On April 9th there was a teleconference call with the focus being on Impoundments and Managed Irrigation. As all of the topics were not able to be covered, and there was a substantial amount of material to be discussed, it was determined that those folks who were available would meet in conjunction with the IWG meeting on May 10. These notes cover both of these meetings. Red indicates agenda, black notes from the meeting, and blue Andy's comments.

Notes taken and prepared by Andy Bobst.

Agenda/Notes

CBNG Interagency Hydrology Task Group
Impoundments/Managed Irrigation Teleconference
Monday, April 9, 2007; 0900

0900 Introductions/Start Meeting

The following people were on the call:
Andy Bobst, BLM, Miles City
Brian Bohm, ALL Consulting
Bud Stewart, WY G&F
Kevin Fredrick, WDEQ, Cheyenne
Robert Mitchell, BLM, Miles City
Tom Reid, MDEQ, Helena
Don Fisher, WDEQ, Sheridan
John Wheaton, MBMG, Billings
Terry Brown, Poudre Valley Environmental Sciences, Inc.
Mike McKinley, BLM, Buffalo

- Round Robin Agency Updates/Information Sharing

Andy:
The MT BLM continues to work on the SEIS. The comment period will close on May 2, 2007.

Don:
There is more of a focus on UIC type managed irrigation (sub-surface drip). Some work in horizontal wells also.

John:
Dave Lopez (MBMG) has developed a map of sub-surface channel sands in the MT portion of the PRB. These would be potential injection zones. This has gone to the printer. It shows 6 different laterally extensive channel sands that map well. Each one is dendritic shaped (paleo-stream courses). Results show that ~9% of the MT portion of the PRB is underlain by one or more of these zones; however due to their dendritic nature a fair portion of the basin is "near" (not defined) one of these. The maps are based on well logs from oil wells, and the data is somewhat sparse but reasonable. Used mainly SP and resistivity with a little gamma.

The annual groundwater report is being pulled together, and should be out soon. We are starting to link in with the WY-GS so that in the future companion reports or one report can be prepared.

Tom:
Have some new issues before the MT legislature with regard to discharges to ephemeral drainages and impoundments. 383 has been tabled; however 407 is to the floor. 407 is the "Emergency stock water" bill which would allow CBM water to be discharged to existing impoundments (this bill was eventually passed by both houses, but then vetoed by the Gov. ALB)

- Overview of Impoundment Research
  - Don Fisher (WDEQ)

Don:
With DOE and ALL the WDEQ has been looking at older impoundments (3-4 years old). 3 on Prarrie Dog Creek (Tongue), ~6 on LX Bar (Powder). Monitoring wells were installed last spring and developed. Sampling occurred in the summer. Are now getting data back, and surveying the wells in to confirm gradients. Preliminary results do not indicate major problems. The TDS is not unreasonable. In one with a class 4 aquifer the pH has gone down (from ~7 to 3) and this appears to have mobilized metals; TDS went from 6,500 to 12,000 mg/L. This site may need more monitoring wells to pick out what exactly is happening. The rest appear to have flushed over this period of time, with little change between up and down gradient. Met with ALL ~ 6 weeks ago, and should have a report out this summer.

WDEQ is also working with Hydrosolutions to examine the WDEQ's new impoundment database. Tom Osborne will present at ASMR in Gillette. This basicly shows that few of the impoundments come out of compliance, and those that do tend to come back in pretty quick. There are about 150 impoundments with compliance monitoring (above Class 3).

Mike:
The sealing of pond floors due to the high SAR may cut off infiltration.

John:
We should be able to see this in groundwater elevations.

Don:
Nance is also looking at impoundments in the Hanging Woman Creek drainage.

John:
The UWY approach may be useful.

Andy:
Lets follow up on the pond sealing issue.

Mike:

Data is not clear but it occurs to occur quite often.

Don:
It depends on the site. Sandy sites tend to work well while clay is an issue.

John:
Are operators doing particle size analysis?

Don:
If they are, they are not submitting it to WDEQ.

John:
In our studies in MT it appears that you do not need much clay to get it to seal up. 10% will do it given enough time.

Don:
I think its going to be very heterogeneious. In some cases 10% will seal, in others it will work well.

John:
Agreed.

Don:
This gets back to the channel sands a bit as well. They are likely to be rather heterogeneous as well.

John:
The depositional setting is similar along their length, though not on cross section. So we can track them longitudinally, but it would be good to combine that with some injection tests.

Andy:
On the ponds, I think that the chemistry of the soils is going to be important. If Ca-Mg salts are present to offset the high SAR the clays will stay together.

John:
There are some ponds that we looked at that we thought had sealed, but now they are taking water again.

Terry:
The introduction of high EC water (2-4) will open the soil back up.

John:
Could we be getting that from runoff?

Terry:

Sure, we can do that by picking up gypsum.

Mike:
The sealing of ponds is a major issue for may operators.

Terry:
Sure, look at Ayers and Westcott. If you don't have enough EC the pond will seal up.

John:
What if they minimize the amount of water that they put in the pond prior to overland flow?

Terry:
That may help.

John:
If you open the clays back up with high EC water will it take as much water the next time around?

Terry:
Probably not, but it can be close if you only wack it once. You don't see permanent damage if you can still get the water in.

Mike:
How much of a change in infiltration is being seen on irrigation areas?

Terry:
You don't see it on sites where amendments are being used.

John:
What about if there are no amendments being used?

Terry:
It would be expected to be severe, but right now the data from the double ring infiltromiter are poor. We are trying to redo this with a tension infiltrometer.

Mike:
At Skewed it sealed up in 10 months with 20% clay.

- Brian Bohm (ALL Consulting)

Brian:
ALL is working with DOE, MBOGC, and WDEQ on looking at impoundments. In the past we have put together a siting design and construction manual. This was out about a year ago. It was more of a BMP document. Currently we are looking at the sites that Don discussed on Prarrie Dog Creek and LX Bar. At two of the sites we are on the DOE

flight lines (resistivity). We are doing downhole geophysics on these. We are also doing HAS every 2-5' or when there is a change in Lithology. Cindi Rice is doing this work.

Mike:
Cindi is not there anymore.

Brian:
Rick Heley is doing it now.

Mike:
Did you get background groundwater quality data?

Brian:
It appears so. We consistently have 1 well that has distinctly different chemistry. This is believed to be the up-gradient well.

Mike:
What kind of impacts are you seeing?

