AN OVERVIEW OF PLANNING AND MANAGEMENT OF THE LAND APPLICATION SYSTEM ON THE GOSLIN FLATS – ZORTMAN AND LANDUSKY MINES, MONTANA[1]

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Abstract. The Zortman and Landusky gold mines are located on the southern reaches of the Little Rocky Mountains in north central Montana. Gold has been mined and concentrated in the area since the late 1800's. Pegasus Gold Corporation acquired the property and began intensive development in the 1970's with state and federal permits. Gold production was based on extraction of the ore by the cyanide heap leach process. Pegasus filed for bankruptcy in 1998 and reclamation became the state and federal agencies responsibility. Process solutions in the heap leach pads rose and disposal became necessary when the danger of their spilling into surface waters became a real possibility. The pad solutions contained elevated levels of cyanide, nitrates, selenium, sodium, salinity, and several other potentially toxic microelements in concentrations above water quality standards. Land application of the effluent was initiated shortly thereafter on the Goslin Flats south of Zortman, MT. The initial system covered 22.3 hectares (55 acres) but was rapidly expanded to approximately 166 hectares (410 acres) – the majority of which was located on an outwash terrace system and floodplain along Ruby Creek. Treated pad solutions were distributed on the land application area via a main line from the water treatment plants to laterals with risers supporting evaporative sprinkler heads. Inadequate design of the initial LAD system limited distribution and applied evaporation concentrated solution near the sprinkler head limiting application to a small portion of the LAD area. Some of the laterals were up to 90+ meters or more in length – often trending upslope from the main. Effluent application from the pads was concentrated near the riser/sprinkler heads. Modifications to the distribution system have been recently initiated. Collection of additional baseline data and an expanded monitoring program were initiated in 2001 to provide information of modification of the LAD system and to determine the impact of the effluent application on soil and plant systems. Preliminary data suggest that currently there currently is limited forage toxicity. Significant impacts to the soil system have occurred with most soils now being both saline and sodic/alkaline and containing potentially toxic levels of selenium.

Additional Key Words: land application disposal (LAD) systems, salinity, sodicity, selenium, nitrates, cyanide, LAD resource baseline studies, LAD monitoring programs, cyanide heap leach pad solution, irrigation impacts.

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[1]Paper was presented at the 2004 National Meeting of the American Society of Mining and Reclamation and the 25th West Virginia Mine Drainage Task Force, April 18-24, 2004. Published by the ASMR, 3134 Montavesta Road, Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2004 pp 593-630
DOI: 10.21000/JASMR04010593
https://doi.org/10.21000/JASMR04010593

Zortman and Landusky Mines

The Zortman and Landusky mines are located approximately 280 kilometers (175 miles) north of Billings and some 80 kilometers (50 miles) southwest of Malta, Montana. The Little Rocky Mountains dominate the regional landscape rising above the surrounding plains. The mines are located on the southern and southeastern edge of the uplift. Two small towns, Zortman and Landusky, are found on the southern and southeastern periphery of the mines. The Fort Belknap Indian Reservation is located immediately north of the mines. The two mines were operated and permitted by the Montana Department of Environmental Quality (DEQ) and the Bureau of Land Management (BLM). Zortman Mining, Inc. (ZMI), a wholly owned subsidiary of Pegasus Gold Corporation (Pegasus), operated the mines from 1977 until its bankruptcy in 1998. Pegasus was a Canadian firm operating eight gold or base metals mines in Montana, Idaho, Nevada, as well as in Australia (Kuipers, 2002). The mines used cyanide heap leach extraction of the low grade ore. Large heap leach pads were constructed and they are a major part of the reclamation process. Heap leach pad solutions are constantly being recharged and the solutions must be treated and discharged.

The Little Rocky Mountains were formed during the Tertiary period 65 million years ago. The upward thrust came from pressure of underlying igneous intrusive rocks resulting in formation of a dome structure about ten miles long. A wide range of rock types, ages, and formation processes are represented in the Little Rocky Mountains. Precambrian rocks are found exposed on the upper slopes of the mountains with more recent formations being exposed lower on the mountain. The plains to the south and east are dominated by deep deposits of Cretaceous sedimentary shales from the Bearpaw formation with occasional remnants of glacial till and/or glacial erratics on higher positions in the landscape.

The Little Rocky Mountains are located in the Northern Great Plains geographic region. These mountains are described as the "island mountain ranges" as they rise abruptly some 760 meters (2500 ft.) from the surrounding sedimentary plains. The gently sloping grassland landscapes lead upward to the mountains/mines and are frequently dissected by deeply incised, -steep walled erosional channels. Drainage from the southern and eastern side of the Little Rocky Mountains flows either south to the Missouri River or north to the Milk River. Glacial and peri-glacial action has altered the morphology of these landscapes. Glacial Lake Musselshell, formed by ice jams on the Missouri River, covered an extensive area on the eastern and southern flanks of the Little Rocky Mountains~~.~~ (Alt and Hyndman, 2003; Davis and Locke, 2003; Alden, 1932).

The regional surface hydrology consists of a radial drainage pattern developing with the Little Rocky Mountains (BLM and DEQ, 2001). The upper headwaters of drainages flow in response to snowmelt and storms. They flow in steep-sided valleys and canyons, which generally become broader as the streams approach the range front. Within the lower valleys and canyons, stream flow becomes more sustained, supported by groundwater from the valley floor alluvial deposits and by springs from the sedimentary rocks forming the flank of the range. For the main streams, flow in the lower valleys is normally perennial. As the topographic gradients decrease at the range front, the streams flow onto broad alluvial fans and floodplains, many of which have coalesced to form a poorly defined piedmont slope at the foot of the range. Losing stream flows are commonly observed as the streams cross the piedmont slope and onto the gently sloping landscapes surrounding the Little Rocky Mountains.

Mining History

The Little Rocky Mountains have had a long cyclical history of exploration and mining for gold and silver. Keyes found indications of placer gold in the area in 1864. In 1884, Aldridge found significant amounts of gold on Alder Creek followed by a "gold rush" of some 2,000 men within two months. This strike did not prove to be productive over the long term. Pike Landusky made a major strike on his August claim in 1893, followed by Pete Zortman's construction of a mill in Ruby Gulch in 1904. This mill and a second one constructed later burned – in 1912 and 1923, respectively. Remnants of the third mill still remain near one of the Zortman Mine leach pads. All three mills used cyanide leach tanks to extract the gold. By the middle of the 1930's, mining and extraction operations were sporadic and ended later in that decade. The property was sold in 1954 at a sheriff's sale for $60,000. (Dougherty, M. and H. Dougherty, 2002; Maehl, 2002; Schneider, 2001).

In 1977, Pegasus initiated evaluation of the property. The Zortman and Landusky mines were permitted in 1979. The cyanide heap leach process was used by ZMI/Pegasus and was the largest of that type operating in the United States. The Zortman mine produced 517,400 ounces and the Landusky mine produced 2,012,244 ounces of gold (total of 2,529,644 ounces). Pegasus encountered unexpected costs, particularly those related to the Australian operations, which resulted in their filing for bankruptcy in January of 1998 (Maehl, 2002 and Abel, 1997).

Zortman and Landusky Mining Operations

Mining consisted of an open pit operation using standard drilling, blasting, and excavation with large equipment. The uncrushed ore was trucked to the heap leach pads. Ore was deposited in a manner to minimize compaction as percolation through the pad is essential to the gold removal process. The pads were constructed with clay and polyvinyl chloride liners at the base to prevent process solutions from moving into underlying soil and groundwater.

Sodium cyanide (NaCN) was applied through a sprinkler irrigation system. The ore and process solution on the pad was maintained at pH 10 with the use of caustic soda or sodium hydroxide (NaOH). The resulting process solution percolated through the heap leach pad solubilizing the gold fraction from the ore and was collected as the “pregnant” solution. This process is efficient and allows gold removal from low grade ore. The “pregnant” solutions were then processed to remove the gold (Stanton et al, 1986).

Pegasus Bankruptcy and Bonding

Pegasus filed for bankruptcy in January 1998. A month prior to this filing Pegasus Australia had filed for bankruptcy in that country. The price of gold gradually dropped from a high of $850 in 1980 to $238 in December of 1997. Meanwhile, Pegasus stock had a high point of $17, a twelve month high of $11, and had fallen to under $1 (McClure, 2001 and Chatterjee, 1977).

DEQ and BLM negotiated with the surety company that held the reclamation bonds and the bankruptcy court receiving $30 million for reclamation. The agencies evaluated several alternatives for reclamation of the site. The preferred alternative selected was estimated to cost $63.5 million. Another alternative requiring more pit backfill was estimated to cost $103 million (Kuipers, 2002). Montana Congressmen repeatedly have tried to obtain the $33.5 million through the Congress without success to date.

