EFFECT OF EARTHEN COVERS ON TAILINGS IMPOUNDMENT HYDROLOGY, PORE WATER CHEMISTRY AND GAS CONTENT[1]

by

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Abstract: At the Golden Sunlight Mine, Montana, a tailings impoundment was covered with 1) 71 cm of coversoil over 139 cm of waste rock; 2) 69 cm of coversoil over 70 cm of clay over 82 cm of waste rock; and 3) 94 cm of coversoil over 128 cm of borrow material, and these treatments were compared to bare tailings (Control). Plant cover and production were excellent and not significantly different between treatments with coversoil while plants failed to establish in bare tailings. During one year of natural precipitation, snowfall and snowmelt, water movement from earthen caps into tailings was not measurable. Lysimeter samples indicated all tailings were producing acid as indicated by decreasing pH, increasing specific conductance, and sulfate concentrations with time. No trends were apparent in profile oxygen concentra-tions with time, but oxygen concentrations generally decreased with depth. No oxygen concentrations were observed that would be limiting to *Thiobacillus ferrooxidans* or pyrite oxidation in tailings material. Since performance of all earthen covers were similar relative to hydrology, pore water chemistry, oxygen content and plant growth, it was concluded that any one of these covers would be equally effective for impoundment closure. Given that the integrity of waste rock and clay layers may degrade with time, use of a borrow material was recommended.

Additional Key Words: impoundment closure, plant establishment, acid production.

Introduction

The objective of this investigation was to evaluate several different tailings cover designs that enabled successful plant growth and minimized water movement into tailings. This field investigation was conducted at the Golden Sunlight Mine, a gold mine in southwest Montana, where a 50 ha tailings impoundment was planned for closure. Bond release on the decommissioned tailings impoundment requires construction of an earthen material cover and revegetation. A soil cover was evaluated in combination with a clay cap, a waste rock capillary barrier and an earthen subsoil buffer zone between soil and tailings. This investigation provided information that can be used to select a tailings cover for a decommissioned impoundment.

Characteristics of Capping and Tailings Material

A randomized complete block experimental design consisting of three replications with four treatments was established on a 50 ha, 30 m deep tailings impoundment (Figure 1). Tailings consisted of intermixed layers of slimes and sands having a pH of 8 and acid-base account of -53 t/1000 t (Table 1). Prior to this investigation, the tailings impoundment had been in a state of saturation. The clay cap was compacted to yield a water percolation rate of 10^{-6} cm/sec or less. Waste rock consisted of oxidized overburden from the mine pit and had a particle size distribution as follows: 5% ≤ 5 cm diameter, 70% 5 to 15 cm diameter, and 25% 15 to 75 cm diameter. Coversoil material had been salvaged from nearby natural soil horizons. Borrow material was excavated from an unconsolidated geologic unit adjacent to the tailings impoundment.

Vegetation Factors

Plots were hydroseeded in fall 1992 with Russian wildrye, wheatgrasses (Pubescent, Western,