Brian:
We see changes, but not really big changes. The pond that Don talked about needs to be looked at more closely. We also really need the survey data. Right now the preliminary interpretations are based on drilling data, but there is a lot of heterogeneity. There is no relationship between topography and gradient. The survey work will let us tie things in better. I have to emphasize that you really need to have holes in the ground to figure things out.

John:
One monitoring well may not cover it.

Brian:
True, but if you hit a Class 4 then it is not an issue. One well give water quality, but not gradient.

Don:
For confined or semi-confined situations over Class 3 we require 3 wells to define the gradient. Only one is required if you are in a clear unconfined setting only one well is needed (this is very rare).

John:
You should not be seeing impacts if it is confined.

Don:
True. Really semi-confined.

John:

Is leakage to daylight an issue for DEQ?

Don:
Yes, it creates a violation of WPDES permits if it flows. Often they are installing secondary dams and pumping back to the impoundment. This happened when if follows a clay bed or a permeable zone to the surface.

John:
Is there a vertical to horizontal distance ratio that seems to cause a problem? 1:5?

Don:
We have not looked at it, but it may be useful for getting better siting. Essentially have a setback distance.

Terry:
Has this data been sent to DOE?

Brian:
Yes.

Andy:
What is the quality of the seeps?

Don:
Don't have the data.

Brian:
It really depends on the system.

Mike:
If the water picks up salts/sulfates along the way the TDS can be quite high.

Brian:
We are still doing the write up, but the biggest point is that there needs to be enough information to have good background, and a good sub-surface understanding of the system.

John:
What specific data should be collected?

Brian:
Initial groundwater quality, soils, SPE, infiltration rates, and stratigraphy would be good starters.

Don:

The operators tend not to do a lot of up front work. If one dose not work they just build more. Why not invest more up front for sites that really work?

Brian:
It seems to be partly cultural.

John:
What is our responsibility to provide guidance? SPE, particle size, strat tests…?

Don:
We have recommended this already. Some operators do it, some don't.

Brian:
We have worked with Fidelity and they seem to do well at it.

Don:
Geophysical information from the well bores would be good, but they are not doing that. SPE could be obtained from the well bores as well.

Mike:
The problem is that you can do all the up front work and still have it not work.

Andy:
I think the objective should be to avoid preventable problems; we can not guarantee success.

Don:
We do flag the monitoring wells where the logs seem to indicate an issue. Clinker layers are a particular concern. Also for a class 3 we can say what we expect will occur. We may recommend non-approval for some sites to the SEO, but the jurisdiction is cloudy.

Kevin:
We encourage operators to look at the DOE flight lines and avoid the hot spots. They still need to do ground truthing, but it is useful.

John:
Preliminary multi-spectral work shows that surface mineral species and concentrations can be determined. At Coal Creek the data looks good, and it may move us toward avoiding preventable problems.

Brian:
We are preparing the report now. Most of the work is on the website and NATC site. The next phase will be tow look at a couple of the sites in more detail. The change in pH is quite interesting.

John:

What would the mechanism be for the low pH?

Don:
Coals-pyrite. H2SO4 lowers pH. Tom Osborne has worked to try to get operators to avoid areas with dry coals.

John:
It seems quite rapid and it is doing it in an alkaline environment. Fe as an oxidizer is interesting. It also seems that it would be hard for it to be very mobile given the alkaline environment.

Terry:
It seems like pyrite is the most likely source, but it should get neutralized rapidly.

John:
Could it be nitric?

Terry:
I don't think so. You can get nitric, but the pH seems wrong. Even with irrigation if you get reduced conditions you can keep metals moving.

Mike:
If it stays in the coal it can stay in solution even if the pH increase (neutralization) since there is no DO. We see this at Skewed.

- John Wheaton (MBMG)

See the WHEATON SLIDES below:

John:
We are looking specifically at the Coal Creek site near UCross. This is an off drainage impoundment which got discharge for a couple of years. This looks at pre and post data, with some info in between.

We looked at the water balance for the pond. There are some gaps in the data, so interpolation was needed. What we see is that ~30% of the water discharged evaporated, and ~70% infiltrated over a 37 Month period. Most of the infiltration occurred over a 7 month period. There was a big drop in infiltration rates after that time. This appears to be due to dispersion of clays from the high SAR water. The % of clays may control the timing of decreased Kz, rather than whether or not the decrease will occur.

Mike:
How was Kz determined.

John:
See slides. Used water balance and water levels. We plan to do slug tests when we can get out there; however effective Kz will be determined by the most resistive units.

Next looking at where the salts went. Samples were obtained at 5' intervals or where there was a change in Lithology. Salts moved down 10-15 feet, to the first groundwater.

Terry:
This looks quite similar to irrigation. Na and Mg move with the water while Ca stays put and pH stays about the same.

John:
The up gradient well shows an increase in head, but little change in EC or SAR.

In the pond the well shows an increase in head, and the EC and SAR go up and stay up. Can't get dilution here at the top of the peak. Also there is not flushing since the pond sealed so the TDS will not even drop to CBNG water levels.

Down gradient the head, EC and SAR went up and then came back down to near initial levels.

In the close cross gradient well head went up by little change in EC or SAR. Further away there is little change in head and no change in EC or SAR.

In the Deeper wells we see an increase in head. This is interpreted as a change in pressure. With TES going up and SAR going down it appears to be the introduction or water in equilibrium with gypsum rather than the introduction of CBNG water. Pushing of water from a lower quality aquifer to a higher quality aquifer. This process seems to be a good parrellel to the coal mine spoils studies where the salts get flushed out.

Don:
Is it temporary?

John:
What we are seeing here occurred in a couple of years.

Don:
It seems that in the coal mine spoils it took longer.

John:
Consider the size of the system. Several miles of newly saturated materials in coal mines, limited cross sectional extent for ponds. Dilution and flushing along with the mineralogy are the keys.

Mike:
What is the total amount of water that moved through.

John:
I will check on it. (Perhaps this should be considered as a pore volume question. ALB)

Terry:
Modeling from the geochemical standpoint did not get a good model. We need to look at the SPE data more carefully. This does not appear to be completely in equilibrium.

John:
We can still use SPE, the DOE survey and multi-spectrial to determine where the poor areas are. We just can't get to exact calculations.

Kevin:
What is the ultimate fate of the salts?

John:
There does not appear to be long distance transport. I think that precipitation is occurring; however we know that dilution is happening as well.

Kevin:
We need to define the extent of the effects.