The presence of reduced sulfur compounds or pyrite at the Zortman and Landusky mines created major reclamation and/or management problems. These compounds are described as acid forming materials (AFM) and their oxidation generally leads to the formation of acid rock drainage (ARD) otherwise known as acid mine drainage (AMD). For reclamation planning and bonding estimates, it is important to predict what materials on a mine site will generate acid, the amount of acid, and its concentration. The analytical and modeling tools do not exist to make these predictions with relative certainty. Limited capacity exists to predict the amount, ion species, and concentrations in the 140 million tons of ore in the heap leach pads at Zortman. The ARD from the Zortman and Landusky heap leach pads will have to be treated in perpetuity. Bond calculations to cover such costs, in advance, are/were simply rough estimates and in this case badly underestimated the costs. When acid forming materials are present in significant quantities it is prudent to be extremely careful about quality and intensity of resource inventories, reclamation planning, bonding, and permitting.

Issues

The Zortman and Landusky mines have contributed to the relatively depressed economies of Phillips County and the State of Montana. Salaries for the 300 or so people employed by ZMI at these mines were above those of the median for the county or state. Multiplier factors expanded the economic impact of these developments throughout the region. The agricultural resources and infrastructural base in this part of the country could not support either the number or salary levels associated with the Zortman and Landusky mineral developments.

The Zortman and Landusky mines have been controversial from their initial development. Many of the native people of the Fort Belknap Indian Reservation (Assiniboine and Gros Ventre tribes) have objected to their development and operation. Spirit Mountain, which was mined extensively by ZMI, was considered a sacred spiritual site. Other concerns included discharge water quality and quantity, disturbance of the land and inhabitants by the mining operation, etc. The problems between the native people and the mining operation lay imbedded in cultural and ethical values of native people – which differ significantly from those of the developers.

Montana has an active environmental community and it has questioned the assumptions in the permit and mine plan(s) as well as the ability of the respective entities to carry out their responsibilities. The lack of bond to cover full reclamation of the site and the related level of agencies financial exposure has increased concern over any mining.

Goslin Flats

Treated process solutions are piped to Goslin Flats for disposal. Goslin Flats is located south of the Zortman in Phillips County, MT. About 166 hectares (410 acres) of the Flats have been irrigated by the land application disposal (LAD) system with treated process solutions from the Zortman and Landusky heap leach pads. Goslin Flats are dominated by gently sloping outwash benches, which have been dissected by runoff waters from the uplands to the north and west. The LAD area has low gradient slopes on alluvial deposits and stream terraces (BLM and DEQ, 1996). The eroded drainage ways have relatively flat floodplains – up to several hundred feet in width at some locations. Frequent channel changes across the floodplain have taken place. The size of the drainage systems far exceeds existing runoff requirements indicating formation under a much moister climate (with larger amounts of precipitation and runoff) or glacial melting/retreat or related peri-glacial actions.

Goslin Flats is divided into a series of north/south trending outwash benches. Ball Field bench is the easternmost of the benches. Goslin bench is central to the irrigation system. Saddle Butte bench is the western portion of the LAD system currently under irrigation. Ruby Creek is the dominant ephemeral drainage system through Goslin Flats and is located between Ball Field and Goslin benches. The geology, soils, and plant communities associated with Saddle Butte bench are more complex than the other two benches.

Hydrology and Water Quality

Ruby Creek is the major ephemeral drainage in the area flowing south and east from the mining area approximately 40 kilometers (25 miles) to the Missouri River. Several tributaries to Ruby Creek drain portions of the ZMI mining area. These include Alder Gulch, Ruby Gulch, and Goslin Gulch with Ruby Gulch being the most important. Ruby Gulch is intermittent above the town of Zortman and surface water infrequently reaches the town, except during periods of heavy runoff. Alder Gulch, located south of the mine facilities, is intermittent and drains the southwestern portion of the Zortman mining area through its intermittent tributaries Carter Gulch, Alder Spur, and Pony Gulch. Goslin Gulch is intermittent and is located between Saddle Butte and Whitcomb Butte and joins Ruby Creek about three miles southeast of the town of Zortman. Surface water quality in Goslin Gulch and Ruby Creek is characterized as being near neutral in pH but having high levels of sulfate, specific conductivity, and total dissolved solids

((BLM and DEQ, 1996). The water quality is due to ongoing water/rock interaction with sediments partially made up of the underlying mineral-rich reduced shales. The shales are characterized as having high sulfate and soluble salt concentrations.

The LAD System

Initially the proposed Goslin Flats LAD system was designed to be an agency permitted facility designed to utilize the treated process water for beneficial agricultural production without adverse environmental impacts. The initial design and operation of the LAD system used pipe and sprinkler heads from the mine heap leach operations. The disposal of treated process solutions from the heap leach pads was done quickly, using heavy application rates on a limited area to prevent overtopping of the heap leach pads. The LAD was used to limit impacts to surface and ground water in the area of the heap leach pads.

All generations of designs and management schemes have prevented overtopping of the leach pads. Impacts to surface and groundwater have resulted from faulty design of the LAD system and **over-irrigation** of the LAD area but improvements have occurred from changes in the irrigation system and its management over the years. Starting in 2001, the objectives for the LAD system have expanded to include – 1) limiting long term negative impacts to the soil resource, 2) maintaining pre-development plant community productivity and diversity potential after termination of use as a LAD area, and 3) production of forage that is not toxic to herbivores.

In 1998, the LAD system was limited to approximately 22.3 hectares (55 acres) on the upper portion of the Goslin Bench for about half of the season and then expanded to 40 hectares (96 acres). Application rates were heavy, approximately 1.4.meters (4.5 ft.) of treated process water/acre on the 22.3 hectares (55 acres) and 0.6 meters/16.5 hectares (2.0 feet/acre) on the added 16.5 hectares (41 acres) [figures based on switching to the 96 acres mid-summer 1998]. Also, these calculations are based on **uniform distribution** across the LAD area, which was not achieved.

Main pipelines from the mines through the town of Zortman transport the treated process solutions to Goslin Flats. A system of laterals and risers with sprinkler heads irrigate or apply the process solutions to the Goslin Flats. Initially, all pipe and sprinkler heads were salvaged from the mining/cyanide heap leach operation. The agencies initially designed the system to evaporate the maximum amount of solution prior to reaching and entering the soil system. This reduced the quantity of solution being applied per unit of land surface. Subsequent problems with evaporative salt crusts on the vegetation and soil surface and preliminary results from the soil characterization and monitoring program forced the agencies to redesign the system. During the 2002 irrigation season, many of these heads were replaced with agricultural irrigation heads with larger droplet size and wider/better distribution, which both reduced evaporative losses and expanded the area of solution application.

The sprinkler pattern around the original heads, and to some extent, even the new heads, is elliptical and oriented northwest to southeast. The pattern with the original sprinkler heads extended a couple of meters north and west of the heads, and down wind some 8 to 12 meters with maximum widths of approximately 6 to 9 meters. The width between the original laterals ranged from 16 to 35 meters or more. Treated process solution contaminant loading was therefore concentrated in these elliptical areas rather than being uniformly distributed across the LAD area. Landscape position influences wind direction and intensity and the resulting pattern of effluent distribution.

Evaporative losses can be quite high in sprinkler irrigation systems in this semi-arid region. Evaporation concentrates residual contaminants in treated process solutions. The quality of partially evaporated treated process solutions entering the soil was not considered in initial irrigation planning - just the quality of the water entering the irrigation system. Improvements have been made in the LAD system design resulting in improved the quality of treated process solutions reaching the soil surface but work is needed to produce uniform application.

Two sets of data are available to support the lack of uniform distribution of process solution. Calculations on the land area covered by the original sprinkler system in 2002 and suggested that it ranged from 28 to 35 percent (Osborne, 2002). During that same year, several random transects were located to map the plant communities impacted by process solutions from the LAD system and found that it ranged from 28 to 30 percent on Saddle Butte and Goslin Bench (Fisher, 2002). As a result, the average 6.5 ft/acre of treated process solution applied to upper Goslin Gulch Bench in 1998 is approximately 19.5 ft/applied acre (from which evaporative losses would be subtracted). Calculation of residual contaminant loading is impacted by this lack of uniform application. Evaluation of the effectiveness of the distribution system using the initial evaporative sprinklers versus the new sprinklers has been made but an insufficient number of sampling sites limit the use of that data. Larger scale studies will be undertaken during the summer of 2004 to better understand the history of application and impact of recent modifications.

The LAD system initially extended for a considerable distance south on the Saddle Butte unit. LAD on this area was discontinued in the 2000 field season because of the soils and their reaction to additional salinity and sodicity from the treated process solution (Osborne, 2000). It was recommended in 2001 that no further applications be made in the Ruby Creek floodplain but limited application did take place during that season and again in 2003. Data from the monitoring work in the fall of 2001 and additional field observations of the irrigation system formed the basis for making these revisions.