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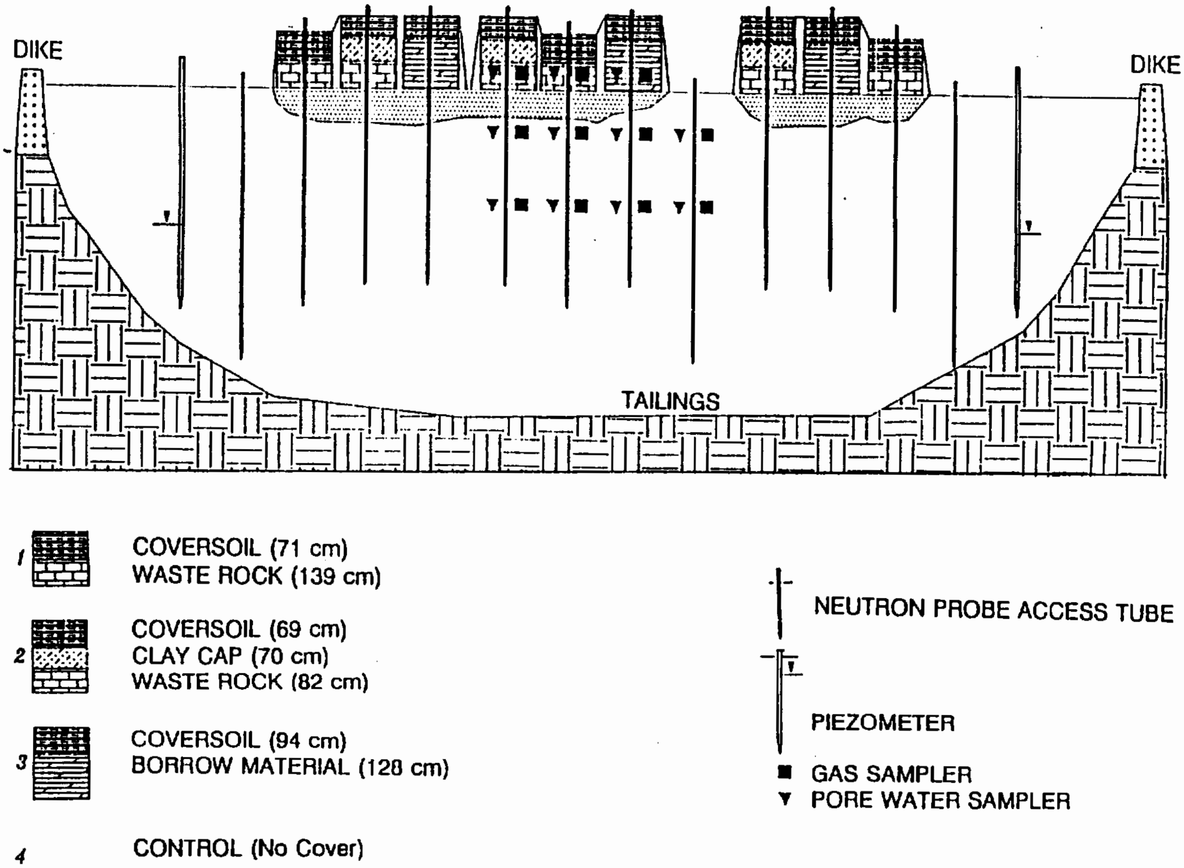

Figure 1. Profile view (not to scale) of the Golden Sunlight Mine tailings cover study.

Table 1. Physicochemical characteristics of tailings and materials used to construct earthen caps.

Material	Dry Bulk Density (g/cm^3)	Saturation Percentage	Percent Coarse Fragment	% Particle Size Distribution Sand	Silt	Clay	Texture Class
Coversoil	1.6	53.1	1.1	44	22	34	Clay Loam/ Sandy Clay Loam
Borrow Material	1.7	35.8	39.1	59	21	20	Sandy Clay Loam/ Sandy Loam
Clay Cap	1.6	75.6	2.0	26	22	52	Clay
Waste Rock	-	22.0	-	-	-	-	-
Tailings	1.4	25.5	0.0	54	35	11	Sandy Loam

Material	pH	Electrical Conductivity (mmhos/cm)	Water Extractable (mg/liter) Mg	Na	Ca	SO_4	Total (mg/kg) Cu	Pb	Mn	Zn	Sodium Adsorption Ratio	Acid-Base Account (Tons $CaCO_3$/1,000 Tons)
Coversoil	8.0	1.7	41	124	200	117	-	-	-	-	2.1	-
Borrow Material	8.2	3.4	94	89	404	372	190	62	150	210	1.0	-1
Clay Cap	8.1	0.7	13	59	52	37	-	-	-	-	1.9	11
Waste Rock	6.3	2.0	70	42	268	403	140	10	440	130	0.6	12
Tailings	8.0	6.5	49	1,030	608	1,429	190	50	130	320	10.8	-53

Crested and Slender), Indian ricegrass, alfalfa, Yellow sweetclover and Fourwing saltbush. Because of slow plant establishment and the need for a plant cover to attain evapotranspiration for a water budget analysis, plots were drill seeded with barley in the spring of 1993. All plots were fertilized with 52.4 kg N/ha, 52.4 kg P_2O_5/ha, and 52.4 kg K/ha.

While the treatment means for percent cover were significantly different from the control, there were no significant differences between treatments (Table 2). Mean average plant production values ranged from a low of 4,490 kg/ha for the coversoil/ borrow material treatment, to 5,260 kg/ha for the coversoil/rock treatments. No significant differences were found between treatment means for plant production, but all treatments were significantly different than the control which had no plant production. Cover was dominated by barley (*Hordeum vulgare*) on all vegetated plots. Barley cover ranged from 30.5 to 74.3 percent. Wheatgrasses (*Agropyron* spp.) were present at 7.3 to 28.8 percent. Legumes and other species constituted less than five percent of the cover.