Andy:
That is what we are trying to do here.

Mike:
There is not enough flow through the system to push it now that the pond sealed. Should not go far.

John:
Eventually it will move out, but it is not likely to be noticeable. It is semi-confined so the gradient is not the best defined.

Kevin:
What about a transport model.

John:
We have looked at it, but have not done it yet.

Andy:
I think we need to focus on the types of impacts instead of getting too tied up in the exact impacts due to the heterogeneity. It is good to do a few sites to get rough magnitude.

Brian:
Geochemically what is the source of Mg?

John:

XRD, optical mineralogy, and geochemical equilibrium modeling have been used to determine that. Epsomite shows up in the model, but we do not see it in XRD or optical. Bloedite (Na-Mg Sulfate) may be a possibility.

Brian:
Gypsum does not seem to work.

Andy:
Models showed that equilibrium with calcite, gypsum, and epsomite provided a good prediction of resultant water chemistry. What is really there may be academic.

Brian:
Should be able to get ratios of availability from the XRD.

John:
SPE seems to work better.

Mike:
Dilutions of ~20:1 can be used to see what the resultant water would look like.

Brian:
What about a comparison of the results using CBM water vs. distilled water?

John:
We looked at this with coal studies and the minerals present really controlled it. There is not enough salt in the coal water to upset the thermodynamics. In the future the critical part is from ~0-25'. Three zones from 30' up would have worked well at Coal Creek.

- Overview of MDEQ Impoundment Regulations
  - Jim Lloyd (MDEQ)

Jim was ill so Tom Reid filled in.

Tom:
MDEQ regulations for impoundments have not been developed under the MT Water Quality Act. They fall into General Provisions. Right now we just have ponds as part of treatment systems, and they are lined.

State waters include surface and groundwaters. For on-channel impoundments there are some requirements from MDEQ under the Water Quality statutes. Off channel CBNG ponds are different. They would be exempt from MDEQ jurisdiction since they are covered by MBOGC.

On Channel impoundments may have the potential to discharge to surface waters. With an existing water body you can create a perennial water body, so the EC and SAR limits for tributaries applies; but not to better than background. With a new impoundment that is to be used solely for the impoundment of a waste associated with oil and gas activities

it would not require a MPDES permit. It could be on or off channel, but it could have no seepage, no outlet, no overtopping, and no discharge to other water bodies. Incidental use by livestock or wildlife would not be disallowed.

Don:
Would there be flood event standards? Some level of required freeboard?

Tom:
Since there is no permit that would govern them there are not design standards; however any discharge would be a violation regardless of the size of the event.

Don:
What about discharge to ephemeral drainages?

Tom:
The MPDES process would determine what could be allowed.

Don:
What ever you discharge at the end of pipe is going to change as it picks up salts.

Tom:
Typically the permits are written with standards at the end of pipe.

Don:
The salts that get picked up along the way are often the bigger issue than the salts in the water initially.

Tom:
Agreed. We are working on this with Fidelity now on Deer Creek. We are looking at having monitoring at other locations along the stream. Also need to consider that the salts may flush out with time. We are not looking at new rules, rather we are looking at developing guidance on how to deal with this.

- Overview of WDEQ Impoundment Regulations
  - Don Fisher (WDEQ)

Don:
The Wyoming Guidelines are on their website. For <2 Acre-feet there is no requirement. The rest require a subsurface investigation. Need to determine the class of use of the underlying aquifer. If it is 1 or 2, no impoundment. Class 3 impoundment can be allowed with monitoring. Class 4 can have impoundment with no monitoring. CBM water is Class 3, so it will never be better than that even if all the salts are flushed out. For semi-confined 3 wells are needed (this is most common) and quarterly monitoring needs to take place. Triggers are set to determine if monthly monitoring is needed. SEO permits the ponds, WDEQ permits the monitoring wells. This applies to all post August 2004 impoundments. We are working to get the data to flow out better from the database. We hope to have it GIS based and available on the website this summer.

Andy:
What is the permitting process for discharges?

Don:
WPDES permits are needed for all impoundment discharges. Impoundments are permitted by SEO, but SEO requires monitoring wells. The monitoring wells are permitted by DEQ. The SEO's permit to construct includes a monitoring requirement, so a compliance monitoring well is designated.

Andy:
I think we need to skip ahead in the agenda to give Terry an opportunity before we run out of time. (This is why it was determined to have another meeting).

- Are there unresolved impoundment regulatory issues?
  - What?
  - Whose jurisdiction are they under?
  - What is needed to resolve them?
    - Additional Research Needs?

- Overview of Managed Irrigation Research
  - Terry Brown (Poudre Valley Environmental)

See BROWN SLIDES below:

Terry:
Irrigation can be done successfully with high SAR water, but you need to keep the EC up. When EC is greater than ~4, SAR is not as much of an issue. We are seeing the salts moving below the root zone so long as there is an adequate leaching fraction. This is why the EC needs to stay up, otherwise the SAR causes the leaching fraction to be lost.

Too much sulfur can be an issue. This can cause the pH go get down to around 4.5 once the HCO3 is dissolved out (loose buffering capacity), at which point Al toxicity becomes an issue.

Treating the water prior to application also seems to work well.

Robert:
In some cases the idea is to monitoring for 2 years after irrigation with CBM water ends. Is that long enough?

Terry:
That needs to be addressed ahead of time. Before irrigation starts. Right now we need studies with more rigorous baseline data. There are a couple of studies going on. Piney Creek and Powder River. At Piney Creek they have applied ~1' of water and the EC and SAR increased at the surface. They need to keep the EC high to keep the soil structure. This has now set for 2 years and now the salts are moving down in the system.

Please note that you NEED to have fairly high EC in the surface to maintain structure (2-3) then the soil can deal with an SAR of ~ 8, and the salts can continue to be pushed down over time. If the soil seals you have real problems.

There are also nutritional issues, which we are still looking at. Also need to keep in mind potential toxicity issues related to sulfur oxidation and the metals which become mobile at low pH (Mn, Fe, and Al in particular).

Don:
How may sites were there in the study?

Terry:
There were 8 repetitions with 7 treatments on each.

We are also looking at the vertical movement of water and salts. Here there was ~1' of water applied from April to September and there was saturated flow to ~3'.

12 noon End of Bridge Reservation

- Don Fisher (WDEQ)

- What regulations are there for Irrigation?

