2007 Progress Report

Tongue River Agronomic Monitoring & Protection Program

Tongue River Information Program

Prepared for: ***Montana Board of Oil & Gas Conservation***
Montana Department of Natural Resources and Conservation

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Executive Summary

Irrigators that rely on Tongue River water for crop and forage production have expressed concern about potential adverse impacts that CBNG development may have on irrigation water quality. Currently, the Tongue River enjoys good quality water that is used to irrigate more than 20,000 acres of land while supporting a healthy fishery within and just below the Tongue River Reservoir.

The Agronomic Monitoring and Protection Program (AMPP) was initially commissioned and funded by Fidelity Exploration & Production Company (Fidelity) in 2003. Since late-2006, AMPP has been supported by the Montana Department of Natural Resources' Board of Oil and Gas Conservation (Tom Richmond, Administrator). AMPP was designed by two professional soil scientists and an agronomist from Montana, namely William Schafer, Kevin Harvey, and Neal Fehringer. During summer and fall of 2003, landowners who irrigated a minimum of 80 acres with Tongue River water were invited to become cooperators in AMPP. All landowners participate on a voluntary basis and the specific location of sampled fields is confidential.

The AMPP soil and crop testing program has provided agronomic assistance to participants, helped irrigators better understand potential effects of CBNG development on their irrigated fields, and has documented regional trends in irrigated soil characteristics. AMPP consists of three tiers of sampling:

- Tier 1, which assesses crop yield factors, soil fertility, electrical conductivity (EC) and sodium adsorption ratio (SAR) in selected fields;
- Tier 2, which includes Tier 1 parameters as well as more detailed sampling, and measurement of exchangeable sodium percentage (ESP), texture, bulk density, water intake rate, clay mineralogy, and soil classification as well as determination of crop yields and forage quality (including sodium content) and soil fertility in 16 fields; and
- Tier 3, which consists of crop and forage test plots employing mixtures of Tongue River water and CBNG production water.

This report contains results of Tier 2 sampling from the program's inception in fall 2003 through fall 2006 sampling. The purpose of the program is three-fold: 1) to measure baseline soil characteristics; 2) to identify changes in soil chemical and physical properties, if any, and to explore the potential relationship to CBNG development; and 3) to annually monitor crop yields and forage quality (including minerals such as sodium). To date, samples have been collected from AMPP sites five times: October 2003, April & October 2004, October 2005, and December 2006.

Study Approach

In selected fields spaced at intervals along the Tongue River (and its tributaries of Prairie Dog Creek and Otter Creek), detailed soil sampling was performed to determine seasonal changes in soil chemistry, and to assess soil characteristics at depths of up to 8 feet. Tier 2 soil sampling used a representative number of composite sub-samples collected from a portion of each field that consisted of a single soil mapping unit from the County Cooperative Soil Survey. Composite samples were collected from the following depth intervals: 0 to 2, 0 to 6, 6 to 12, 12 to 24, 24 to 36, 36 to 60, and 60 to 96 inches. Laboratory analyses included soil texture, EC, SAR, ESP, soil texture, clay mineralogy, trace metals, plant available nutrients, and other properties. Neal Fehringer, Certified Professional Agronomist, has formulated ranch-specific recommendations for all Tier 2 fields annually.

Laboratory Analysis and Quality Assurance

Samples were collected, handled and analyzed under a stringent quality assurance program. The objective of the quality assurance plan is to ensure that data collected in the Tongue River AMPP are of known and acceptable quality to differentiate spatial and temporal soil chemical trends for Tier 2 samples and to provide agronomic advice.

Each set of Tier 2 soil samples were collected from the same composite sub-sample locations using GPS technology and from the same depth increments. This controlled sampling approach is necessary to minimize effects of natural soil variability on results. Samples were transported to the laboratory under chain-of-custody. The certified laboratory used an internal quality assurance program to maintain analytical precision and accuracy. Analytical results from all five sampling events, including quality assurance samples, are available to the public via the Energy Laboratory web site. (http://energylab.com/default.aspx). The AMPP web site also contains details of the program (http://www.tongueriverampp.com). The generalized location of AMPP sites is shown in Figure A. Only landowner/cooperators were provided with the alpha code corresponding to their fields.

Results

Sixteen fields were selected for the Tier 2 AMPP. Ten fields are irrigated with Tongue River water and are distributed along the entire length of the River from above the Tongue River Reservoir to the lower T&Y Irrigation District east of Miles City. Two additional Tongue River fields are non-irrigated, but are located in the floodplain in the same soil-mapping unit as the nearby irrigated AMPP field~~s~~. Finally, two fields are irrigated with water from Tongue River tributaries (Prairie Dog and Otter Creek), and two non-Tongue River Drainage reference fields are irrigated with Yellowstone River and Big Horn River water.

Tongue River irrigation water is of high quality, which except for occasional exceedances of EC near the mouth of river during low flows, meets irrigation water quality standards recently adopted by the State of Montana (Figure B). Irrigation water has year-to-year variations in EC and SAR, which are mostly related to the rate of river flow, with EC and SAR declining in higher flow years such as 2003 and 2005 and increasing in dry years such as 2002, 2004, and 2006. The EC and SAR increase somewhat in the downstream direction below the Tongue River Dam. An overview of the hydrology and water quality of the Tongue River watershed is presented in a companion report, *The Tongue River Hydrology Report*, prepared under this same contract by HydroSolutions Inc.