In 2002, areas from Saddle Butte and Ruby Creek units and all of the Whitcomb Butte area were excluded from LAD because of soil and plant concerns. Currently, a reduced amount of treated process solution application takes place on the Ball Field bench because of the rapid discharge to surface water in this area. Currently, the southern portion of the Ruby Creek floodplain is being used for the LAD system. The upper 22.3 hectares (55 acres) of the Goslin Bench receives a reduced quantity of treated process solution. Full applications are taking place on the lower portion of the Goslin Bench. Portions of Saddle Butte unit have been removed from the LAD system. The original LAD system encompassed more than 166 hectares (410 acres) and now it has been reduced to about 220 acres – when the full modifications in the irrigation system are complete. The reduction in acreages is the result of concern over the potential impact of the LAD system on long-term use and management of soil and plant resources.

As described above, rising pad solution levels caused LAD to begin in 1998. The original LAD system on Goslin Flats consisted of 22.3 hectares (55 acres) of land; evaporative sprinkler heads concentrated treated process solutions on approximately 30 percent of the area and applied 19.5 ft/acre. Within two months seeps along the southern escarpment was noted and the LAD area was expanded. Later that year the area within the LAD system was expanded to 96 acres and subsequently in 1999 and 2000 further expanded to approximately 166 hectares (410 acres). The application system was redesigned to limit seeps, soil and plant impacts, and increase forage production (Osborne 1999, 2000.

Significant improvements in the LAD system were made during 2003 as more data became available and a better understanding of the site developed. The evaporative sprinkler heads have largely been replaced with more efficient heads, length of the lateral lines reduced, alternate lines between the existing laterals were installed, length of application was reduced to an eight hour period, and detailed planning was done to apply minimal treated process solutions as possible at uniform application rates across the LAD area. Construction of the new system encountered some delays preventing full installation on the LAD area in 2003.

In 2004, completion of the system upgrade can be accomplished with limited disruption of the LAD schedule. An improved LAD schedule with provisions for down time will be developed. Evaluation of the uniformity of application will be undertaken and the data utilized to make necessary adjustments in the schedule. Residual contaminant loading calculations, for 2004 and earlier seasons will be made. The 2004 loading calculations will be reviewed when data on the uniformity in application, amount of process solution to be applied is defined, and the quality of the treated process solution becomes available. A cursory review of 2003 soil and plant tissue analytical data from the Ruby Creek floodplain unit suggests that additional process solution application might be inappropriate. With installation of the laterals, data from some lysimeters may become available. Such data could provide a rough estimate of the amount of residual contaminants from the treated process solutions being held or attenuated by the soil resource versus that which percolates into the porous mid- and lower regolith. More data on the quality of the effluent entering the soil system is needed and will be collected in 2004. The quality of treated process solutions entering the LAD main lines is quite variable (depending on treatment, leach pad source, dilution, etc.). Climatic conditions such as relative humidity, wind, temperature, etc also affect water quality. The information will be used in evaluating residual contaminant loading, LAD scheduling, amounts to apply to each unit, interpreting lysimeter data, etc.

The Ball Field bench unit has been difficult to manage and limit discharge from seeps. In 2003, treated process solution application was delayed on this unit to allow sufficient forage growth and enhanced utilization of antecedent soil moisture prior to LAD. However, application was delayed too long, the dominant cool season grasses matured, and only limited plant growth was occurring by the time of application. A modified approach to treated process solution application on this unit will be developed and utilized in 2004.

The primary limiting factors in planning and operation of LAD system on Goslin Flats is the limited knowledge of the amount and quality of the treated pad solutions to be applied in any year. Many factors influence these parameters including success in operation of the biotreatment plant, pre-treatment required for the biotreatment system, potential dilution with better quality waters, and treatment of pad solutions to be discharged to the Goslin Flats LAD system, etc.

Treated Process Solutions

The heap leach pads continue to be recharged by both surface and subsurface waters. Most of the pads have been topdressed and reseeded. Revegetation and the mine soil system will remove a portion of the infiltrating and percolating waters. Success will be dependent upon the quality of the reclamation and revegetation programs. Seasonal recharge in the heap leach pads will measure success of reclamation at the Zortman and Landusky mines.

The volume of treated process solution that has been land applied has varied over the years. The amount carried over the winter and spring snow melt entering the heap leach pads influences the amount applied on Goslin Flats. The volume applied through September 30, 2003, excluding a two-week period in October totaled 203.1 acre/feet (Table 1). An acre/foot equals the amount of water it takes to cover an acre one-foot deep.

Table 1. Volume of treated process solutions applied through September 2003.

May	1,407,400 gallons	4.3	acre/feet
June	4,850,000 gallons	14.9	acre/feet
July	24,548,900 gallons	75.4	acre/feet
August	12,317,900 gallons	37.8	acre/feet
September	23,065,400 gallons	70.8	acre/feet
Total as of	**79,030,600 gallons**	**203.1**	**acre/feet**

AFM in the ore are oxidizing and the pH of the pad solutions has dropped in several of the heap leach pads at both mines. A biotreatment system has been constructed at the Landusky mine. Pad solutions must be pretreated prior to entering the biotreatment plant because of the developing acidity. The acid forming materials (AFM) in the ore are being oxidized and pH of the process solution has dropped in several of the heap leach pads. Caustic soda (NaOH) was selected rather than calcium-based pH control product. Caustic soda is used to reduce the acidity because calcium precipitated sludge would be many times the volume of that from caustic soda.

Recently, the Landusky biotreatment plant has removed sufficient contaminants to allow direct discharge from the plant when diluted with better quality water available at Landusky. The biotreatment plant's long-term success is critical to water treatment at both mines and reducing the amount of water that needs to be land applied at Goslin Flats. Experience with biotreatment at the Beal Mountain mine near Anaconda, MT documents that the biologically-based treatment systems are not as stable as more conventional chemical treatment processes. Fortunately, there is considerable storage capacity in the heap leach pads at Zortman and Landusky to allow for periodic disruptions in flow through the biotreatment plant.

Water quality data has established that the solutions in the pads are different in chemistry during the year (Table 2), between each other, and with important annual changes. Pad solution quality entering the biotreatment plant is monitored and pH adjusted with caustic soda (NaOH) to meet the requirements of the biological/biotreatment system. The source and treatment of pad solution will alter the chemistry of pad solutions land applied on Goslin Flats. Table 2 provides the quality of the pad solution land applied during 2003.

Table 2. Chemistry of Treated Pad Solutions Land Applied on Goslin Flats in 2003.

Parameters	***Units***	***5.5.03***	***6.6.03***	***7.8.03***	***8.9.03***	***9.9.03***
pH	Std. units	6.4	6.5	5.9	4.6	5.7
Conductivity	umhos/cm	7860	7330	7900	9000	8890
TDS	mg/L	7270	6800	8120	8460	7930
Chloride	mg/L	85	77	56	63	89
Sulfate	mg/L	4570	3970	4880	5040	5240
SAR	unitless	11.5	- - - -	- - - -	18.5	16.1
Cyanide, total	mg/L	0.168	0.17	0.123	0.30	0.382
Cyanide, WAD	mg/L	0.059	0.047	0.013	0.093	0.077
N, ammonia	mg/L	0.96	0.88	1.21	2.19	1.30
N, nitrate + nitrite	mg/L	125	118	107	148	158
Ca, dissolved	mg/L	418	- - - -	- - - -	28	407
Mg, dissolved	mg/L	176	174	222	14	141
Na, dissolved	mg/L	1110	1180	1250	483	1480
As, total	mg/L	ND	ND	0.003	ND	ND
Cd, total	mg/L	0.121	0.151	1.38	0.233	0.0863
Cu, total	mg/L	0.076	0.145	2.11	0.628	0.169
Se, total	mg/L	0.098	0.115	0.276	0.438	0.517
Zn, total	mg/L	8.16	11.2	122	18.0	9.00

Table 2 raises issues from the agronomic/crop irrigation perspective. The TDS, conductivity, and SAR values are well above those commonly used or considered suitable for irrigation. In some respects, it is beneficial that the solution has a high soluble salt content because it provides sufficient salt to flocculate the soil system thereby counteracting the dispersive effect of the sodium ion. Soil analytical data reflects this balance and is the basis for the definition of the LAD soils as saline-alkaline (Heil, 2002).

The dominant anion in the treated pad solution is sulfate, a product of pyrite or other reduced sulfur mineral oxidation. The impact of elevated soluble salt levels on plant growth is reduced in the presence of the sulfate anion. Much of the crop salt tolerance work has been done with soils dominated by the chloride anion (Soil Salinity Laboratory, 1954). A large amount of nitrogen is being applied in the treated process solutions. The recent emphasis on maximizing forage production is an attempt to utilize this nutrient and attenuate its discharge to surface waters. Cyanide application is of lesser concern when considering impacts on soil and vegetation resources but decomposition products contribute to the amount of nitrogen being applied. Residence time in the soil is essential to degrade cyanide. Controlling residence time has been problematic on Goslin Flats because of the volumes of solutions land applied and the inefficient distribution pattern. Selenium is a problem in many western irrigation districts and is of concern on the LAD area. The values in the treated pad solutions applied on Goslin Flats and the soil resources are a concern. Monitoring of soil and plant tissue selenium concentrations was initiated in 2001 and should continue for an extended period of time after applications are terminated.