- Are there unresolved managed irrigation regulatory issues?
  - What?
  - Whose jurisdiction are they under?
  - What is needed to resolve them?
    - Additional Research Needs?

Other topics as needed

Tier2 IWG Presentation
- What topics should be addressed
- Who should present

1200 - Meeting Closeout – End of Bridge Reservation

5/10/07
Follow up impoundment meeting
Notes taken off flip chart by Andy Bobst.
Mike provided a DRAFT Jurisdictional breakdown for Wyoming which covered impoundments, LAD, and SDI. This is attached. Please review to ensure accuracy and provide comments to Mike.

Impoundment Issues

1. Discharge to groundwater with salts
    a. Existing WDEQ monitoring requirements (impoundments >2 Ac-ft)
        i. Determine Class of first groundwater.
            1. Less that 50 Ac-ft, first water or 150'
            2. Greater than 50 Ac-ft, first water or 250'
        ii. No CBM impoundments are above Class 1 or 2 groundwaters.
        iii. Impoundments above Class 3 groundwaters require monitoring (typically 3 wells).
            1. Quarterly groundwater levels and water quality.
                a. Trigger values are set, if exceeded go to monthly monitoring.
        iv. Impoundments above Class 4 groundwaters do not require monitoring.
    b. Potential supplemental information
        i. Detailed drilling log
        ii. SPE investigations
            1. EC
            2. Majors
            3. Se
        iii. Conductivity logs with gamma (stratigraphy)

2. Leaking impoundments (with flow)
    a. Problem Avoidance
        i. BLM-NRCS impoundment standards
            1. Work well if followed (SEO)
            2. May help to have COA that requires post construction certification that they have been followed.
        ii. Avoid sites with high permeability units in the sides of impoundments (Clinker, Carbonaceous Shale, Coal…)
        iii. Detailed drilling log
        iv. Conductivity logs with gamma (stratigraphy)
        v. Keep away from head cuts
    b. Post-Problem Enforcement
        i. Dam Stability (SEO): Can shut down regardless of size
        ii. Unpermitted discharge to surface waters (WDEQ): Notice of Violation
        iii. Violation of approved Water Management Plan (BLM)

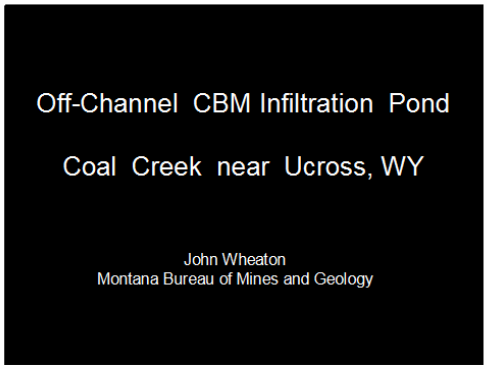
3. Impoundment Reclamation
    a. Need to have consistent expectations
        i. Recontour and revegetate to approximate original contours and species composition is roughly the standard for all agencies.
            1. This may need to be defined better to ensure that implementation is seamless.
        ii. Overbuilt Drainages
            1. SEO requires reclamation if there is insufficient drainage (can not just turn them all over to land owners).
            2. May need to develop a new rule to deal with this.
                a. Limit number of Ac-ft of storage based on Acreage and precipitation?

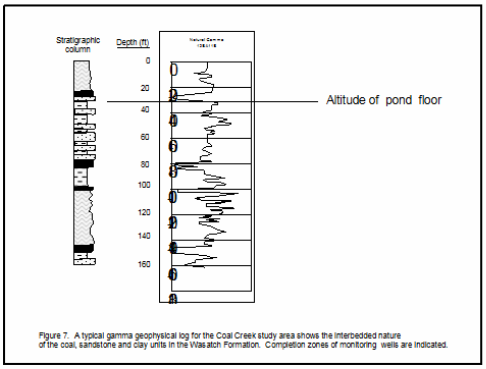
Irrigation Issues

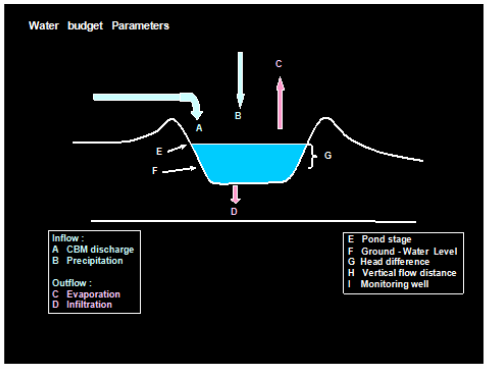
1. Jurisdiction
    a. SDI
        i. DEQ permits SDI as UIC
            1. Require shallow groundwater monitoring to ensure that produced water will not enter surface waters.
        ii. WDEQ, SEO, WOGCC, BLM involved in impoundments which support SDI.
        iii. BLM must prepare NEPA analysis of impacts associated with soils and vegetation
    b. LAD
        i. DEQ permits LAD under Chapter 3
            1. Required monitoring of soils, agronomic application rate, and vegetative cover.
        ii. WDEQ, SEO, WOGCC, BLM involved in impoundments which support SDI.
        iii. BLM must prepare NEPA analysis of impacts associated with soils and vegetation

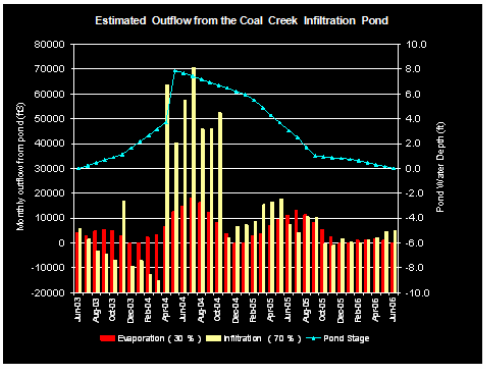
2. Management Issues
    a. Use agronomic rates
    b. Use amendments if needed to keep EC up and SAR down
        i. Maintain the infiltration capacity of the soil
    c. Do not over apply sulfur
        i. Need to maintain a bicarbonate buffer to prevent mobilization of toxic metals