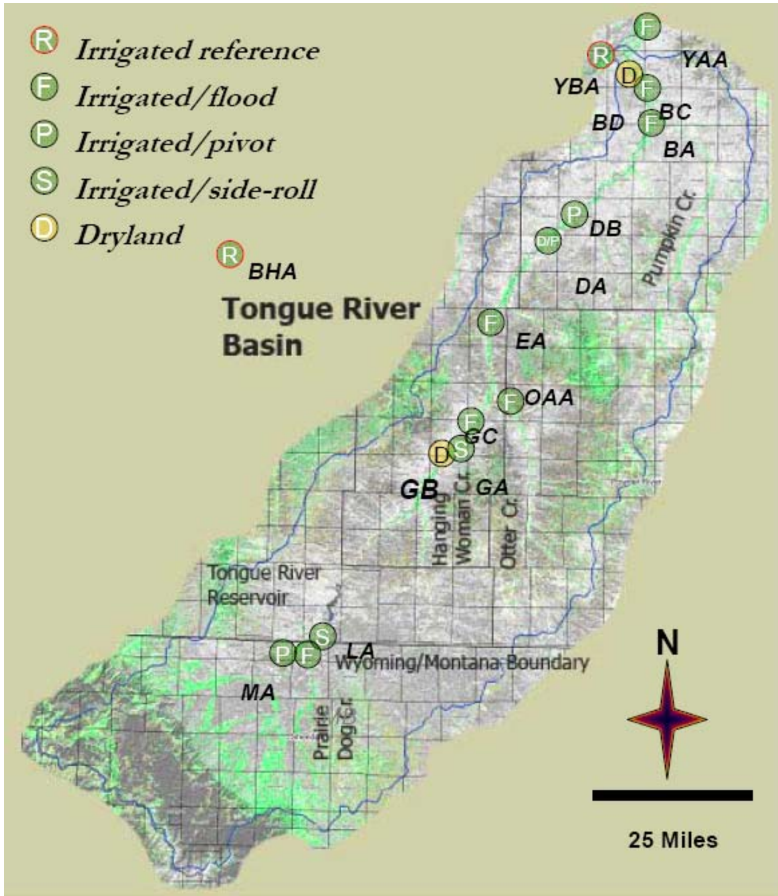

Figure A. Location of fields used in the Tongue River AMPP.

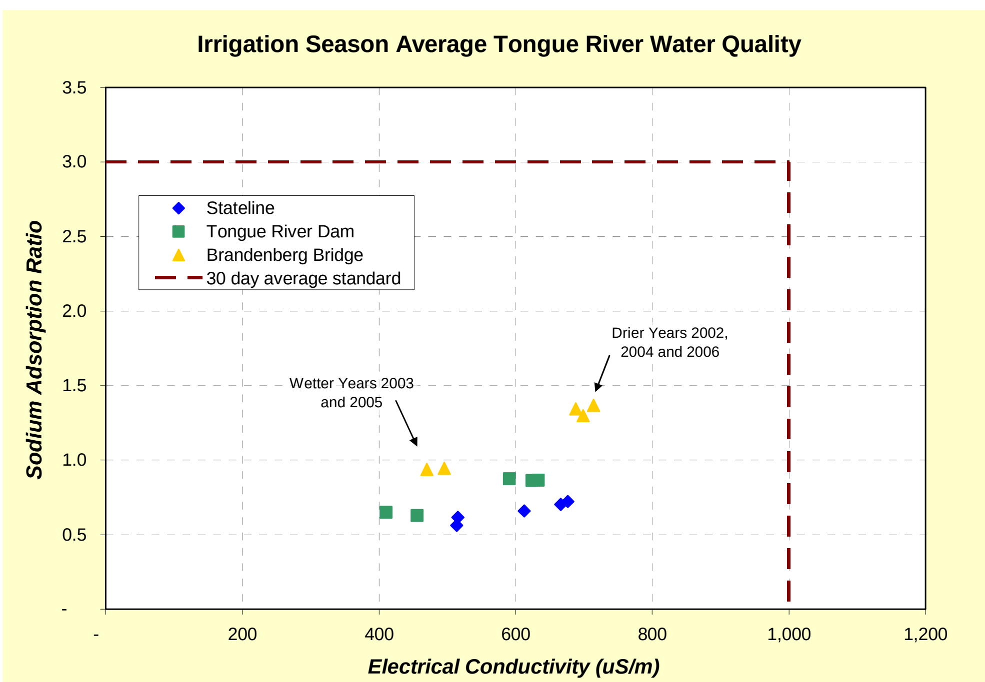

Figure B. Calculated average Tongue River irrigation water quality in 2002 through 2006.

Variation in Crop Production & Mineral Content of Forages

Documented crop yields for 2003 were based on grower records. During the 2004 through 2006 growing seasons, plant clippings were taken in Tier 2 fields at every soil sample collection point (GPS waypoint) prior to each forage cutting. Plant material from each field was dried, if normally hayed, weighed, processed through a chipper/shredder, and a representative sample sent to a laboratory for analysis. Crops that were ensiled were process immediately to replicate this harvesting process. Yields were adjusted to 12% moisture content for hayed forages and 70% for corn silage. Feed analyses include nutritional parameters and as well as a complete mineral determination (sodium, calcium, sulfur, etc.).

Large differences in forage yields were evident between sites, but yield variations showed no systematic changes through time. A myriad of factors have affected forage crop yields including age of stand, quantity of irrigation water used, fertilizer applied, weed control, climate, and number and timing of cuttings. Although it is difficult using existing data to precisely determine causes of yield variations among AMPP fields, it is clear that:

- Yields are comparable to average irrigated forage production from Big Horn, Custer, and Rosebud Counties in 2003 through 2006.
- Yields do not show a decreasing trend between 2003 and 2006.
- Yield differences are not correlated with average salinity (Figure C) or sodium levels.
- Yields appear to be limited to around 2 tons per acre in fields where less than 8 inches of irrigation was applied.
- Yields in 2004 were reduced by a late killing freeze on May 12.
- On certain years at various locations, alfalfa yields have been reduced by severe alfalfa weevil infestations prior to first cutting.

No changes in sodium content of forages were detected in 2004 and 2005 due to CBNG development. In 2004 and 2005, forage sodium contents were relatively constant in fields that were in the same crop both years. However, for 2006, eight of the ten fields that have had the same crop for at least two of the three years had decreased in sodium levels (Figure D). Alfalfa at the EA site, near Brandenburg Bridge, increased in sodium substantially in the third cutting, which resulted in the 2006 average sodium content for the field to increase compared to 2005. Site BA, planted to corn for silage in 2004 and 2005 and spring wheat in 2006, was the other site that did not have a sodium decline. Sodium levels were the same for both years of corn silage (0.02%). The spring wheat grain was not analyzed for feed value and mineral content.

With elevated sodium levels in CBNG water, increases in sodium content of forage crops should be among the first effects of CBNG activity because plants take-up what is applied to the soil. Alfalfa at site MA, which is located near most of the CBNG water discharge sites, had a sodium level of 0.07% in both 2004 and 2005. It then declined to 0.04% in 2006. LA, which is also near most of the discharge points, has had sodium decline from 0.06% in 2004 to 0.05% in 2005 and to 0.04% in 2006. Sodium decline in 2006 forages could be attributed to ESP decline in the fall 2005 soil samples (Figure M).

