
Profile 1	0-15	124	74.1	36.3	Profile 1	0-15	126	75.5	48.9
	30-45	85.2	80.3	43.2		30-45	94.8	106	92.8
	60-75	48.4	98.2	73.1		60-75	52.5	126	121
Control 1	0-15	1.7	---	---	Control 1	0-15	3	---	---
	30-45	2	---	---		30-45	21.3	---	---

Cl (meq/L)	Depth (cm)	1999	2000	2001	SO_4-S (meq/L)	Depth (cm)	2000	2000	2001
Profile 1	0-15	492	643	396	Profile 1	0-15	78.1	87.6	83.3
	30-45	352	670	550		30-45	56.2	38	38.9
	60-75	386	894	684		60-75	87.9	33.9	52.3
Control 1	0-15	7.7	---	---	Control 1	0-15	2	---	---
	30-45	8.4	---	---		30-45	4.9	---	---

--- no data

Site Summary

Spill 32

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Passive
Natural region:	Unknown	Source removal details:	None reported
Soil texture:	Unknown	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	2002 and 2003
Year of release:	2000	Control data?	Yes
Brine origin (formation):	Midale	Parameters analysed:	Detailed salinity
Spill volume:	3 m^3	Groundwater monitoring?	None
Size of impacted area:	730 m^2	Sample points:	1 plus 1 control
Max investigation depth:	0.3 m	Details of EM surveys:	None
Maximum impact depth:	> 0.3 m		
Overview:			
Remediation is continuing.			

The Data

EC (dS/m)	Depth (cm)	2002	2003	SAR	Depth (cm)	2002	2003
Profile 1	0-15	8.5	5.8	Profile 1	0-15	14	8.9
	15-30	10.1	6.4		15-30	16.8	9.9
Control 1	0-15	0.5	1.2	Control 1	0-15	0.2	0.3
	15-30	---	---		15-30	---	---

Cl (mg/L)	Depth (cm)	2002	2003	SO_4-S (mg/L)	Depth (cm)	2002	2003
Profile 1	0-15	1880	517	Profile 1	0-15	2230	2770
	15-30	2390	587		15-30	2680	3250
Control 1	0-15	5	25	Control 1	0-15	32.6	112
	15-30	---	---		15-30	---	---

--- no data

Site Summary

Spill 35

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Passive
Natural region:	Unknown	Source removal details:	None reported
Soil texture:	Clay loam	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	1994, 1995, 1997, 2001
Year of release:	1993	Control data?	Yes
Brine origin (formation):	Unknown	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	None
Size of impacted area:	80 m^2	Sample points:	1 composite plus 1 control
Max investigation depth:	0.75 m	Details of EM surveys:	None
Maximum impact depth:	> 0.75 m		

Overview:

Other lab analysis is available, but sampling depths are inconsistent. Remediation at this site does not appear to be making much progress.

The Data

Sample Point	Depth cm	Sample Date	pH	EC dS/m	SAR	Cl mg/kg	SO_4-S mg/kg
Spill Comp	0-15	1994	7.3	16.9	19	3692	59
Spill Comp	15-45	1994	7.4	19.6	25.8	4651	11
Spill Comp	0-15	1995	7.5	17.7	18.9	3003	425
Spill Comp	15-45	1995	7.8	20.9	24.6	3920	376
Spill Comp	0-15	1997	7.1	16.3	13.6	2310	457
Spill Comp	15-45	1997	7.3	16.3	19.1	2870	456
Spill Comp	0-15	1999	7.3	15	15.1	2540	189
Spill Comp	15-45	1999	7.3	17.4	21.2	3500	639
Spill Comp	0-15	2001	7.2	14.2	15.1	1900	460
Spill Comp	15-45	2001	7.4	13.7	24.8	2540	217
Spill Comp	0-15	2003	7.6	16	18.6	2100	533
Spill Comp	15-45	2003	7.7	---	---	---	---
Control	0-15	2003	8.2	0.37	0.5	16	3
Control	15-45	2003	8	0.44	0.2	4	16.6

--- no data

Site Summary

Spill 36

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Passive
Natural region:	Unknown	Source removal details:	None reported
Soil texture:	Loam	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Lloyd	Sampling events (dates):	1998, 2000 and 2003
Year of release:	1998	Control data?	Yes
Brine origin (formation):	Unknown	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	None
Size of impacted area:	500 m^2	Sample points:	2 plus 1 control
Max investigation depth:	0.45 m	Details of EM surveys:	None
Maximum impact depth:	> 0.45 m		
Overview:			

The Data

Sample Point	Depth cm	Sample Date	pH	EC dS/m	SAR	Cl mg/kg	SO_4-S mg/kg
Breaksite	0-15	1998	7.5	14.9	21.6	3130	10.7
Breaksite	15-45	1998	7.4	14	16.3	2540	12.3
Breaksite	0-15	2000	6.9	1.16	6.3	35.8	19.4
Breaksite	15-45	2000	6.9	7.09	53.1	285	82.2
Breaksite	0-15	2003	7.3	1.21	5.7	55	32.2
Breaksite	15-45	2003	7	2.34	13	109	30
Spill Path	0-15	2000	7.2	4.65	5.2	236	12
Spill Path	15-45	2000	7.3	4.22	3.3	380	6
Spill Path	0-15	2003	7.1	0.87	4.1	17	15.8
Spill Path	15-45	2003	8.1	2.65	29.9	137	17
Control	0-15	2003	7.7	0.47	0.6	7	3.2
Control	15-45	2003	7.6	0.29	0.7	3	5