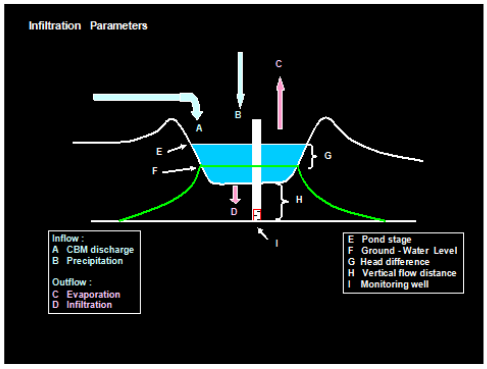
WHEATON SLIDES

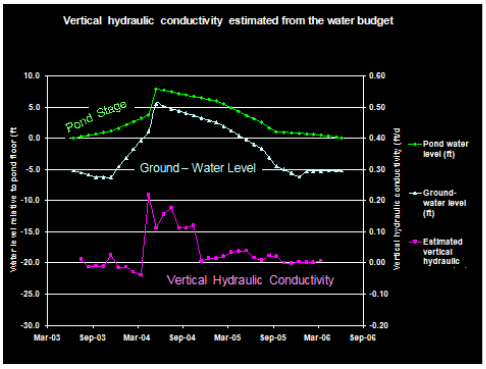




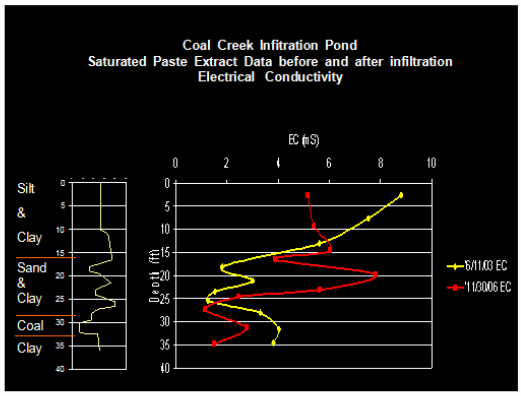


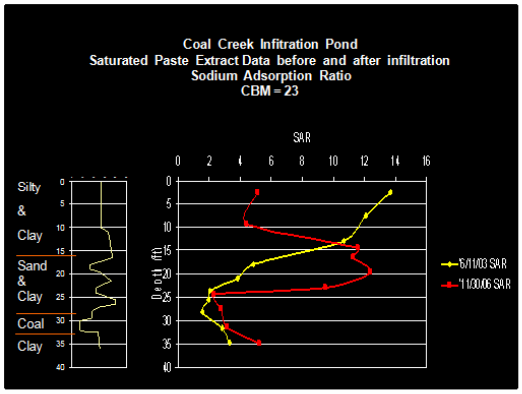


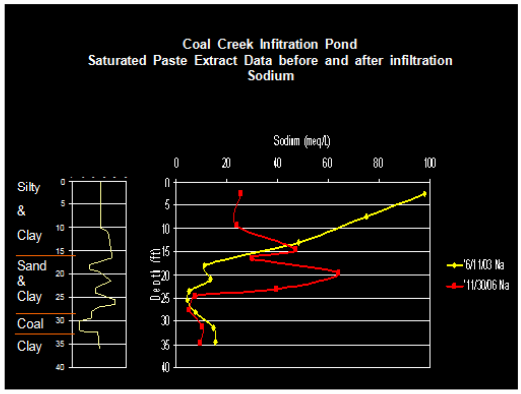


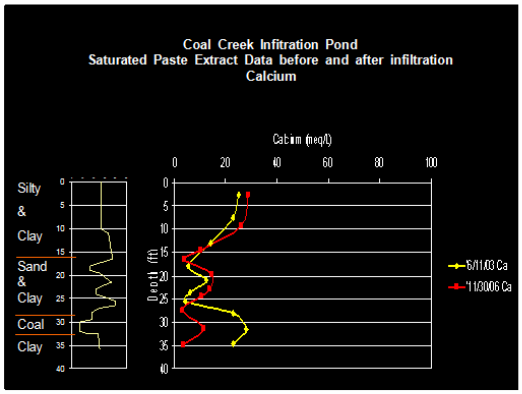


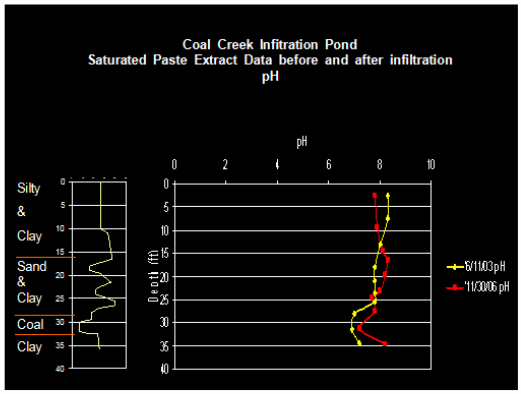
- Very low infiltration rates were seen at all sites after a period of time.
- Percent clay does not appear to relate to the ultimate infiltration rate.
- Percent and types of clays may strongly influence timing of decreased vertical hydraulic conductivity rather than the magnitude.