In 2004, the highest sodium level (0.47%) was in hay barley at YBA, which is irrigated with Yellowstone River water. In 2005, YBA also had the highest sodium level (0.59%) which was hay barley under seeded to alfalfa for first cutting. However, sodium was only 0.17% in the pure alfalfa hay harvested for second cutting in 2005. For 2006, three cuttings of alfalfa contained an average of 0.14% sodium. Site DA, which had the highest soil EC and ESP, had a sodium level of 0.27% in the 2004 alfalfa but only 0.02% in the 2005 corn silage. Sodium levels have varied between AMPP locations due to soil EC and ESP as well as crops being grown (Figure E).

Another example of plants absorbing what is applied to the soil was that mineral content changed at individual AMPP locations in response to fertilizer applications. In 2004, phosphorus in alfalfa hay at YAA site increased from 0.20% to 0.29% in the first cutting to second cutting, respectively. The landowner applied 20-100-0 (actual N-P205-K2O) per acre after first cutting. Normally, phosphorus levels decline from first to third cutting.

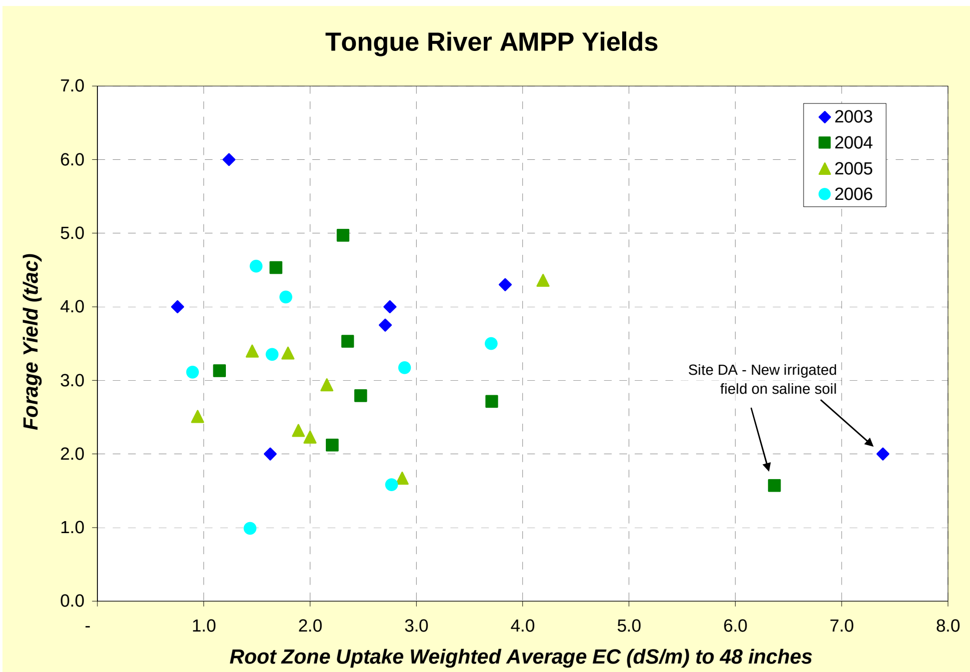

Figure C. Comparison of AMPP forage yield to average root zone salinity (EC dS/m) in 2003 through 2006.

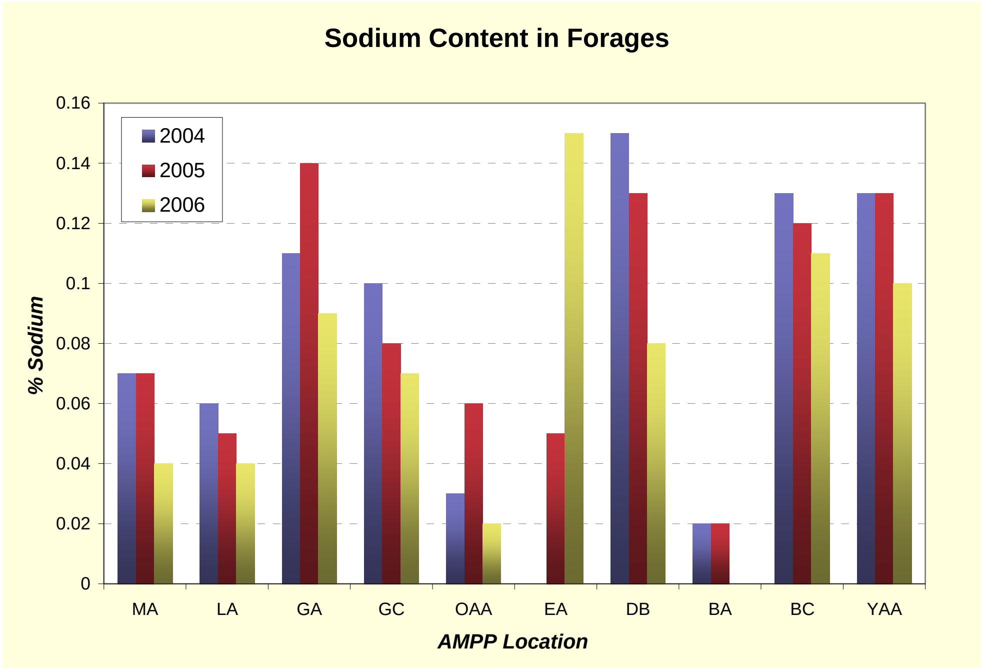

Figure D. Comparison of sodium content in forages in fields that have been planted to the same crop for at least two out of three years, 2004 to 2006.