Impoundment Hydrology

Prior to earthen cap construction, the saturated impoundment was allowed to drain. Within three months, piezometers indicated the saturated zone had dropped to the 6.5 m tailings depth. It was hoped that these earthen caps would intercept precipitation and with evapotranspiration, little or no water would move into tailings.

Changes in profile water content during July 1992 to July 1993 were compared to recharge from precipitation and loss due to evapotranspiration (Figure 2). Precipitation during this period was 12% greater than the longterm average of 33.8 cm. During the period October through February 1992 all earthen covers lost small amounts of water (1.5 - 2.0 cm), but none of this water entered the tailings impoundment. By May 1993, spring precipitation recharged all earthen caps with approximately 6 cm of water compared to the lowest water content in covers during winter. During this period, tailings water content remained stable or decreased under all cover

Table 2. Plant cover and production in test plots.

Treatment	Cover (Percent)			
	Replication 1	Replication 2	Replication 3	Mean
Coversoil/Waste Rock	82.0	77.5	61.7	73.7b[1]
Coversoil/Clay Cap/Waste Rock	77.5	61.7	67.5	68.9b
Coversoil/Borrow Material	71.7	73.3	50.8	65.3b
Control	0.0	0.0	0.0	0.0a

Treatment	Production (kg/ha)			
	Replication 1	Replication 2	Replication 3	Mean
Coversoil/Waste Rock	7680	5090	3010	5260b[1]
Coversoil/Clay Cap/Waste Rock	5780	5070	4200	5020b
Coversoil/Borrow Material	6170	3370	3930	4490b
Control	0	0	0	0a

[1] Means in the same category marked with same letters are not significantly different at P = 0.05 level.