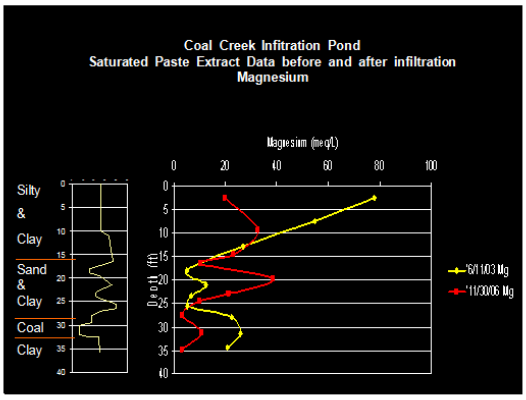


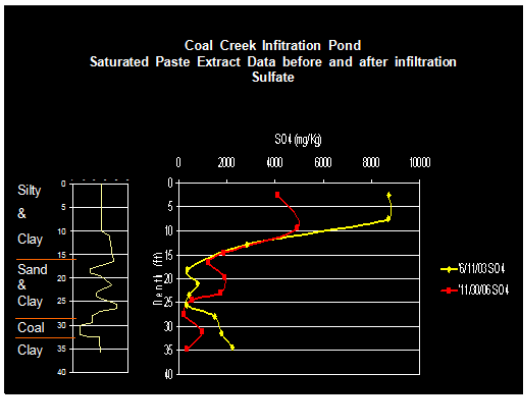




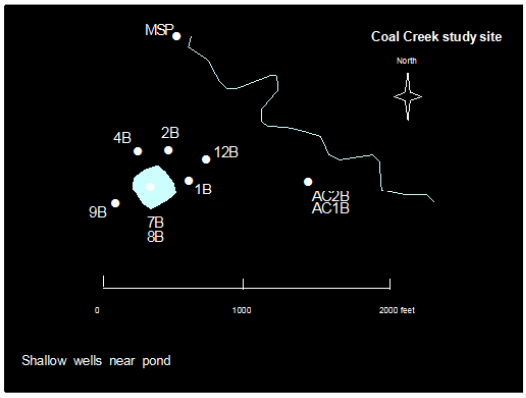


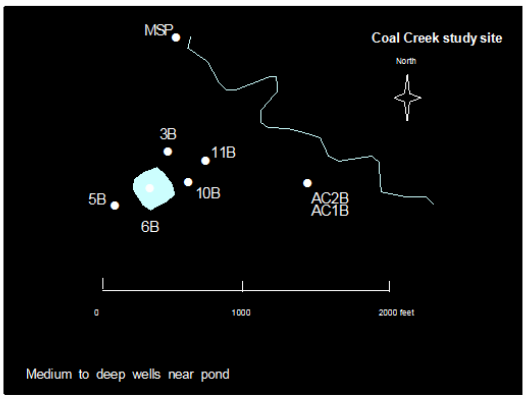


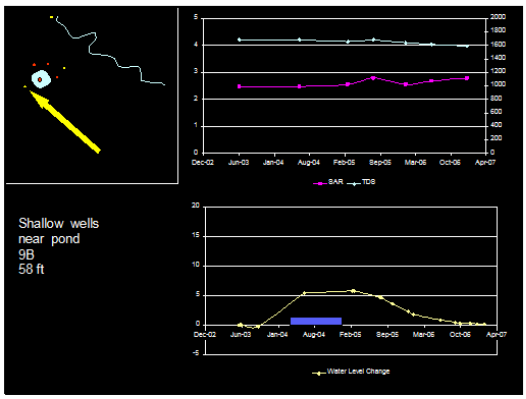


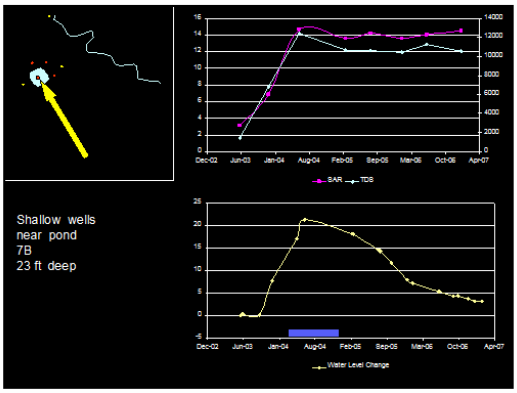


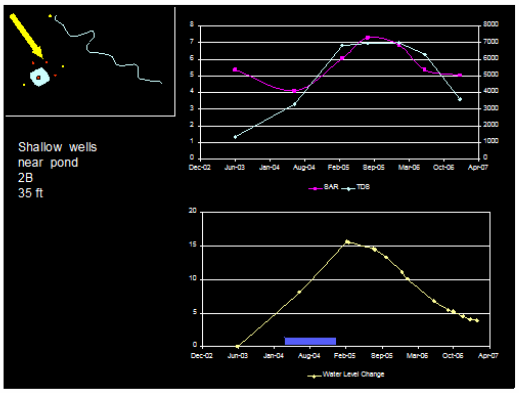
- Salts have been moved down to 20 to 25 ft.
- May be sequestered at that depth.

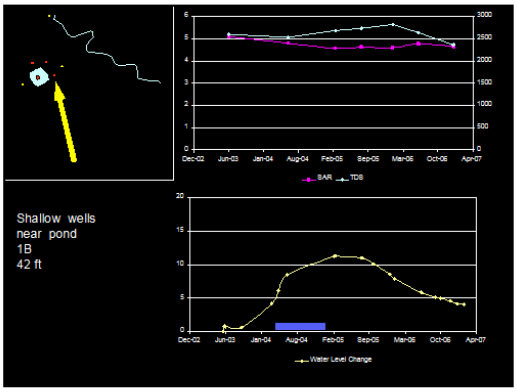


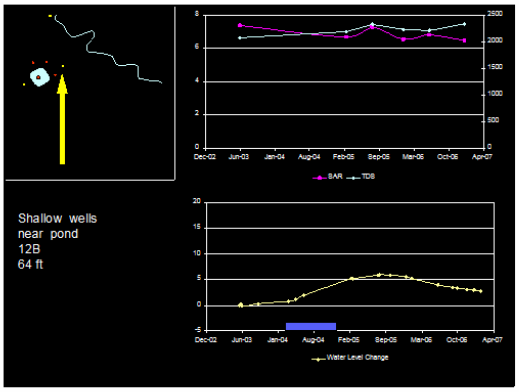


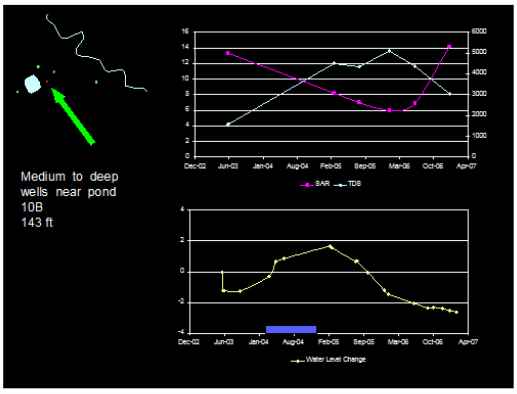












- Limited area of increased TDS.
- Generally TDS increased and is now returning to pre-pond conditions.
- This follows our hypothesis based on coal mine spoils research.

BROWN SLIDES

Overview of Managed Irrigation Research

Terry Brown, Principal Scientist
PVES, Inc
April 9, 2007

Status of Irrigation Practices using CBNG Produced Water

- Managed irrigation can be successful using high SAR water (30^{+} range)
- EC and SAR levels of the soils are higher - using appropriate leaching fractions maintain good soil conditions
- Salt movement below the root-zone
- Use of amendments
  - Fertility issues – pH, elemental toxicity (Mn, Fe, Al), decreased soil buffer capacity
- Water treatment
  - Total treatment or treat and blend

Research Efforts

- Laboratory and greenhouse studies – Bauder at MSU and by Suarez at USSL
- Several field studies have been done without adequate baseline development
- Several field studies have been initiated with good baseline development
  - Cooksley – Piney Creek, partial irrigation season (no water)
  - Powder River - ongoing (partial irrigation season during 2006)

Piney Creek Study – C. Johnston, UW

- Well designed, baseline established
- Study shortened due to the availability of water (1ft or 30 cm of water applied)
- EC and SAR increased
- 2 years after irrigation, salts moving to lower levels in the system – natural conditions
- Conclusion – sodium is not accumulating near the surface and is leaching to lower levels in the soil profile.