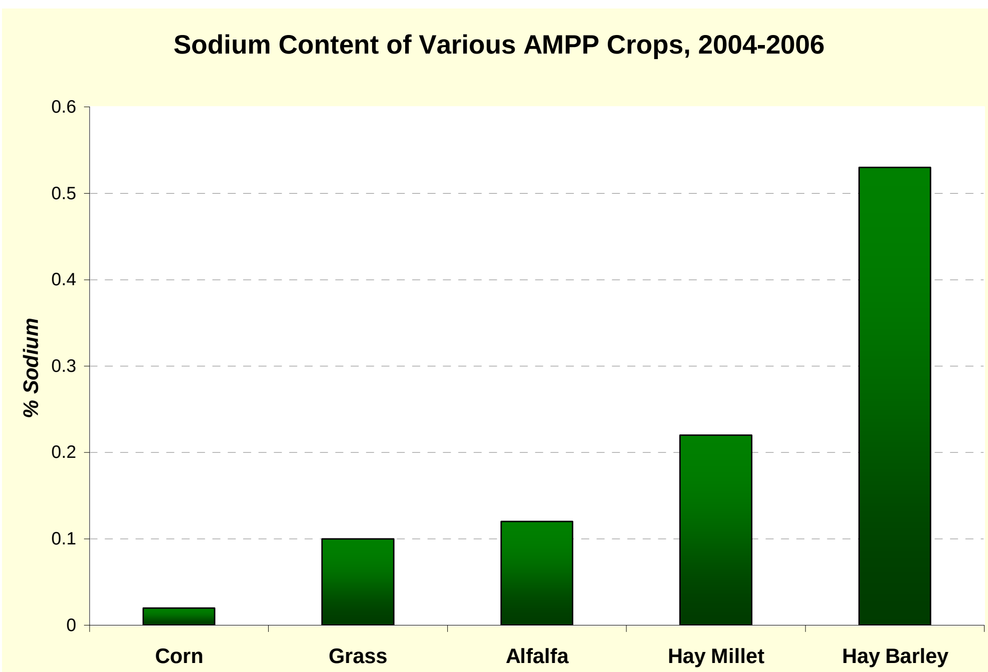

Figure E. Average sodium content of AMPP forages harvested, 2004 to 2006.

Properties of AMPP Soils

Irrigated Tongue River soils exhibited both similarities and differences. All AMPP soils were derived from recent floodplain sediments and showed characteristic horizontal layering with slight differences in clay content and organic matter. All soils had abundant lime at every-depth, indicative of their geologic youth. Additionally, all soils were lower in clay content and expansive clays than is conventionally believed to be the case in southeastern Montana.

Overall, irrigated fields in the Tongue River Drainage were medium-textured, meaning they had nearly equal proportions of sand, silt, and clay. Soil texture is important in irrigated soils because soils with too much clay may have low permeability and poor drainage. However, soils with too much sand may drain too rapidly and will have low water and nutrient-holding capacities. Tongue River soil textures were classified as loam, clay loam or silty clay loam (Figure F).

Clay mineralogy of irrigated soils affects their susceptibility to excess sodium levels. For example, Bauder (no date) illustrated the dependence of sodium sensitivity to clay mineralogy based on irrigation water quality guidelines developed by the United Nations (Table A). According to Bauder, SAR levels in irrigation water less than 6 do not create a problem if the dominant clay mineral is smectite. This "safe" level of SAR increases to 8 for illite-dominated soils and to 16 for kaolinitic soils. Irrigated Tongue River soils have a mixed mineralogy (Figure G) in which kaolinite is the most abundant clay mineral followed by illite. Based on UN irrigation water quality guidelines, a SAR level in irrigation water up to 8 would be safe to use on Tongue River soils. The current Montana water quality standard for SAR on the Tongue River is 3.0 (30-day average) or 4.5 (instantaneous) during the irrigation season.

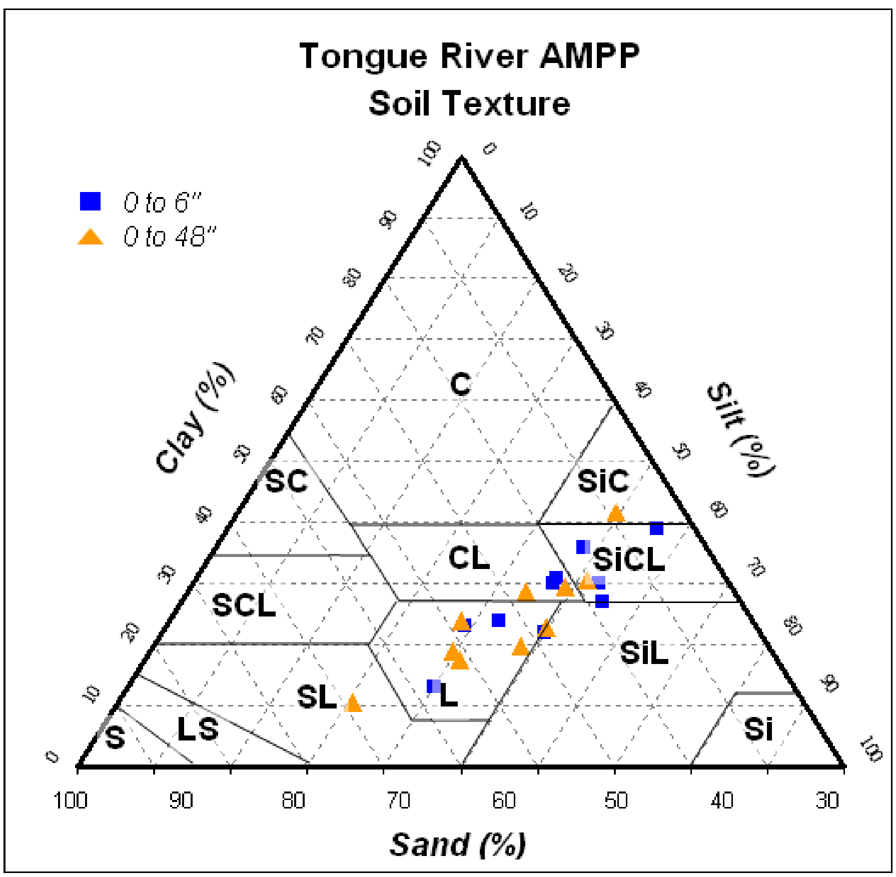

Figure F. Texture of surface soils and the average root zone texture of AMPP soils.