Site Summary

Spill 37

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Passive
Natural region:	Unknown	Source removal details:	None reported
Soil texture:	Loam	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	1998, 2000, 2001, 2002, 2003 and 2004
Year of release:	1998	Control data?	No
Brine origin (formation):	Unknown	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	None
Size of impacted area:	Unknown	Sample points:	2
Max investigation depth:	1 m	Details of EM surveys:	None
Maximum impact depth:	> 1 m		
Overview:			
Site appears to be slowly remediating over time. Not yet near background/guideline levels.			

Spill 37

Spill 37 Data

Sample Point	Depth cm	Sample Date	pH	EC dS/m	SAR	Cl mg/kg	SO_4-S mg/kg
Spill Path	0-15	1998	---	21.4	63.4	5390	---
Spill Path	15-45	1998	---	25.9	30.9	5270	---
Spill Path	0-15	2000	7.8	2.96	21.4	603	95.9
Spill Path	15-45	2000	7.3	10.25	72.7	2400	284
Spill Path	45-75	2000	7.3	12.84	---	3460	182
Spill Path	75-100	2000	7.1	26.4	30.9	6670	82
Spill Path	0-15	2001	6	20.4	10.5	4070	530
Spill Path	15-45	2001	5.7	18.6	24.3	2940	52
Spill Path	45-75	2001	5.3	14.9	---	3310	15
Spill Path	75-100	2001	5.7	18.5	16	4380	12
Spill Path	0-15	2002	6.5	17.6	22.7	2750	738
Spill Path	15-45	2002	7	17.2	40.3	3010	768
Spill Path	45-75	2002	7.7	17.3	---	4430	225
Spill Path	75-100	2002	7.8	21.9	35.7	4500	110
Spill Path	0-15	2003	7.1	5.8	10.4	191	843
Spill Path	15-45	2003	6.9	9.59	44	1810	430
Spill Path	45-75	2003	7.2	17.2	---	3930	88
Spill Path	75-100	2003	7.6	22.6	32.3	4430	53
Spill Path	0-15	2004	7.1	3.65	2.8	43	556
Spill Path	15-45	2004	7.1	7.06	15.8	187	763
Spill Path	45-75	2004	7.3	10.3	---	1400	1000
Spill Path	75-100	2004	7.2	16.2	27.2	3270	466
Collection Area	0-15	1998	---	57.1	68.7	17800	---
Collection Area	15-45	1998	---	24.5	26	6040	---
Collection Area	0-15	2000	6.3	9.25	24.8	3200	26
Collection Area	15-45	2000	3.2	15.7	35.5	5410	36
Collection Area	45-75	2000	5.9	15.2	20.4	4380	24
Collection Area	75-100	2000	5.9	14	11.2	3680	26
Collection Area	0-15	2001	6.7	5.08	20.7	1110	42
Collection Area	15-45	2001	6.1	8.27	32.2	2120	23
Collection Area	45-75	2001	5.7	9.61	16.8	1830	24
Collection Area	75-100	2001	5.9	10.97	11.5	2500	40
Collection Area	0-15	2002	6.8	5.75	21.7	1060	108
Collection Area	15-45	2002	6.4	11.05	34.1	2200	60
Collection Area	45-75	2002	5.7	12.71	20.1	2730	20
Collection Area	75-100	2002	5.9	12.05	14.3	2580	30
Collection Area	0-15	2003	7	1.18	10.4	120	89.1
Collection Area	15-45	2003	6.7	2.97	28	561	37
Collection Area	45-75	2003	6.1	7.21	18.3	1590	19
Collection Area	75-100	2003	6	8.6	12.7	1790	21

--- no data

Site Summary

Spill 38

Site Description		Remediation Efforts	
Location:	Southeast Saskatchewan	Remediation system:	Passive
Natural region:	Unknown	Source removal details:	None reported
Soil texture:	Sandy loam to loam	Amendment details:	Not reported
Soil Classification:	Unknown		
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	1998, 2000, 2003
Year of release:	1998	Control data?	No
Brine origin (formation):	Unknown	Parameters analysed:	Detailed salinity
Spill volume:	Unknown	Groundwater monitoring?	None
Size of impacted area:	Unknown	Sample points:	2
Max investigation depth:	0.45 m	Details of EM surveys:	None
Maximum impact depth:	> 0.45 m		

Overview:

Spill path data appears somewhat inconsistent.