Ongoing Powder River Study

- Irrigation Study – beneficial use of CBNG produced water
- Irrigation model simulation – FAO-SWS
- Soil Fertility Concerns
  - Salinity
  - Nutritional imbalances
  - Toxicity
  - Soil buffer capacity
- Reclamation of CBNG produced water impacted site
- Revised method for CEC on impacted soils - ongoing

Plot Installation

- Treatment randomization
  - 7 treatments
- Plot location randomization
  - Using distance and degrees
- Plot layout
- Amendment (Treatment) applications

Initial Treatments

- gypsum 1 (4 T/acre)
- gypsum 2 (6 T/acre)
- gypsum 1 + sulfur 1(1.6 T/acre)
- gypsum 1 + sulfur 2 (0.8 T/acre)
- gypsum 2 + sulfur 1
- gypsum 2 + sulfur 2
- no treatment

Installation of Monitoring Equipment

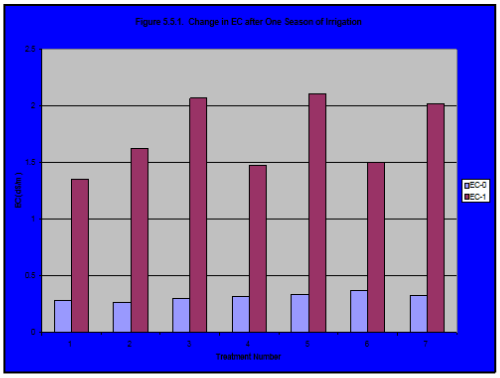
- ECH_2O probes – T, soil water and EC (Decagon)
- Gee Drain Gauge (Decagon)
- Rain gauge (Decagon)
- Lysimeters (planned)

Baseline Development

- Soil sample collection
- Soil sample analysis
  - One sample from each subplot
  - Parameters
    - EC, pH, saturated extract - solution Ca, Mg, Na, percent saturation, SAR (sodium adsorption ratio), particle size analysis, CEC, ESP (exchangeable sodium percentage).
- Infiltration
  - Tension infiltrometer
    - Duplicates for each subplot

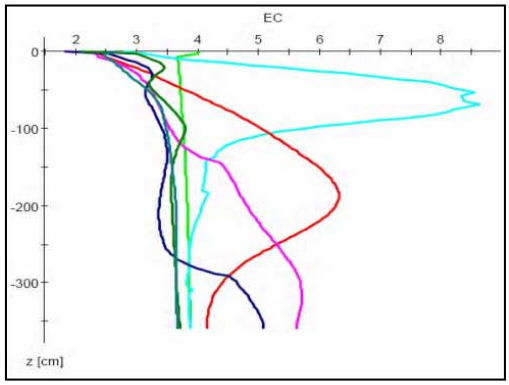
Treatment Application

- Amendment placement
  - Amendments
    - gypsum – Wyoming source (96%)
    - sulfur – Lo-Cat Sulfur (by-product from Wyoming Refining Company, New Castle, WY) – approved for use as an amendment by WDEQ (90%)
  - Materials weighed
  - Hand placement



Irrigation Simulations

- FAO-SWS Model (Unsatchem) – USDA ARS SSL
- Preliminary calibrated for Powder River Basin
- 10 year simulation
- Data collected from the irrigation research site will be used to calibrate the model



Soil Fertility Concerns

- Use of sulfur must be well managed
  - Oxidation forms acid for reaction with HCO_3^{-1}
  - Localized increases in solution of Fe and Mn
    - Impacted plants contain high levels of both
  - Too much will deplete natural calcite levels (pH buffer capacity)
    - pH of some sites < 4.5
    - Al toxicity becomes very important at pH of 4.5

Sample #	Depth	pH	EC	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	SAR	Lime (calcite)	Iron (Fe) (AB-DTPA)	Manganese (Mn)) (AB-DTPA)
	(Inches)		mS/cm	meq/L	meq/L	meq/L		%	ppm	ppm
NP-1	0 - 6	4.4	3.45	32.0	6.86	12.8	2.9	0.6	166	37.3
NP-1	6 -12	5.6	4.60	21.8	17.2	34.9	7.9	1.0	25.9	8.90
NP-2	0 - 6	7.6	3.50	5.55	1.60	32.9	17	2.4	11.5	4.90
NP-2	6 -12	7.9	4.15	11.4	3.80	38.3	14	2.5	4.72	1.66
NP-3	0 - 6	3.5	4.69	22.1	14.4	36.1	8.4	0.2	451	60.8
NP-3	6 -12	6.1	4.12	27.8	9.65	26.7	6.2	1.1	14.4	6.60
NP-4	0 - 6	5.1	3.24	26.1	7.23	16.6	4.0	0.7	76.7	27.2
NP-4	6 -12	7.7	4.16	23.2	5.86	28.7	7.5	5.4	2.07	0.83
NP-5	0 - 6	5.3	4.34	18.5	10.4	33.5	8.8	0.9	41.5	20.2
NP-5	6 -12	7.6	4.20	11.7	10.2	39.4	12	1.7	4.71	0.94
NP-6	0 - 6	6.7	3.20	20.9	4.13	18.5	5.2	1.4	13.3	6.64
NP-6	6 -12	7.2	3.10	17.1	6.40	19.7	5.8	1.2	3.47	0.95
NP-7	0 - 6	3.8	3.75	26.4	9.20	17.8	4.2	0.4	282	55.1
NP-7	6 -12	7.0	4.18	25.2	12.5	27.7	6.4	1.5	6.55	2.85
NP-8	0 - 6	7.9	1.39	1.95	0.54	13.5	12	1.5	8.35	1.43
NP-8	6 -12	8.3	1.51	1.99	0.70	13.5	12	1.5	5.29	0.83
NP-9	0 - 6	7.5	2.68	11.0	2.90	21.0	8.0	1.6	3.43	1.89
NP-9	6 – 12	7.7	4.45	20.7	8.46	32.4	8.5	3.3	1.03	1.07
NP-10	0 – 6	5.4	3.09	24.6	3.75	16.1	4.3	0.6	27.5	13.2
NP-10	6 - 12	6.7	3.38	26.1	7.47	18.6	4.5	1.1	6.75	2.69