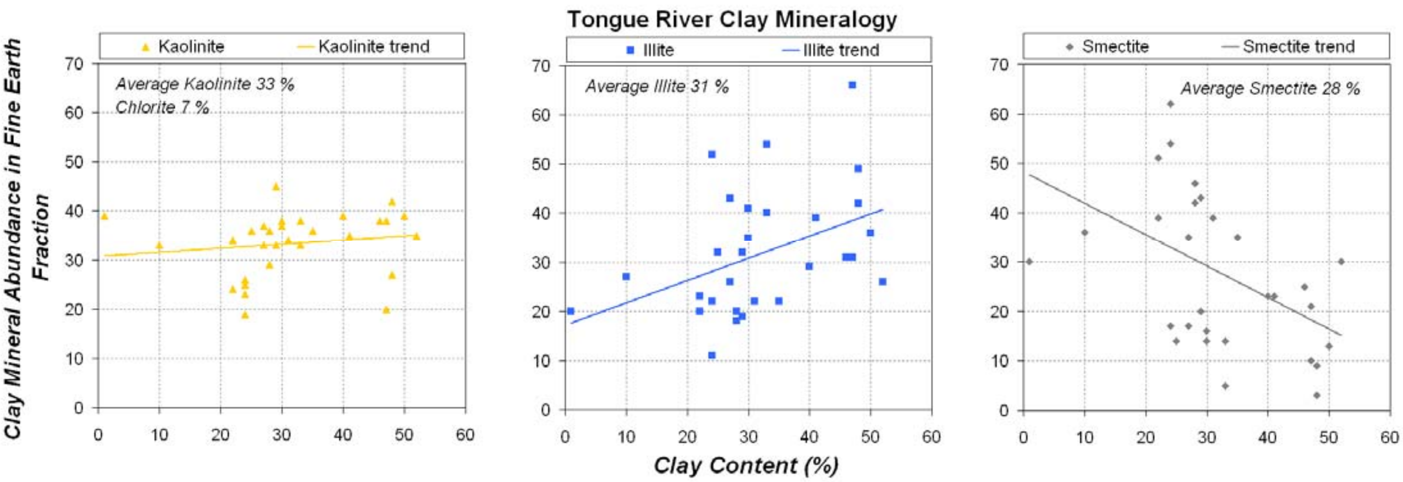

Figure G. Clay mineral abundance in AMPP soils.

Table A. Guidelines for irrigation water quality established by the World Food and Agriculture Organization (after Bauder no date).

	Intensity of Problem[1]		
Water Constituent	**No Problem**	**Moderate**	**Severe**
Salinity (decisiemens/meter)	<0.7	0.7-3.0	>3.0
Permeability (rate of infiltration affected) by Salinity (decisiemens/meter)	>0.5	0.5-0.2	<0.2
Adjusted SAR; soils are: Dominantly smectites	<6	6-9	>9
Dominantly illite-vermiculite	<8	8-16	>16
Dominantly kaolinite or sesquioxides	<16	16-24	>24

From Bauder (no date)

Source: Modified from R.S. Ayers and D.W. Westcott, "Water Quality for Agriculture," Irrigation and Drainage Paper, 29, FAO, Rome, 1976; rev. 1986.

[1]*Based on the assumptions that the soils are sandy loam to clay loams, have good drainage, are in arid to semiarid climates, that irrigation is sprinkler or surface, that root depths are normal for soil, and that the guidelines are only approximate.*

Lastly, surface samples collected from 0 to 6 inches in irrigated Tongue River soils were, with one exception, non-saline and non-sodic (Figure H). This means that Tongue River soils do not exhibit an adverse accumulation of soluble salts or sodium, even though these conditions are common elsewhere in southeastern Montana soils (Bauder, no date). The single exception was site DA, which is located near the mouth of an ephemeral tributary to the Tongue River. The soil was brought under irrigation in August 2003. During the first full irrigation season (2004), enough salts were leached from the 0-6 inch depth that the soil was no longer classified as saline.

Statistical Variation in AMPP Samples

Statistical analysis was performed to determine whether there were any significant changes in soil chemical properties during the time spanned by the five sampling events. All measured soil properties exhibited significant statistical variation between AMPP sites and also differed according to soil depth. However, only a few soil properties significantly varied with time. These included soil pH, CEC, ESP, and lime content. Some of these apparent variations may be due to analytical differences associated with laboratory techniques.

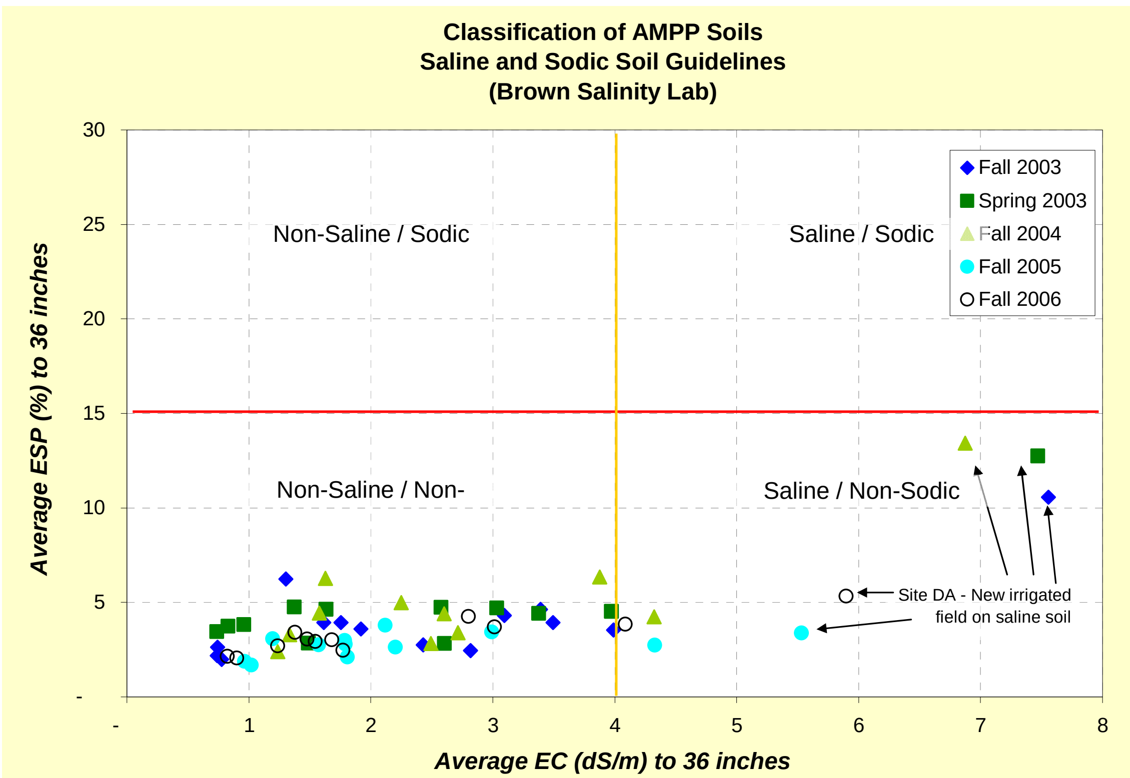

Figure H. Salinity and sodium levels in irrigated Tongue River soils in fall 2003, spring 2004, and fall 2004 through 2006.