Baseline and Monitoring Studies on Goslin Flats

The objectives for the baseline data collection and monitoring programs on the Goslin Flats have developed over time. Initially, the effort was confined to evaluating potential forage toxicity related to selenium. Later the effort was expanded to encompass the earlier soil monitoring work of Osborne (2000). From the outset, it was apparent that the baseline resource data was not adequate to design or modify the irrigation system and its management. These studies have concentrated on collection of sufficient plant and soil resource information to better design and manage the land application system. Currently, the objectives for the baseline and monitoring program on the Goslin Flats are as follows:

- To collect appropriate soil resource information, both chemophysical properties and soil distribution, to facilitate modification of the design of the LAD system and its management and operation,
- to generate sufficient soil resource data to allow assessment of the impacts of the LAD system on those resources, evaluate long term implications for management and land use potentials,
- to acquire sufficient soil data to assess the need for and type of reclamation post-LAD operation on the Goslin Flats,
- to evaluate soil resource data in terms of its potential to produce forage that could be toxic to herbivores,
- to collect sufficient plant tissue samples to assess any existing potential forage toxicities,
- to determine the amount of standing crop on the LAD areas and its potential for limiting forage production in the future, and
- to collect appropriate plant and soil resource data in sufficient detail that it can be with other resource data, particularly hydrologic and related LAD water quality information, to allow development of the LAD system to have the least long term impacts and to enhance its productivity.

Large amounts of salinity and sodicity/alkalinity have accumulated in soils within the LAD area (Hydrosolutions, 2000). Additional sampling of forage for plant tissue selenium analysis on Goslin Flats occurred during July of 2001. The primary purpose was to examine potential toxicities prior to cattle grazing on the land application LAD area in August 2001. Limited plant tissue analysis had taken place prior to that time. Field observations, during the plant tissue sampling, of the soils and plants suggested that developing salinity and sodicity problems might have taken place. In fall 2001, soil and plant investigations were initiated in the Whitcomb Butte and upper Saddle Butte areas to describe any impacts to the soil resources and/or plant species/tissue.

Preliminary results from the fall 2001 work suggested that some modifications in the design and management of the LAD system were necessary. The design of the baseline and monitoring studies were amended during the winter of 2002 to emphasize data collection to be used in meeting the objectives set forth above. Data from these studies have been used to modify design and management of the land application system.

<u>Sampling and Preparation Methods and Procedures</u>

The diversity in the soil and plant systems on the LAD area has created management and sampling problems. The degree of differences in quality and application of treated pad solution were not fully appreciated when the initial design of the LAD system and monitoring and baseline studies began.

The soil sampling procedure has remained constant and reflects that developed by the Natural Resources Conservation Service and experience in evaluation of impacts from irrigation systems. Soil pits were dug by backhoe 2 to 4 meters south or east of and parallel to the lateral. They were located approximately perpendicular to the riser. Pits were 3 to 5 meters in length and sloped upward from the deep end (2 to 3 meters) to allow access. Soils at the base of the riser and up to 1.5 to 2 meters into the elliptical pattern have received the maximum amount of treated process solution. The soil profile sampled in this manner represents an intermediate zone in terms of amount of treated pad solution application. Soil profile descriptions have been prepared at each site. Soil samples were collected from each horizon identified. Samples were placed in Ziplock freezer bags and double bagged for samples containing large quantities of gravel. One or two bags were collected for samples having limited coarse materials content while as many as five bags were used for samples containing large amounts of coarse fragments. Samples were stored in areas not subjected to high temperatures. Samples were transported to the analytical laboratory directly or within four weeks of collection.

At the laboratory, sample bags were combined and dried at room temperature. After drying, they were sieved using a 10 mesh or 2 mm sieve. A few of the samples required grinding prior to sieving. Instructions were given to the laboratory to do a minimum of grinding/disaggregation to allow sieving of the sample. The shale and shale derived samples were treated somewhat differently – being air dried, ground using a “chipmunk” grinder to reduce particle size, and then further ground to less than 10 mesh or 2 mm. This process is the same as utilized for paralithic spoil or overburden samples. Larger coarse fragments from horizons below the soil solum were often coated with noneffervescing salt crystals. Many of these were dislodged during sampling, sample transport, and drying. Intermountain Laboratory in Sheridan attempted to remove these crystalline materials from the larger coarse fragments but found it not practical to do so. Coarse fragment content was determined by weight with the > 2 mm fraction being discarded. The prepared sample was then placed in a Ziplock bag. Instructions were given to the laboratory to thoroughly mix the sample prior to subsampling for analysis. Once the analytical work was complete, the samples were placed in quart canning jars, and stored moderate temperature.

Plant tissue samples were collected from each of the study sites and other locations as needed. Sampling was confined to an area within 8 meters of the riser and respective soil pit. Woody species were sampled by collection of 1 to 1.5 decimeter stem lengths. Herbaceous species were clipped one to three centimeters from the soil surface, placed in Ziplock bags and in coolers. Each sample had any spurious plant or foreign materials removed from the sample. The prepared samples were placed in Ziplock bags, labeled, and frozen. Samples collected late in the trip were transported in coolers to Helena, prepared, and frozen. Samples were kept in a freezer until taken to the laboratory.

At the laboratory, the plant tissue samples were thawed and air-dried at room temperature. Dried plant tissue was ground with a Wiley mill to insure that all tissue types were fully represented in the sample. Instructions were given to the laboratory to thoroughly mix the sample prior to subsampling for analysis. The plant tissue samples are archived in a freezer. When the analytical work was complete, the frozen samples were picked up, transported in coolers, and placed in a freezer.

Analytical Methods and Procedures for Plants and Soils

Most of the analytical methods for soil testing were adopted from Soil, Overburden, and Regraded Spoil Guidelines (DEQ, 1998) (Attachment 2). In several instances, two or more methods were utilized to obtain the best data as authorities differ on which method would be the most appropriate. The selection and duplication of methods and work on quality assurance/quality control was undertaken to generate the best quality data possible. Plant tissue and soil sampling methods were adopted from literature (Steward, et al., 1994 and Spackman, et al., 1994).

The baseline and monitoring studies on Goslin Flats developed over a period of time. The initial effort consisted of collection of plant tissue samples from representative plant species for selenium analysis to assess potential livestock toxicity. Quantities of soluble salts found on plants and soil surfaces identified the need for irrigation related agronomic soil sampling as well. Sampling for potentially toxic microelements in soils and plants was included as recommended by HydroSolutions and others. Additional parameters of concern in plants and soils were added after the initial phase of the study. Continuing changes in treated pad solution quality contributed to the expanding parameter list. Potentially toxic microelements now being analyzed for in both soils and plant tissue include: arsenic (As), boron (B), cadmium Cd), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), selenium (Se), sodium (Na), and zinc (Zn).

Selenium uptake from soils is poorly understood and levels present in the treated pad solutions are sufficiently high to be of concern. Initial analyses of soil samples suggested the ammonium bicarbonate DTPA (AB-DTPA) extractable levels could produce seleniferous vegetation. As a result, additional data was collected and three soil extraction procedures were used. The hot water extraction procedure (citation i.e. EPA 1981) produces lower values and lacks consistency compared to the AB-DTPA extraction (XXX). The hot water extraction has been adopted by the Wyoming Department of Environmental Quality (WY-DEQ Guideline No. 1 - Topsoil and Overburden 1994). The AB-DTPA extraction is more rigorous than the hot water procedure and has the advantage of having had correlated selenium uptake by plants studies done on soils similar to soils on Goslin Flats. Total sample analysis is the third analysis used for soil selenium.

<u>Soils and Surficial Geology</u>

Semi-rounded coarse fragments of mixed lithology dominate the near surface 6 to 9 meters of the Ball Field and Goslin Bench soils. Paralithic Thermopolis shales (Mohs' hardness of <3) underlie much of the glacial outwash benches in Goslin Flats LAD area. The underlying shale on the Ball Field bench dips to the east and to the west on the Goslin Flats Bench. Small springs and seeps primarily resulting from LAD are located along the escarpment on the sides of the benches. The depths of outwash deposits thin out north and west of the Goslin Flats LAD area and contain more clay in the coarse fragments of the regolith. Outcrops of paralithic sedimentary materials occur of Goslin Flats. Coarse fragment content (>2 mm. diameter) of the outwash deposits ranged from 50 to 80 percent with individual fragments ranging up to 0.8 meters or greater in diameter. The coarse fragments are poorly sorted and well graded and size of the fragments suggested that the benches were formed by rapidly moving waters. Ice dams on the Missouri River and along the glacial front are thought to have had an influence on the surficial geology of the area (Alt and Hyndman, 2003). Plant and soil studies in the Willow Creek drainage located approximately 100 kilometers (65 miles) east of Goslin Flats provide further supporting evidence for these conclusions – personal work.