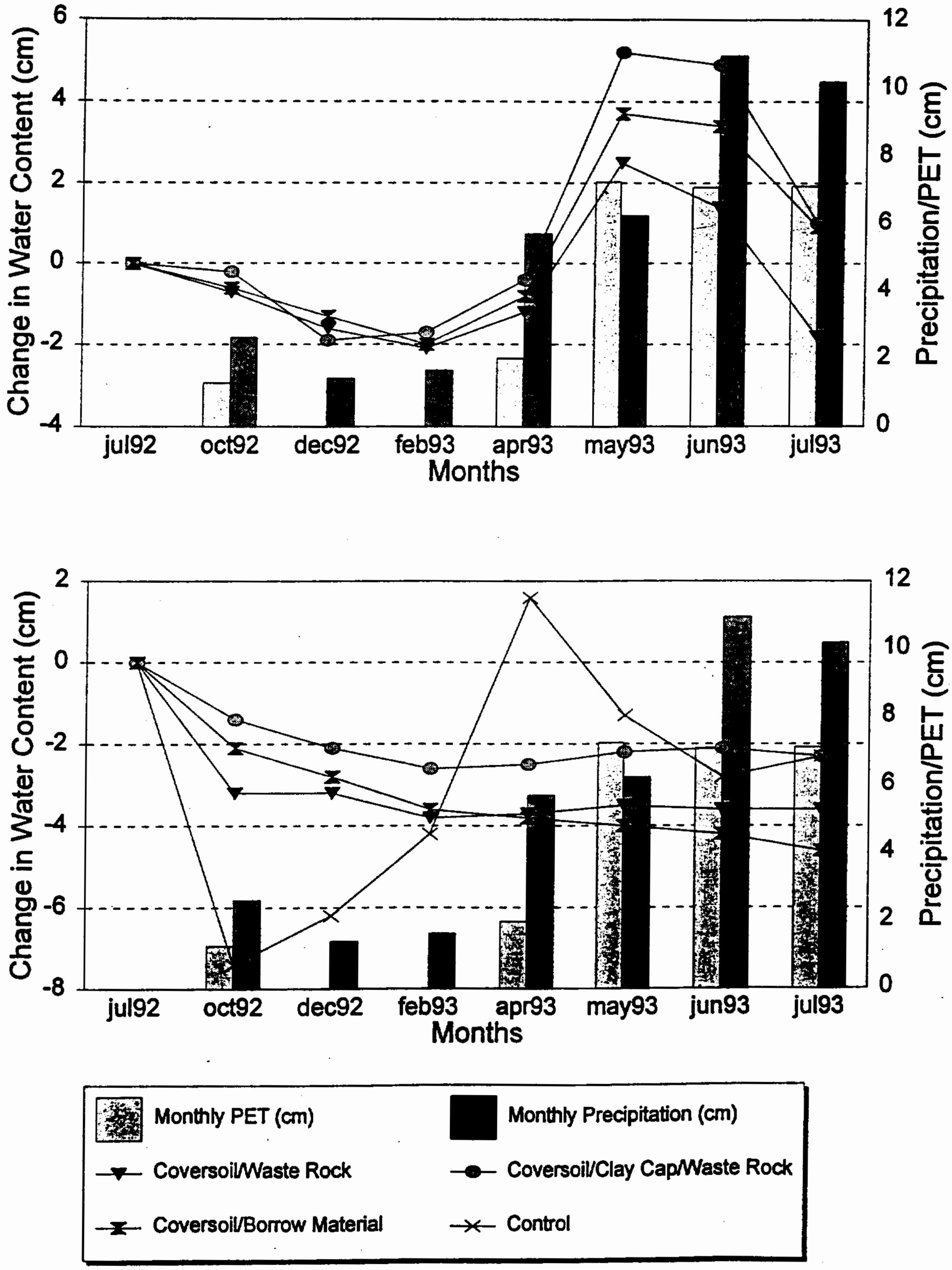

Figure 2. Changes in water content from July 1992 levels in the total cover (top figure) and top 91 cm of tailings (bottom figure) compared to potential evapotranspiration (PET) and precipitation.

treatments. Most of the spring recharge water was lost to evapotranspiration during June and July 1993, even though precipitation totaled approximately 21 cm during these two months. During the May through July period of heavy precipitation, tailings water content remained stable or decreased. These data indicate that during one hydrologic year of natural precipitation, snowfall and snowmelt, water movement from earthen caps into tailings was not measurable.

Profile Oxygen Distribution

Oxygen samples were collected via an access pipe equipped with sampling ports at the prescribed depth interval (Figure 1). Each port was connected to a tygon tube to the surface. At the surface, a syringe was used to evacuate a gas sample after the port and tubing line had been evacuated. The gas sample was transferred from the syringe to a vacu-pak plastic bag for analysis. The access pipe was packed in silica sand.

These data indicated oxygen decreased with depth for all treatments and the control but no definitive trend toward decreasing concentrations with time was apparent (Figure 3). These data indicate the clay cap with a mean hydraulic conductivity of 1.6×10^{-7} cm/sec was not a barrier to entry of oxygen into tailings.

Other investigators (Myerson 1981, Harris and Ritchie 1986, Barnes and Romberger 1968) have reported critical oxygen levels limiting to *Thiobacillus ferrooxidans* at 0.03154% O_2/L, and Singer and Stumm (1970) suggested total elimination of oxygen would be required to eliminate acid production. Therefore, none of these capping systems were effective at precluding oxygen entry into tailings that could prevent acid production.

Tailings Pore Water Chemistry

Pore water samples were evacuated from soil using lysimeters (SoilMoisture Equipment Company, Model 1920) placed at the prescribed profile depth (Figure 1). The lysimeter porous cup was packed in silica sand and a bentonite seal prevented surface entry of water and vertical flow along the access pipe.

Tailings pore water pH generally declined one to two units during the one year monitoring period (Figure 4). This was the case whether an earthen cap was present or not. During this same period, specific conductance (SC) increased 2.5 to 7.0 mmhos/cm and sulfate increased from 2500 to 8000 mg/L in tailings pore water.

The overall trends (decreasing pH, increasing SC and sulfate) suggest that acid production is continuing in tailings beneath all earthen cap materials tested. Although tailings will produce salts and acidity over time, these contaminants are not expected to migrate into earthen cap materials and will not impact plant growth.

Effectiveness of Tailings Impoundment Earthen Covers

The waste rock layer remained dry during the study period and appeared to be an effective capillary barrier. Since materials atop the waste rock, i.e. borrow material, clay, coversoil, will migrate into voids in the waste rock in time, the long-term functionality of the capillary barrier may be impaired. Although not impossible, it is very difficult to build a capillary barrier that will be stable forever. Therefore, implementation of a waste rock capillary barrier would require careful selection of material placement in the vertical sequence.