Variations in Soil Properties Related to Soil Depth

Statistical analysis showed that all soil properties exhibited significant variation with soil depth and between locations. Additionally, the pattern of change in soil properties with depth tended to differ between sites. While changes in soil properties with depth differed greatly from site to site, the "average" relationship between various soil properties and depth accurately portrays the general depth trends. For example, clay content tended to be higher near-surface than at depth, which is typical of floodplain deposits. Conversely, soil pH was slightly lower near-surface than at depth, which is typical of most western soils. At depth, abundant lime tends to control pH around 8.0, while closer to the soil surface, organic matter causes a slightly lower pH.

Average EC increased with depth to about 36 inches, where the maximum average value of 4 dS/m occurred and then decreased to around 2.5 dS/m at 8 feet in depth (Figure I). The increase in EC that occurs with depth is typical of both dryland and irrigated soils in semi-arid climates. Infiltration of rainwater and low EC irrigation water tends to maintain low EC levels near the surface. As plant roots extract water from the soil, they absorb water and exclude most soluble ions causing a progressive accumulation of salts. Roots are primarily distributed throughout the upper 3 to 5 feet of soil, causing a build-up in EC near the base of the root zone. The difference between the top and base of the root zone provides an indication of the amount of water that percolates through the soil. When this quantity of water is expressed as a percentage of applied water, it is called the "leaching fraction" (LF) in irrigated soils. Estimated average leaching fraction for AMPP soils was 11%.

ESP (Figure J) also increased with increasing depth in a similar manner to EC, except that the maximum average ESP occurred at a depth of 3 to 5 feet, somewhat deeper than for EC. Soil water has higher EC and ESP deeper in the soil profile due to the pattern of water removal by plant roots. Changes in sodium status with depth are a bit more complex, because as salts are concentrated by plant water uptake, soil minerals enriched in calcium and magnesium tend to form, causing a shift towards higher proportions of sodium vs. calcium and magnesium, resulting in a higher SAR and ESP.

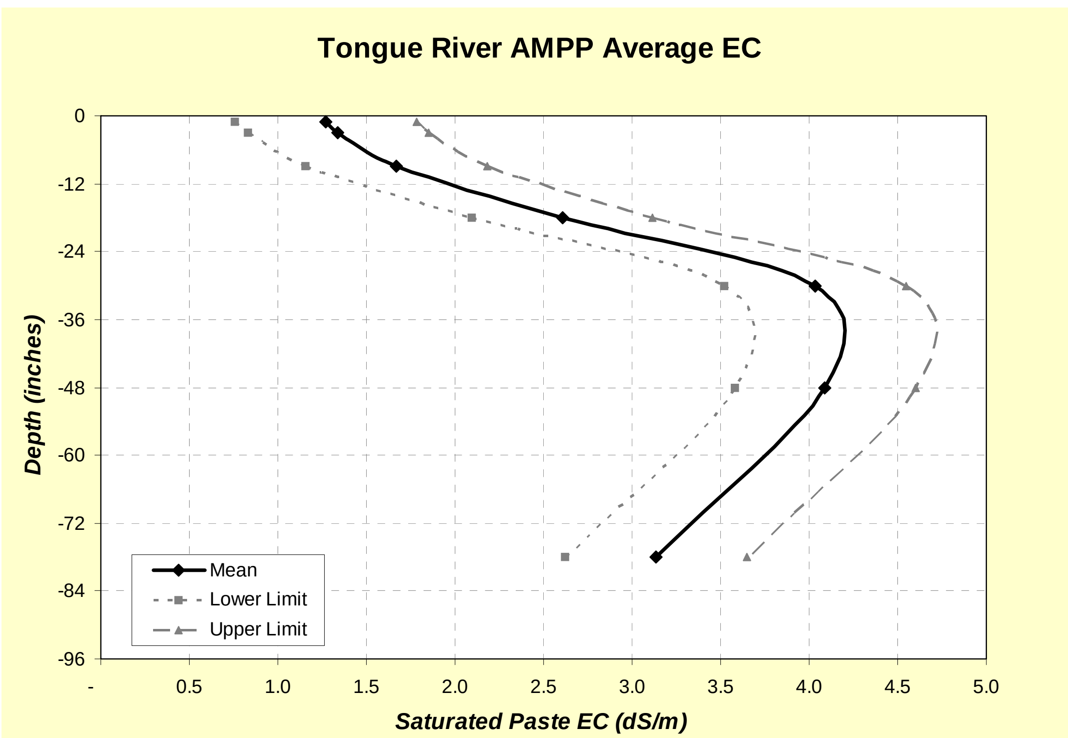

Figure I. Trend in average EC with depth in composite samples from fields irrigated with Tongue River water.