Cobbles and an occasional boulder are found on the surface of outwash benches and Ruby Creek floodplain and to a lesser extent on the eroded landscapes of Saddle Butte and Whitcomb Butte LAD units. The quantity and size of coarse fragments is sufficient to prevent plowing or most other types of intensive agricultural use. Native grass hay was harvested for many years from the Goslin Flats with the use of horses and/or small mechanized farm equipment (John Kalal, personal communication). Recent experience with harvesting hay from Goslin Flats has not been successful because of damage to large modern farm equipment from the cobbles and boulders. It is essential to management of the LAD areas to remove forage LAD areas to stimulate regrowth/production and evapotranspiration thereby limiting ground and surface water recharge. The inability to utilize plows, disks, etc. will limit most future reclamation options. Harvesting of forage from the site can and should be undertaken using small farm equipment operated cautiously. Regular removal of the standing crop is important to the management and to meet the objectives of the LAD plan.

The soils of the Goslin Bench and the Ball Field outwash benches are similar - having dark surface horizons (mollic epipedons). The B horizons subsoils have either structural types (cambic) or horizons with significant amounts of clay (argillic) horizons. The C horizons or parent materials are not related to surface horizons. The "Ball Field" series (*) represents a majority of the soils found on the benches (Attachment No. 1). The surface materials dominating the outwash benches are significantly higher in clay and have lower coarse fragment content than the underlying and unrelated regolith materials. The A and B horizons are

(*) The term soil series in this instance refers to an aggregation of soil pedons similar in chemical and physical characteristics and their capabilities for supporting irrigation and application. It is not intended to meet the requirements nor be equivalent of the soil series as utilized by the Soil Survey Division of the NRCS (USDA). Fragment contents in the regolith found within six to eight feet of the surface in the range of 45 to 90 percent by volume. Sandy loam to medium clay loams dominate the A horizons. The B horizons have clay loam to light clay textures. Calcium carbonate is present in limited amounts in the A and B horizons and found in very slightly increased amounts in the underlying regolith. The underlying materials have a mixed lithology and occasionally a coarse fragment will effervesce.

occasionally are skeletal with greater than 35 percent coarse fragment content (by weight) while the underlying regolith materials are dominated by coarse fragments ranging up to 80% by weight. Field observations have estimated coarse

Outwash bench soil chemical properties are typical for the area for similar regional soils of similar parent materials – with pH values ranging from 6.5 to 8, sodium adsorption ratios (SAR) of less than 1, high surface organic matter contents ranging from 3 to 6 percent, cation exchange capacities of 15 to 40 milliequivalents/100 grams of soil, and no toxic microelement concentrations. Table 2 provides some important physical or chemical parameters for non-irrigated or control soils on the Goslin Flats LAD area. Table 3 provides soil physical and chemical characterization data for two of the irrigated soils on the upland outwash bench study sites.

Table 2. Soil Characterization Data for Non-irrigated Control Sites, Goslin Flats LAD Area

Saddle Butte – North Heil Transect; Control/Central Site

Depth	**Centimeters**	0-10	10-17	17-33	33-43	43-95	95-150+
Texture	USDA	l	c	c	cl	sl	scl
pH sat paste	Std units	5.5	5.7	6.6	7.2	7.4	7.4
Organic matter	percent	5.5	1.7	1.6	1.5	<0.01	<0.01
EC sat paste	mmhos/cm	0.87	0.28	0.39	0.38	0.28	0.25
SAR	calculated	0.3	0.61	0.43	0.33	0.59	0.72
ESP	percent	0.07	<0.01	<0.01	<0.01	<0.01	<0.01
Se AB-DTPA	ppm	0.02	0.02	0.02	0.02	<0.02	0.02
Se hot water	ppm	<0.02	0.02	<0.02	<0.02	<0.02	<0.02

Ball Field – North Control Site

Depth	**Centimeters**	0-10	10-25	25-38	38-50	50-65	65-85	85-115	115-135+
Texture	USDA	l	c	c	scl	sl	sl	sl	sl
pH sat paste	Std units	5.7	6	5.8	6.9	7.3	7.3	7.4	7.4
Org matter	percent	1.6	4.7	1.1	1.3	0.2	<0.1	<0.01	<0.01
EC sat paste	mmhos/cm	0.34	0.52	0.3	0.45	0.39	0.35	0.25	0.39
SAR	calculated	0.67	0.34	0.84	0.38	0.43	0.78	0.72	0.88
ESP	percent	<0.01	<0.01	0.02	0.02	0.07	0.09	0.26	0.42
Se AB-DTPA	ppm	0.02	0.02	0.02	0.02	<0.02	<0.02	<0.02	<0.02
Se hot water	ppm	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Textures: sl = sandy loam; l = loam; scl = sandy clay loam; cl = clay loam; c = clay

Table 3. Soil Data for Irrigated Sites, Goslin Flats LAD Area

Ball Field: L5/R4 – Irrigated Site

Depth	Centimeters	0-15	15-38	38-66	66-91	91-137	137-180+
Texture	USDA	cl	c	cl	sl	sl	sl
Org matter	Percent	3.1	0.8	1.2	<0.1	<0.1	<0.1
pH sat pst	Std units	5.7	5.8	6.9	7.4	7.7	7.6
EC sat pst	mmhos/cm	6.89	6.88	7.62	7.16	5.89	6.68
SAR	Calculated	15.1	14.6	16.4	14.6	12.3	14
ESP	Percent	7.52	10.5	11.5	11.8	10.4	13.2
Se AB-DTPA	ppm	0.22	0.32	0.42	0.22	0.12	0.12
Se hot water	ppm	0.2	0.3	0.32	0.22	0.1	0.14

Goslin Bench: L12/R3 – Irrigated Site

Depth	Centimeters	0-8	8-33	33-50	50-80	80-100	100+
Texture	USDA	l	c	scl	sl	sl	sl
Org matter	Percent	3.4	1.2	1.2	<0.1	<0.1	<0.1
pH sat pst	Std units	5.8	5.7	7.4	7.6	7.6	7.6
EC sat pst	mmhos/cm	4.8	6.37	8.7	7.1	6.18	5.65
SAR	Calculated	7.39	15.4	19.5	15.7	13	11.6
ESP	Percent	2.63	12.2	15.2	14	9.3	10.6
Se AB-DTPA	ppm	0.14	0.28	0.6	0.26	0.14	0.06
Se hot water	ppm	0.06	0.26	0.6	0.24	0.12	0.06

Textures: sl = sandy loam; l = loam; scl = sandy clay loam; cl = clay loam; c = clay

The soils in the Ruby Creek floodplain differ widely in chemical and physical characteristics from the upland benches and eroded landscapes of Whitcomb Butte and the central portion of Saddle Butte. Different depositional events have led to major changes in soil characteristics over short distances. Soils range from skeletal, moderately coarse and coarse textured profiles to profiles having medium and moderately fine textured strata interspersed with skeletal materials to profiles dominated by clay horizons throughout. Evidence of older braided channels is found on the surface and subsurface strata of this landscape. Tailings from the historic mills and mining activities in upper Ruby Creek are encountered at or near the surface of many soils and are visible at greater depths near the active channels.

Several soil surveys and related studies have been completed on and near to Goslin Flats. Pegasus completed a baseline Order 1 soil survey in the area but detailed soil profile descriptions on Goslin Flats were limited (Noll and Houlton, 1991). The survey encompassed a large area and used generalized mapping units. The Phillips County soil survey included Goslin Flats (NRCS, unpublished data). These surveys are not adequate for designing irrigation or land application systems. Detailed on site investigations are required to meet this type of resource planning needs.

Twenty geotechnical test pits were dug by Pegasus (Golder, 1993), using composite sampling procedures, with some chemophysical characterization work being accomplished. They failed to analyze some of the parameters required for design and management of the LAD system – also lacking sampling intensity required for the system.

Studies on contaminant loading and cyanide attenuation were conducted on Goslin Flats by Pegasus (Shafer and Associates, 1993). Use of the data is limited. The report used pH 9-10 for leach pad solution chemistry to be land applied on Goslin Flats. Currently, some leach pads have pH's as low as 2. Lack of uniform distribution of pad solution across the LAD area was not considered in development of contaminant loading calculations. Field observations strongly suggest that treated pad solutions are moving differentially rather than uniformly through the soil system and regolith. Predicted cyanide attenuation is limited by lack of residence time in this soil system due to application rates which exceed evapotranspiration rates and allow percolation through the soil profile through the root zone. Contracted soil scientists reviewed the LAD system and management decisions made to date, provided alternatives, assisted in locating additional study sites, and described representative soil profiles (Heil, 2002).