The clay barrier was successfully constructed and had a mean hydraulic conductivity of 1.6×10^{-7} cm/sec. This barrier should inhibit the downward flow of water. However, the other earthen caps evaluated also served as an effective barrier to water penetration into tailings. Data indicated the clay cap was not a barrier to entry of oxygen into tailings. Since tailings were allowed to drain prior to construction of earthen caps, air quickly entered several meters into tailings to the depth where materials were saturated. This effect may have masked the ability of the clay cap to impede oxygen entry into tailings. However, oxygen levels did not decrease with time beneath the vegetated clay cap system. The clay cap had fluctuating water contents during the period of this investigation. Clay cap stability may decrease with time as a function of fluctuating water contents in combination with freezing and thawing and as the tailings settle over time. For example, in a laboratory setting, Kim and Daniel (1992) found that the hydraulic conductivity of a clay layer compacted dry to optimum density increased 2 to 6 times after five freeze/thaw cycles. When the clay layer was compacted wet, the hydraulic conductivity increased 100 times after five freeze/thaw cycles.

Construction of the borrow material layer was performed with greater ease compared to other cover treatments. Hydrologic characteristics were not

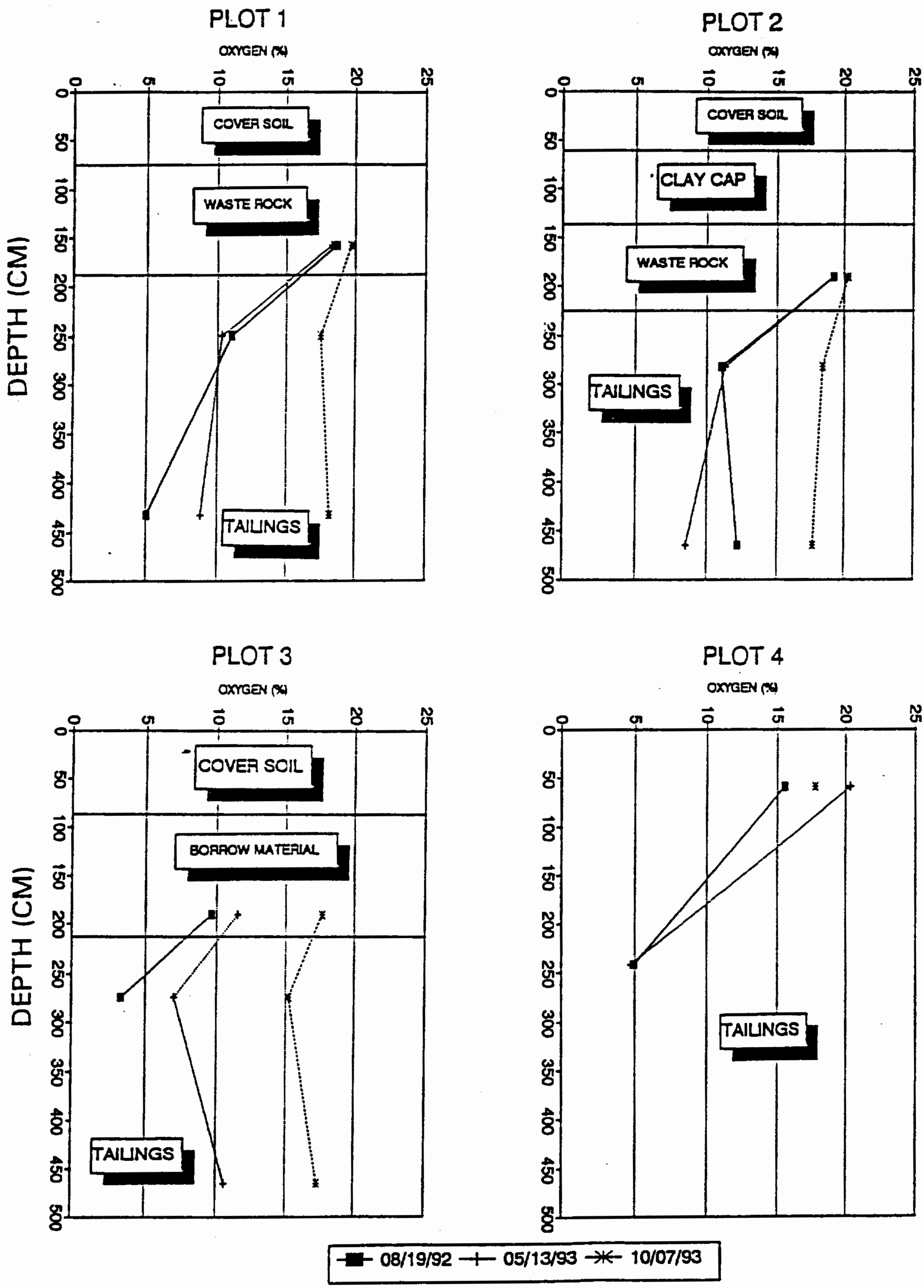

Figure 3. Changes in soil oxygen concentrations (% O_2/L) with depth and time for the Golden Sunlight Mine tailings pond reclamation study.