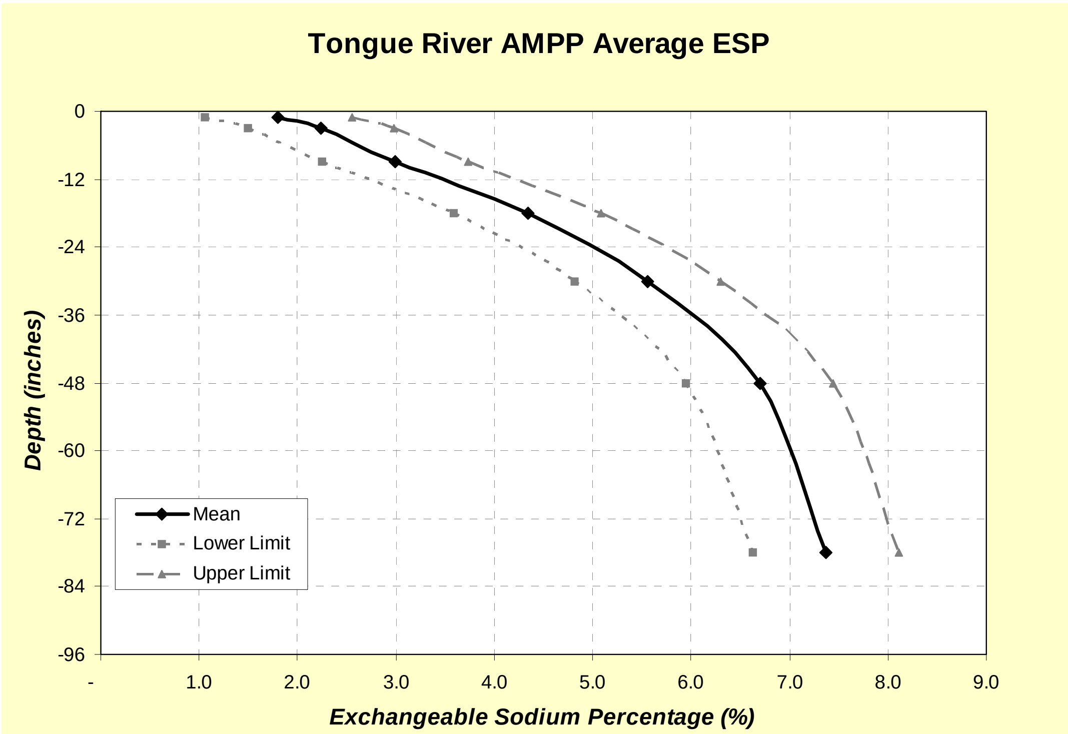

Figure J. Trend in average ESP with depth in composite samples from fields irrigated with Tongue River water.

Comparison of EC and ESP in AMPP Fields through Time

EC and ESP (Figures K and L) are properties that are more sensitive to changes in management, water quality, and climate than most other soil properties such as texture. Consequently, if after a period of one or more growing seasons, changes in irrigated soils occur due to CBNG activity, increases in EC and/or ESP will be detected. No statistically significant change in root zone EC was evident through time. ESP also did not change from fall 2003 to fall 2004; however, average ESP **decreased** from 5.5 to 3.1 between fall 2004 and fall 2005 and remained low (3.7) in fall 2006.

Some individual fields exhibited changes in ESP due to site specific agronomic management even when no basin-wide trends were evident. For example, ESP at 0 to 2 inches decreased from fall 2003 to fall 2004 at the BHA reference site which is irrigated from the Big Horn River. The field was in sugar beets in 2003 and had high soil moisture at harvest. Once the beets were defoliated and dug, soil moisture and salts were drawn to the surface by evaporation, leaving salts behind. The fall 2003 ESP was 6.1 in the 0 to 2 inch depth. Then in 2004 and 2005, winter wheat was in the field. The wheat canopy was more open than the beet crop, therefore the soil surface dried slowly as the crop matured, which reduced surface salt accumulation. Fall 2004 and 2005 ESP values were 2.1 and 3.3, respectively. BHA was in beets again in 2006. Fall 2006 ESP at 0 to 2 inches was 8.2 even though over four inches of precipitation was received between the 2006 final irrigation in early September and harvest in late November. The increase in ESP is unique to the 0 to 2 inch depth following beets. ESP for 0 to 6 inches was 4.2 (beets), 2.0 (wheat), 2.9 (wheat), and 2.6 (beets) from fall 2003 to fall 2006, respectively.

Depth-weighted average EC in the upper 36 inches is shown in Figure I. Average EC for all soils was around 2.5 dS/m and most individual fields fell close to this value. Sites GC, DB, and BA had lower than average EC, probably owing to application of a greater quantity of irrigation water at these sites. Site DA had higher than average EC, which was probably caused by contributions from tributary runoff onto this field that was non-irrigated prior to 2003.

Depth weighted ESP (Figure J) averaged just over 4 % and all but one field had ESP values close to this value. This exception was site DA, a field recently brought under irrigation that also had high EC values. Greasewood, a common indicator of sodium-enriched soils, is abundant in the vicinity of this field near the mouth of Foster Creek.

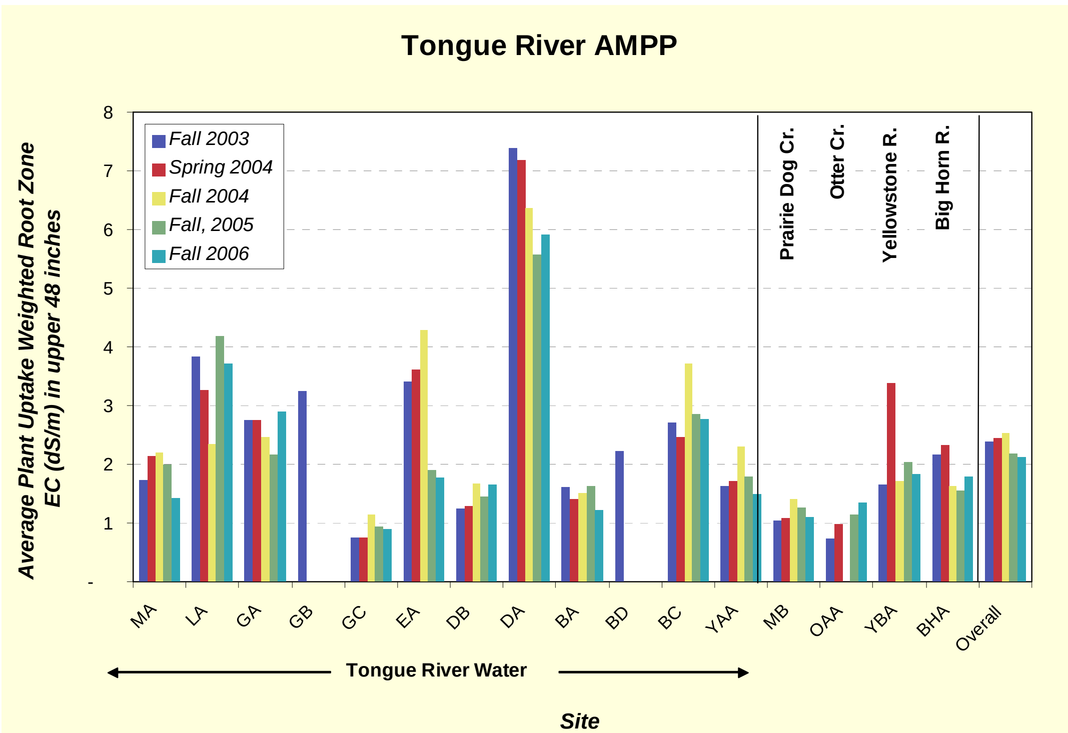

Figure K. Root zone water uptake averaged paste EC (dS/m) to 36 inches in AMPP sites for each sampling period.