The Data

Sample Point	Depth cm	Sample Date	pH	EC dS/m	SAR	Cl mg/kg	SO_4-S mg/kg
Breaksite	0-15	1998	---	8.65	54	1490	35.3
Breaksite	15-45	1998	---	16.5	68.2	3680	15.8
Breaksite	0-15	2000	7.8	2.95	12.9	128	43
Breaksite	15-45	2000	7.9	6.47	48.8	527	139
Breaksite	0-15	2003	7.6	4.97	4.97	65	67
Breaksite	15-45	2003	8.4	5.32	5.32	543	17.7
Breaksite	0-15	2004	7.9	---	---	---	---
Breaksite	15-45	2004	7.8	---	---	---	---
Spill Path	0-15	1998	---	20.4	62.8	4190	13.5
Spill Path	15-45	1998	---	21.8	59.9	4300	8.6
Spill Path	0-15	2000	7.7	0.67	6.8	21.2	7.3
Spill Path	15-45	2000	7.7	0.98	9.2	33.8	17.9
Spill Path	0-15	2003	7.8	3.83	9.6	58	254
Spill Path	15-45	2003	8.1	6.27	48	381	125
Spill Path	0-15	2004	7.3	---	---	---	---
Spill Path	15-45	2004	7.4	---	---	---	---

--- no data

Site Summary

Spill 40

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Unknown
Soil texture:	Clay loam to clay	Amendment details:	
Soil Classification:	Unknown	Applied 200 lbs of gypsum and 80 lbs of calcium nitrate, paratilled site to a depth of 40 cm; amended with two bales of straw and worked with a rotospic to 10 cm	
Depth to groundwater:	Unknown		
Discharge or recharge?	Unknown		
Spill Description		**Monitoring**	
Brine source:	Subsurface line failure	Sampling events (dates):	2001 and 2003
Year of release:	1998	Control data?	None
Brine origin (formation):	Mannville	Parameters analysed:	Detailed salinity
Spill volume:	3 m^3	Groundwater monitoring?	None
Size of impacted area:	160 m^2	Sample points:	1
Max investigation depth:	1.0 m	Details of EM surveys:	None
Maximum impact depth:	Unknown		

Overview:

SAR has persisted, may be due to naturally occurring salts.

The Data

Sample Point	Depth cm	Sample Date	EC dS/m	SAR	Cl mg/kg
Spill area	0-30	2001	4.8	15.1	589
Spill area	0-15	2003	1.2	5.0	143
	15-30	2003	1.1	6.1	71
	50-100	2003	4.3	6.9	213

Site Summary

Spill 42

Site Description		Remediation Efforts	
Location:	East Central Alberta	Remediation system:	Passive
Natural region:	Central Parkland	Source removal details:	Impacted surface soil and subsoil removed to 2.5m depth in 2003.
Soil texture:	Loam to sandy clay loam surface and root zone subsoil (till) to about 5m, sand (or sandy) from 5m to 17m.		
Soil Classification:	Unknown	Amendment details:	None recorded, but lab data indicates gypsum and possibly other sources of calcium have been applied in the past.
Depth to groundwater:	16 m bgs		
Discharge or recharge?	Discharge		
Spill Description		**Monitoring**	
Brine source:	Unknown	Sampling events (dates):	2003 to 2005
Year of release:	1994 to 1997	Control data?	yes
Brine origin (formation):	Unknown	Parameters analysed:	detailed salinity
Spill volume:	1,105 m^3 cumulative	Sample points:	3 within initial spill area; one control
Size of impacted area:	Unknown	Groundwater monitoring?	Yes. Based on 2004 monitoring, produced water did not appear to have significantly impacted groundwater.
Max investigation depth:	14.25 m	Details of EM surveys:	Main anomaly is roughly 25 x 30 m in size, based on an EM 31 survey carried out in fall 2005
Maximum impact depth:	9.75 m		

Overview:

Several spills occurred at this site between 1994 and 2003. The site is gently sloping farm land on soils that are naturally non-saline. The data presented here includes data collected in 2004 from the 1994 spill area. Although no data is available from 1994 immediately after the spill occurred, data collected shortly after an adjacent spill in 2003 was considered to be a good substitute since the same brine was spilled in similar volumes in both events.

Spill 42

The Data

See Table 7

Sample point		Depth cm	Sample Date	EC dS/m	SAR	Na mg/L	Cl mg/L	SO_4- mg/L
After 2003 spill (average of 4 points)		Surface	2003	40.4	55.8	--	--	--
1994 spill area								
	Site 1	0-20	2003	13.6	18.8	2300	4150	1630
		20-100	2003	18.8	32.6	3650	6530	800
	Site 2	0-20	2003	13.6	17.9	2250	3960	1870
		40-100	2003	18.7	34.1	3640	6470	704
	Site 3	0-75	2003	15.5	35.2	3540	5760	681
		300-375	2003	8.09	8.7	894	3040	69.1
		600-675	2003	5.37	2.9	295	1860	6.6
		900-975	2003	4.36	4.4	356	1450	18.7
		1050-1125	2003	1.48	1.6	80	387	26.8
		1200-1275	2003	1.16	0.9	45	309	23.7
		1350-1425	2003	1.04	1.3	60	196	151

-- no data