Improve Plant Growth Conditions of Impacted Sites

- Closely manage the use of sulfur
- Calcite expected to increase with the reaction of HCO_3^{-1} with Ca contributed from gypsum
- Apply gypsum containing calcite
- Apply calcite to increase soil pH
- Plant areas void of vegetation

Revised method for CEC on impacted soils - ongoing

- Problem – Ca and Mg is dissolved during the extraction process
  - Gypsum, calcite and amorphous materials
  - Ca is present in 3 or 4 extractions
    - Bleeding into solution from unknown sources
  - Currently – CEC data is worthless and ESP values are not obtainable

Revised Method

- A method developed by Suarez et al. used as a starting point
  - Used Mg as a tracer for soils low in extractable Mg
    - Tracers used to account to dissolution of unknown minerals in the system
- Revised method for PRB soils
  - Mg can not be used since PRB soils contain high levels of extractable Mg
  - Other potential tracers are being evaluated

Jurisdiction and Direct/Indirect Effects from Leaking CBNG-Produced Water Impoundments

Regulatory Jurisdiction

WDEQ (Surface Water Division)

- Bonding of on-channel impoundments over fee and state mineral
- Notice of Violation (NOV) for un-permitted release from full-containment impoundment
- WYPDES permit establishes effluent limits into on and off-channel impoundments

WDEQ (Ground Water Division)

- Water re-surfacing from off-channel impoundments over fee and state mineral
- Shallow ground water monitoring well compliance program

WSEO

- Permitting of S.W.3, S.W.4, & S.W. CBNG on-channel impoundments
- Accept for record of toe drain/sump pump designs and construction specifications (ACRs) as mitigation of leaking impoundments (WDEQ compliance requirement)
- Cease storage on impoundments with potential dam integrity problems

WOGCC

- Approval and bonding of off-channel impoundments over fee and state mineral

BLM

- Bonding of on and off-channel impoundments over federal mineral
- Approves environmental siting of impoundments
- Compliance with Onshore Order No. 7

Direct Effects

- Potential decrease of shallow ground water quality from leaching of soluble salts.
- Seeping, piping, and potential hillslope or embankment failure resulting in discharge to surface waters of the state
- Leaching of soluble salts and metals decreasing quality of stored produced water inside the impoundment.

Indirect Effects

- Potential impacts to soils including salts and metals accumulation, change from aerobic to anaerobic, erosion/deposition, and mass wasting
- Vegetation change from dry land species to wetland species which may be less palatable to livestock
- Ability and timeframe to revert from riparian back to a dry land regime
- Livestock may become mired in bog and perish

- Saturation below impoundment may produce slow moving water, or stagnant pockets, which could be preferential mosquito habit and breeding ground
- Opportunity for entry of invasive species including salt cedar, cockle burs, Canada thistle, Scotch thistle, etc.
- Fencing of artificial riparian areas? Livestock Management?

Concerns:

- There is no jurisdictional entity that can regulate sediment deposition and transport associated with piping and leaking reservoirs into the channels below them.
- If full-containment requirements go away as a result of utilizing Chapter 1, Section 20 analysis (Agricultural Use Policy to be instituted as a Rule) then the loss of the best forage in the basin occupying these bottom lands will be changed to wetlands with no protection for the landowner.
- Unsuccessful sump-pump mitigation may require additional downstream mitigation. How far do we chase it and when do we pull the plug.

Jurisdiction and Direct/Indirect Effects from Land Application Disposal (LAD) of CBNG-Produced Water

Regulatory Jurisdiction

<u>WDEQ (Water Quality Division)</u>

- Chapter 3 permitting of LAD prior to discharge to impoundment, i.e. ground water application only
- Required monitoring of soils, agronomic application rate, and vegetative cover

<u>WSEO</u>

- Permitting of S.W.3 allowing for LAD beneficial use, in on or off-channel impoundment
- Required reporting of LAD location and acres irrigated

<u>WOGCC</u>

- Approval and bonding of off-channel pits associated with LAD storage

<u>BLM</u>

- Bonding of off-channel impoundments over federal mineral for LAD storage
- NEPA analysis of potential impacts associated with soils and vegetation (has not been approved on federal surface)

Direct Effects

- Potential decrease in infiltration rate, i.e. dispersion of clays
- Accumulation of salts in the root zone causing decrease in productivity
- Stochiometric loading of ions while not exceeding SAR ratio
- Increased forage for hay production

Indirect Effects

- Potential long-term, irreversible impacts to soils
- Vegetation change from native species to salt tolerant species
- Source of water for soil flushing post CBNG production

Concerns:

- There are no usable thresholds to determine 'significant' impacts to soils or vegetation. Change of soil classification is not acceptable potentially 1,000%
- Can the soils be returned to baseline conditions?
- Management success is difficult to quantify
- Best sites for future agricultural use

Jurisdiction and Direct/Indirect Effects from Subsurface Irrigation (SDI) with CBNG-produced water

Regulatory Jurisdiction

<u>WDEQ (Water Quality Division)</u>

- UIC permitting of SDI with discharge to impoundments or direct ground water application
- Required shallow ground water monitoring and assurance that produced water will not enter surface waters

<u>WSEO</u>

- NA

<u>WOGCC</u>

- Approval and bonding of off-channel pits associated with SDI storage

<u>BLM</u>

- Bonding of off-channel impoundments over federal mineral for SDI storage
- NEPA analysis of potential impacts associated with soils and vegetation (has not been approved on federal surface to date)

Direct Effects

- Potential decrease in infiltration rate in the B_T horizon, i.e. dispersion of clays producing a shallow soil profile
- Accumulation of salts in the root zone causing decrease in productivity
- Stochiometric loading of ions in the subsurface while not exceeding SAR ratio
- Increased forage for hay production (beneficial use)
- Possible short-term landowner benefit and long-term liability

Indirect Effects

- Potential long-term, irreversible impacts to soils in the subsurface not easily identifiable
- Vegetation change from native species to salt tolerant deep rooted species
- Source of water for SDI continuation post CBNG production

Concerns:

- Can impacts that happen below the ground surface be easily mitigated?
- Management success is difficult to quantify
- Best sites for future agricultural use
- Depth of SDI in relation to soil horizons in a heterogeneous matrix