Results and Discussion

From an agronomic perspective, the increases in salinity electrical conductivity (EC), sodicity sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP), and selenium are of greatest concern in the LAD area soils (Table 3). They have been the parameters of most concern to the planning and operation of the LAD system. Salinity increases the osmotic concentration in the soil solution making it difficult for plants to extract water. Elevated sodicity can disperse soil aggregates (or structure) and limit infiltration and percolation of water and gaseous exchange. Selenium in soil, under most concentrations, has limited impact on plants but can be taken up by roots and incorporated into plant tissue. Tissue concentrations exceeding 5 ppm selenium are thought to be toxic to herbivores (National Academy of Science, 1983).

Increases in salinity and sodicity have occurred in soils receiving treated pad solution in the LAD area and exceed recommended soil level guidelines (Table 3) (DEQ, 1998). Salinity values are sufficiently high to limit selection of plant species, germination and establishment of plants, and biomass production. LAD area soils have high sulfate to chloride anion ratios that tend to provide some mitigation of the impact on plants. Elevated salinity concentrations in these soils can limit the impact of the elevated sodium. Sodium can disperse the soil aggregates or structure limiting infiltration and percolation of water. Soil dispersal has been noted in irrigated soils in the upper portion of the Goslin Bench during LAD. Soils being used for LAD on Goslin Flats are currently saline/alkali (Heil (2002). The elevated salinity and sodicity provides an opportunity for reclamation of the soils during or after - LAD if deemed necessary.

The high concentration of nitrogen compounds in the treated pad solution (Table 1) and the excessive quantities applied are thought to be important factors in the continued productivity of Goslin Flat's vegetation Field observations of tip burning on alfalfa (*Medicago sativa*) and salt encrustation on grass blades indicate a potential impact on vegetation. Impacts from salinity and sodicity are hard to assess because of the many variables in the LAD area. Laboratory data is the first step in assessing impacts but greenhouse and field tests using plant species need to be conducted. A greenhouse study has been developed to assess treated pad solution impact on germination, establishment, and production of several plant species.

Selenium

Selenium concentrations in LAD soils are elevated but with limited corresponding increase in plant tissue (Table 3) (DEQ, 1998). The AB-DTPA extractions result in higher values, which is characteristic of that procedure. Understanding of the uptake of selenium by plants is limited and influenced by many factors. Plant species differ in their capacity to take up selenium and incorporate it into tissue. Inorganic versus organic selenium compounds, differing ion species, and microbiological influences – impact selenium uptake. Plant tissue samples from the LAD area range from low to high levels exceeding the 5 ppm standard (NAS, xxx). Blood analysis from steers normally grazing the LAD area from November through April reveal toxic concentrations of selenium. Mule deer heart, liver, and renal tissue from Goslin Flats area likewise do not show concentrations above the 5 ppm standard or other microelemental toxicities. Monitoring plant tissue and herbivores utilizing the forage for selenium must continue. Soil monitoring for selenium and selenium partitioning must conducted.

Native and Irrigated Plant Communities (*)

At a regional level, several individuals have mapped the vegetation surrounding the Little Rocky Mountains. Kuchler (1975) described the vegetation as blue grama (*Bouteloua gracilis*), needle and thread grass (*Stipa comata*), and western wheatgrass (*Agropyron smithii)* (Kuchler, 1975). Morris's description (1964) was similar noting the prairie was composed of needle-and-thread/western wheatgrass/blue grama (*Stipa comata*/*Agropyron smithii*/*Bouteloua gracilis*) species. These species are dominant on the coarser textured soils and those of glacial origin but are rarely encountered to the south and east of the Little Rockies where Bearpaw shales dominate the landscape. Greasewood (*Sarcobatus vermiculatus*), western wheatgrass and alkali sacaton (*Sporobolus airoides*) dominate the saline and alkaline shale units. On the better shales, western wheatgrass, big sagebrush (*Artemisa tridentata*), green needlegrass (*Stipa viridula*), and prairie sandreed grass (*Calamovilfa longifolia*) are dominants. The green needlegrass (*Stipa viridula*) is indicative of soils described as Vertic intergrades or and Vertisols. The Missouri breaks are found to the south and southeast of the Little Rockies and are dominated by Ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), wheatgrasses (*Agropyron sp*.), and two species of juniper (*Juniperus sp*.).

Plant communities are not static and many factors have and continue to influence those dominating the LAD area and surrounding area. Hay has been harvested from the Whitcomb Butte unit since the early days in Zortman. Cultivated species such as smooth brome grass (*Bromus inermis*) and timothy (*Phleum pretense*) are dominant in this area.

Hay was harvested off of the outwash benches and in the Whitcomb Butte unit (Kalal, personal communication) and interseeding with more productive species probably took place during those times.- Introduction of more productive forage species into the hay fields probably has taken place. Heavy utilization by livestock and exclusion of fire has had significant impacts on the plant communities found today on Goslin Flats.

(*) All species nomenclature follows that of Hitchcock and Cronquist, 1973 and Hitchcock et al, 1955 – 1969.

The first detailed vegetation inventory covering the Goslin Flats was completed by Culwell, et al. (1990) and encompassed an approximate 10.9 hectares (27 square miles). The size and lack of special need for intensive inventory on the Goslin Flats resulted in the use of relatively generalized mapping units. The authors described the Flats as being dominated by mixed prairie grassland.

In April 2000, 99 hectare (245 acres) of the Goslin Flats land application area was interseeded with the following seed mix:

Grasses:		
Agropyron smithii	western wheatgrass	5 PLS pounds/acre
Agropyron trachycaulum	slender wheatgrass	2 PLS pounds/acre
Agropyron elongatum	tall wheatgrass	2 PLS pounds/acre
Forb:		
Medicago sativa	alfalfa	2 PLS pounds/acre

The interseeding was done on the Ball Field, Ruby Creek floodplain, and southern half of the Goslin Bench. The existing vegetation on the upper half of Goslin Bench, Whitcomb Butte, and Saddle Butte land application units strongly suggests that they were also interseeded. No records exist to document this action but Maehl (personal communication) with Scow (2002) suggests that if extra seed had been available it is possible that these areas might have been interseeded.

Scow (2002) studied the plant communities found on the Goslin Flats – sites having received full irrigation, those marginally being irrigated or subject to drift from the sprinklers, and "control" sites. They collected data from 74 sample locations on the Flats primarily within the snowberry/grassland mapping unit. Vegetative characterization was undertaken at every study site where soil profile descriptions and sampling/analysis had been undertaken. Sampling was accomplished with 0.01 acre circular plots (Franklin et al, 1970). Table 4 summarizes the 2002 field season work Scow/Westech. Summarizing their findings –

1) Total vegetative cover in the twenty control plots averaged 78 percent relative cover while on the irrigated or irrigation influenced sites it was 82 percent,

2) Perennial grasses comprise 55 percent of the relative cover in the control vegetation and 66 percent in the irrigated or irrigation influenced sites,

3) Perennial forbs averaged 30 percent relative cover on control sites and 20 percent on the irrigated or irrigation influenced sites,

4) Perennial native bunchgrasses, bluebunch wheatgrass (*Agropyron spicatum*) and needle-and-thread grass (*Stipa comata*), have been essentially replaced with rhizomatous perennial grasses – thickspike (*Agropyron dasystachyum*) and western wheatgrass (*Agropyron smithii*).

Plant tissue collections and analysis for nine elements have been made in the fall of 2001 and spring/fall in 2002 and 2003. From the standpoint of selenium, many of the values are marginal and Hay was harvested off of the outwash benches and in the Whitcomb Butte unit (Kalal, personal communication) and interseeding with more productive species probably took place during those times. Introduction of more productive forage species into the hay fields probably has taken place. Heavy utilization by livestock and exclusion of fire have had significant impacts on the plant communities found today on Goslin Flats.

, 6474 hectares (245 acres) of the Goslin Flats LAD area was interseeded with the following seed mix:

Table 4 Goslin Flats Seed Mix.

Grasses:		
Agropyron smithii	western wheatgrass	5 PLS pounds/acre
Agropyron trachycaulum	slender wheatgrass	2 PLS pounds/acre
Agropyron elongatum	tall wheatgrass	2 PLS pounds/acre
Forb:		
Medicago sativa	alfalfa	2 PLS pounds/acre

The interseeding was done on the Ball Field bench, Ruby Creek floodplain, and southern half of the Goslin Bench. The existing vegetation on the upper half of Goslin Bench, Whitcomb Butte, and Saddle Butte LAD units suggests that they were also interseeded - no records exist to document this action. Maehl (personal communication, 2002) with Scow (2002) indicated that if extra seed had been available, it is possible that these areas might have been interseeded.