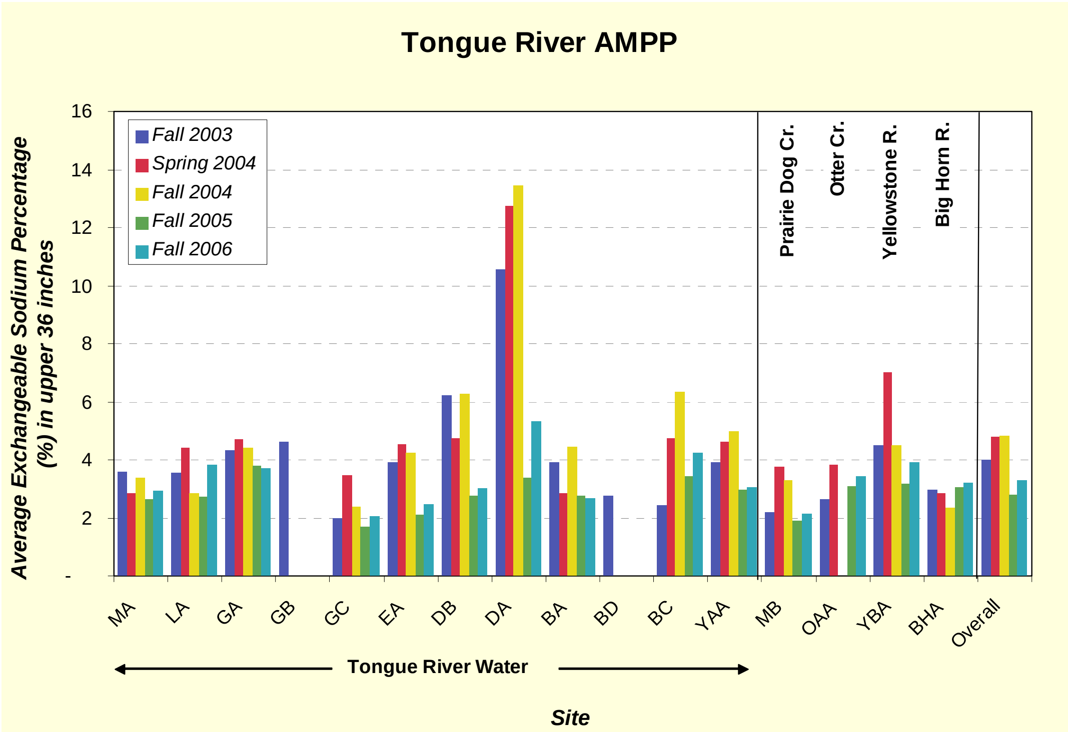

Figure L. Average ESP (%) to 36 inches in AMPP sites for each sampling period.

Changes in AMPP Soil through Time

A statistical analysis was performed to determine whether there were any significant changes in soil chemical properties during the time spanned by the five sampling events (October 2003 to December 2006). If CBNG activity was having an adverse effect on irrigated Tongue River soils, then an increase in average EC and/or ESP should have been evident. Statistical analysis was confined to composite samples from the 10 sites that are irrigated with Tongue River water. Although no statistically significant change in EC was evident, ESP decreased significantly between 2004 and 2005 samplings (Figure M). The decrease is attributed to an increase in growing-season precipitation and available irrigation water in 2005.

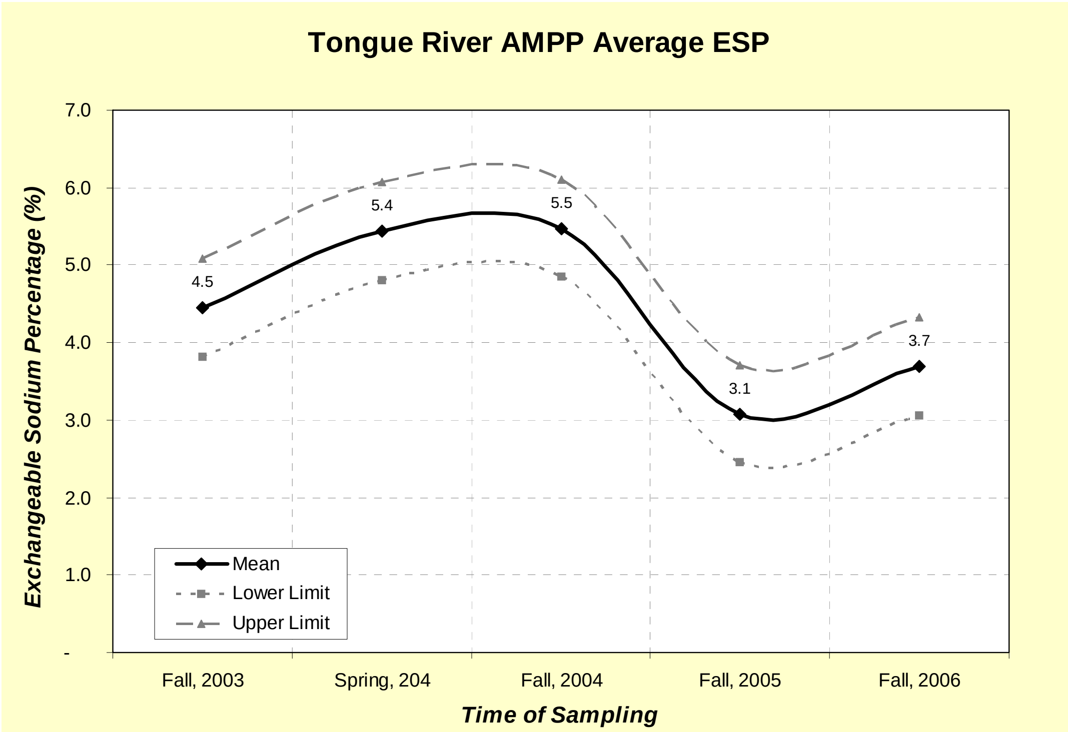

Figure M. Trend in average exchangeable sodium percentage from composite samples irrigated with Tongue River water.