Plant communities on Goslin Flats that received full irrigation, those marginally irrigated-or subject to drift from the sprinklers, and "control" sites were studied (Scow 2002) (Table 5). Data from 74 sample locations primarily within the snowberry/grassland mapping unit was collected. Vegetative characterization was accomplished at every site where soil profile descriptions and sampling had been undertaken. Sampling was accomplished with 0.01 acre circular plots (Franklin, et al, 1970).

The twenty control plots averaged 78 percent relative vegetative cover and the irrigated or irrigation influenced sites averaged 82 percent. Perennial grasses comprised 55 percent of the relative cover in the control vegetation and 66 percent in the irrigated or irrigation influenced sites. Perennial forbs averaged 30 percent relative cover on control sites and 20 percent on the irrigated or irrigation influenced sites. Perennial native bunchgrasses, bluebunch wheatgrass (*Agropyron spicatum*) and needle-and-thread grass (*Stipa comata*), have been essentially replaced with rhizomatous perennial grasses – thickspike wheatgrass (*Agropyron dasystachyum*) and western wheatgrass.

Plant tissue analysis for potentially toxic microelements have been made in the fall of 2001 and spring/fall in 2002 and 2003. Many of the selenium values were marginal and some exceeded 5 ppm chronic toxicity standard. Selenium concentrations in plant tissue generally were highest at the peak of the growing season and declined afterwards. As a result, tissue collections have been made in May and June and again in September and October. The fall samples identify forage selenium values that would be consumed by steers under the current grazing management program.

The Future of the Goslin Flats LAD System

Long Term Management of Goslin Flats

Any long-term management scheme is dependent upon the characteristics of the natural resources at a specific point in time, i.e. what is the quality of the soil resource? What are the characteristics of plant communities in the area? What is the health of the ecosystem? What are the land use objectives? The collection of baseline data will be completed with limited work in 2004. The 2004 monitoring program will provide the current status of the resources on LAD area and long-term management considerations. The amount of treated pad solution to be applied, its chemistry, and the number of years the LAD system will be operated on Goslin Flats is not known. At the time the LAD is terminated – and perhaps before, decisions about soil reclamation, reseeding, forage and livestock management programs, abruptly ending vs. weaning the LAD area from the irrigation, appropriate livestock management plans, etc. will have to be made. All of these considerations will have to be developed with the landowner.

Removal of litter or dead biomass from the LAD area has become both a short and long term management problem. Livestock numbers currently grazing on the site are not adequate to consume the amount of biomass needed to allow for full production the following year and to produce a healthy sustainable plant community. Distribution of livestock is poor because of the limited distribution of water. Biomass harvest can be partially accomplished by increasing the numbers and distribution of livestock but it will still fall short of that needed to properly manage forage. Some form of mechanized hay harvest must be developed to serve as the primary method for biomass removal. The large standing crop, particularly in the fall, presents a potential fire hazard and may burn whether it is a part of the management program or not.

Long-term Operation of the LAD System

Quantity and quality of the treated pad solution applied on Goslin Flats will define the nature of the long-term operation. Baseline studies and monitoring of the soil and plant resources will be pivotal in deciding if and how long the LAD system can operate, where it should take place, and the contaminant loading rates and levels to maintain the capability of the ecosystems and their capacity to support a variety of land uses. The need for reclamation of the soil resource remains an unknown in terms of long-term operation of the system. Contaminant levels could force termination of use of the LAD area.

Future Characterization and Monitoring Efforts

The plans for 2004 field season on Goslin Flats will be the end of the intensive work unless major operational changes occur or unforeseen problems develop. As indicated, long-term monitoring will be required. The following tasks are scheduled for the coming field season:

- Completion of the baseline study site characterization work in 2004. Five to eight sites remain to be characterized in the lower portion of Saddle Butte and Ruby Creek floodplain. Soil descriptions/sampling and plant community characterization work will be accomplished on these sites.
- Soil monitoring will be done to depths of two feet or contact with the gravelly and cobbly underlying regolith on eighteen selected study sites in the LAD area to determine concentrations and trends in contaminant loading.
- Pot culture/greenhouse testing of contaminated and control soils to evaluate germination and establishment problems with dominant plant species and to measure initial productivity depression due to contaminant loading.
- Follow-up and expansion of the 2002 Westech plant community studies will be undertaken. New study sites and re-measuring communities studied in the earlier work will be done to better understand the vegetation on the Goslin Flats and changes in response to the LAD system.
- Plant tissue sampling/analysis will be done at peak standing crop rather than spring and fall sampling to assess soil contaminant loading, plant uptake, and potential toxicity to herbivores.
- Establish soil and plant study sites on new control sites probably further from the LAD area because of the concern over potential contamination of existing control sites.

- Establish soil and plant sampling transects across the application zone from both sprinkler types and between the lateral~~s~~ distribution lines. Objective is to better define the impact zones of current and earlier LAD systems.
- Evaluate soils and plant communities in the Goslin Gulch drainage channel to review contaminant levels and examine potential shrub mortality in the floodplain.
- Additional characterization and monitoring of areas where LAD has been terminated to assess natural recovery or leaching of the soils, trends in plant community composition, and plant uptake of contaminants.
- Initiate biomass production studies on sites within and outside of the LAD area.
- Determine treated pad solution quality and quantity entering the soil resource through sampling at ground level under differing weather conditions and proximity to risers within the sprinkler application area

<u>Land Application Systems – a Developing Reclamation Tool</u>

From a technical or resource management standpoint, the experience with LAD areas in Montana has been educational. Operations in the past have been inadequately planned and have assumed that existing sprinklers and piping on site could be used to set up the LAD system. Water to be land applied has been inaccurately characterized and the water chemistry has continued to evolve over time complicating treatment before LAD and changing the quality of the water being land applied over what was predicted.

Detailed baseline inventories of soil and plant communities, evaluations of quality and quantities of the various waters to be land applied (i.e. treated process solutions, stormwater, mine drainage, etc.) and irrigation planning is needed. Irrigation planning by professionals with experience in irrigation and land application are essential. Experienced installation personnel supervised by the designers of the system are an important factor in successful installation and operation. Management and operation plans are pivotal to the success of the LAD system. Individuals who have had agricultural experience with irrigation are essential and they should understand the consequences of improper operation. Operating a LAD system requires regular maintenance as lateral pipes and risers break, pumps quit working, sprinkler heads fail, and elk, livestock, and vehicles damage LAD system components which require immediate responses.

LAD systems are not meant to be primary treatment systems. They are meant to be polishing treatment systems only. Most primary water treatment systems at mine sites removing metals or cyanide complicate LAD system water quality by adding sodium and other parameters that are not removed in the primary treatment system. This limits the ability to land apply volumes of water on a particular soil or plant community.

LAD systems also have limited seasons of use because of the short growing seasons in Montana especially at higher elevations. Detailed planning is needed to identify storage requirements needed over winter. LAD simply may not work at a site unless water can be piped to lower elevations for storage and more efficient disposal during the growing season.

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Attachment 1.

GOSLIN FLATS LAND APPLICATION AREA
Soil Profile Description
S. Fisher 9.22.03

BALL FIELD "SERIES"(*)

Location: Goslin Bench Heil transect site - west pit on remnant bench, 30 yards west of the end of old lateral #66 and #108 in the new numbering system; drainageway separates this western site from the eastern location which is very close to the last riser on the lateral – subsequently removed in 2002

Classification:

Site Status: site has not been irrigated with effluent from the heap leach pads; low probability of much drift reaching this bench as it lies to the west of the land application system with prevailing wind direction to the southeast

Physiography: southwestern facing A (0 to 2 percent) slope; nearly level bench top; thought to be of fluvial, lacustrine, and glaciofluvial origin

(*) the term series in this instance refers to an aggregation of soil pedons similar in their chemophysical characteristics and capabilities for supporting land application; it is not intended to meet all of the requirements of the soil series as utilized by the Soil Survey Division of the NRCS-USDA.

Description:

A_{11} 0 to 4 cm.; weak to moderate fine granular peds separating readily to a single grain structureless condition; few roots; estimated less than 10 percent coarse fragment content with few as large as 2.5 inches in diameter; mixed lithology in the coarse fragment materials; noneffervescent; lower boundary is clear and smooth.

A_{12} 4 to 10 cm.; weak fine and medium subangular blocks separating to moderate medium granular structure; few roots but more than in the A11 horizon – horizon not matted with roots as is encountered in some sites in the land application area; estimated 10 to 20 percent coarse fragments with some as large as 3.5 inches in diameter; mixed lithology in the coarse fragment materials; noneffervescent; lower boundary is clear and smooth.

Bt 10 to 23 cm.; weak to moderate fine and medium prisms separating to moderate to strong fine prismatic structure; many roots with large concentrations in the vertical cracks between the prisms; estimated 20 to 35 percent coarse fragments ranging up to 3 inches in diameter; mixed lithology in the coarse fragment materials; noneffervescent; lower boundary is clear and wavy.

IIB_3 23 to 35 cm.; weak to moderate fine and very fine angular blocks grading to a structureless condition in the lower portion of the horizon; structural ped development overwhelmed by the coarse fragment content; many roots – slightly less than in the Bt; estimated 45 to 60 percent coarse fragments ranging up to 1.5 inches in diameter; coarse fragment content is very distinct from above/below horizons – well rounded, smaller in diameter, packed in horizontally with soil fines occupying potential voids between the coarse fragments; effervescent in upper portion of horizon increasing to strongly effervescent in lower portion; lower boundary is clear and wavy.

IIIC 35 to 66 cm.; massive structureless condition; few roots; horizon moderately cemented with carbonates; estimated 60 to 80 percent coarse fragments ranging to 4.5 inches in diameter; mixed lithology in the coarse fragment materials; slightly effervescent; lower boundary is gradual and wavy.

IVC_1 66 to 84 cm; massive structureless condition; no roots; horizon cemented to a lesser degree than IIIC1 – check NP and EC analytical data as sulfates may be higher; estimated 50 to 70 percent coarse fragments; violently effervescent; lower boundary is gradual and wavy.

IVC_2 84 to 106 cm.; massive structureless condition; no roots; weak if any cementation; estimated 60 to 80 percent coarse fragment material; violently effervescent; lower boundary is gradual and wavy; sample number

IVC_3 106 to 130 cm.; massive structureless condition; no roots; no cementation; estimated 60 to 80 percent coarse fragment material; violently effervescent; lower boundary is gradual and wavy; sample number

Attachment 2.

ANALYTICAL METHODOLOGIES FROM THE MONTANA DEPARTMENT OF ENVIRONMENTAL QUALITY, PERMITTING AND COMPLIANCE DIVISION – SOIL, OVERBURDEN, AND REGRADED SPOIL GUIDELINES (1998)

Parameters	Procedures
(a) (i) Preparation of soil samples for analysis	Air dry samples at less than or equal to 35^{o} C. Break up clods for disaggregation of sample (less than or equal to 2 inch). Pick out and set aside rock fragments (gravel, pebbles, etc.) for further analysis [see (m) below]. Disaggregate sample material until it just passes a 10-mesh (2-mm) sieve (avoid grinding coarse fragments). Rock fragments left on the sieve after disaggregation should be set aside for further analysis [see (m) below]. A rubber pestle in an agate mortar, a roller, or a motorized disaggregator should be used to disaggregate samples. During the entire sample preparation procedure, excessive disaggregation of sample material must be avoided.
(ii) Subsampling of sieved (<2 mm) soil materials for analysis	U.S.D.A. Handbook 60, 1954 - Diagnosis and Improvement of Saline and Alkali Soils, pp. 83-84. Or use standard sample splitter to obtain the specified sample size.
(b) Preparation of saturation extract and saturation percentage determination. Endpoint of saturation may be difficult to determine in montmorillonitic-dominated materials.	U.S.D.A. Handbook 60, Methods 2 and 3a, pp. 84 and 88, and Method 27a, p. 107 or A.S.A Monograph #9, 1982 Methods of Soil Analysis Part 2, Method 10-2.3.1, p. 169.
(c) pH (determination using saturated paste)	U.S.D.A. Handbook 60, Method 21a, p. 102 or A.S.A Monograph #9, 1982 Methods of Soil Analysis Part 2, Method 10-3.2, p. 171 and Method 10-2.3.1, p. 169.
(d) Conductivity of saturation extract in dS/m (mmhos/cm) at 25EC	
U.S.D.A. Handbook 525, 1978, Laboratory Methods Recommended for Chemical Analysis of Mined-Land Spoils and Overburden in Western United States, Method 1, pp. 22-24 or A.S.A. Monograph #9, 1982 Methods of Soil Analysis Part 2, Method 10-3.3, pp. 172-173.	Analysis by atomic absorption spectrometry (AAS), U.S.D.A. Handbook 525, Method 2, pp. 24-25, or by inductively coupled plasma optical emission spectrometry (ICP-OES), A.S.A. Monograph #9, Part 2, 2nd ed., 1982, Method 3-5.4, pp. 57-59 or A.S.A. Monograph #9, 1982 Methods of Soil Analysis Part 2, Method 10-3.4, pp. 173-174.
(e) Calcium content in the saturation extract in meq/l	
(f) Magnesium – same as for calcium	Same as for calcium.
(g) Sodium - same as for calcium	Same as for calcium.
(h) SAR (sodium adsorption ratio)	U.S.D.A. Handbook 60, p. 26. Use concentrations from e, f, and g above.
(i) Boron (ppm of soil)	Hot water soluble extract, A.S.A. Monograph #9, 1982 Methods of Soil Analysis Part 2, Method 25-9.1, pp.

	Parameters	Procedures
		443-444. Analysis of extract by azomethine-H (Method 25-5, pp. 435-436 in same reference) or by ICP-OES (see Calcium above).
(j)	Selenium - The occurrence, density, and distribution of primary and secondary selenium-accumulating plant species (Rosenfeld and Beath, 1964; Fisher et al, 1987) on the proposed mine plan area should be noted and described as part of the vegetative survey. The Department, in consultation with the company, will then determine a testing and evaluation program, if necessary, for soils in question.	
(k)	Particle size analysis. Report as % sand, % silt, and % clay, as well as the U.S.D.A. textural classification.	Hydrometer Method. A.S.A. Monograph #9, 1986, 2nd ed., Part 1, Method 15-5, pp. 404-408.
(l)	Percent organic matter (soil only). To be used in determining first lift salvage depths. Analyze samples of the A and upper B horizons.	Loss on Ignition at 375EC in a muffle furnace for 24 hours (adapted from Davies, 1974).
(m)	Percent rock fragments by volume.	Calculate % by weight and convert to % by volume, U.S.D.A., Soil Survey Investigations Report No. 42, 1992 - Soil Survey Laboratory Methods Manual, Methods 3B1b and 3B2, pp. 79-81.

Attachment No. 3

SUITABILITY GUIDELINES FROM THE MONTANA DEPARTMENT OF ENVIRONMENTAL QUALITY, PERMITTING AND COMPLIANCE DIVISION – SOIL, OVERBURDEN, AND REGRADED SPOIL GUIDELINES (1998)

Unsuitability Criteria for Soil or Soil Substitutes

Parameter	Suspect Level[1]	
pH		<5.5 >8.5
Conductivity (mmhos/cm)	Lift 1 Lift 2	> 4.0 > 4.0-8.0[2]
Saturation percentage	> 90% < 25%	
Sodium Adsorption Ratio	Lift 1 Lift 2	> 10.0 > 15.0
Boron		> 5.0 ppm
Molybdenum		> 1.0 ppm[3]
Selenium		> 0.1 ppm
Textural Class	c, sic, si, s, sc	
	Rock Fragments	Lift 1 > 20%[4 5] Lift 2 > 35%[4 5]
Other Parameters	Evaluated on a case-by-case basis	

[1]The suspect levels are to be used as a guide in evaluating the suitability of a soil material for reclamation. An evaluation should take into account the 'total system', including post-mining land use, topography, plant communities, wildlife habitat needs, etc. Interactive parameters may either nullify or verify the significance of a potential problem. [2]The actual maximum acceptable salt level will depend on the plant species proposed in the revegetation plan and the potential for upward salt movement. [3]The actual maximum acceptable salt level will depend on the plant species proposed in the revegetation plan and the potential for upward salt movement. [4]The actual maximum acceptable molybdenum level will depend upon the plant species proposed in the revegetation plan and their potential for molybdenum accumulation.

[2] These values may vary depending upon the plant species proposed for revegetation and wildlife habitat reestablishment in specific locations (e.g., a soil with a very high rock fragment content throughout its profile may be completely salvaged if used for certain shrub or tree plantings).

[3] These values are based upon the >2mm fraction found in soils; this fraction can be determined by summing field % volume estimates of the 20-75, 75-250 and >250mm fractions and the laboratory % weight (converted to volume) of the 2-20mm fraction.

Unsuitability Criteria for Overburden and Regraded Spoils

Parameter	Suspect Level[1]
pH	< 5.5 > 8.5
Conductivity (mmhos/cm)	> 4.0-8.0[2]
Saturation Percentage	< 25% > 90%
SAR	> 20
Boron	> 5 ppm
Molybdenum	> 1.0 ppm[3]
Nitrate-Nitrogen	>130 ppm
Selenium	> 0.1 ppm
Textural Class	c, sic, si, s, sc
Acid-base potential	< -5 tons $CaCO^3$ equiv./1000 tons material
Other Parameters	Evaluated on a case-by-case basis

[1]See footnote 1 in Appendix A

[2]See footnote 2 in Appendix A

[3]See footnote 3 in Appendix A