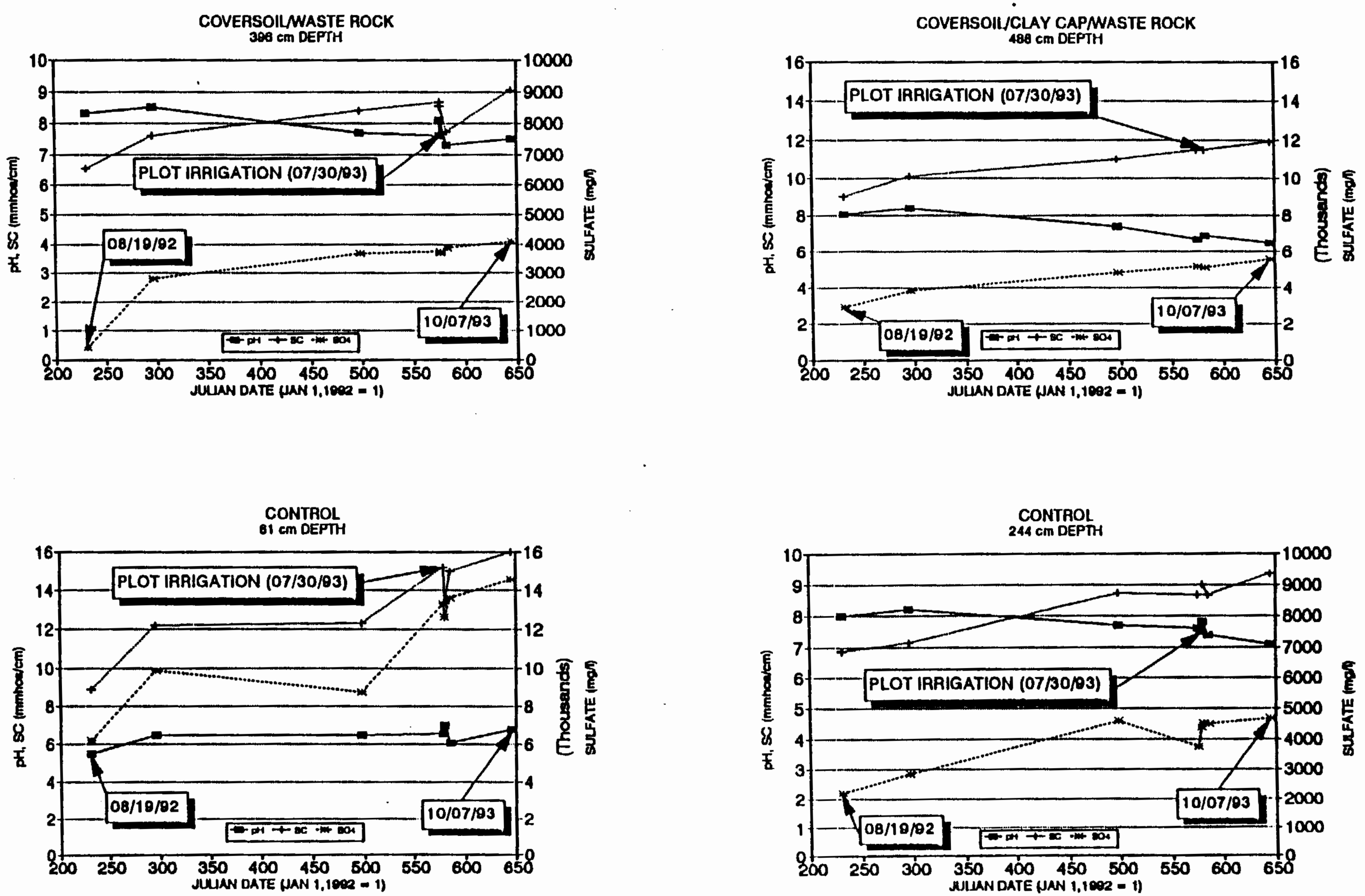

Figure 4. Changes in pore water pH, SC, and sulfate with time in tailings material with and without the presence of earthen caps.

significantly different within the framework of a scientific experimental design, there was in fact no differences between covers pertaining to drainage into tailings. Given that the integrity of waste rock and clay layers may degrade with time, use of borrow materials was recommended for this impoundment.

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* This paper is a synopsis of findings that are presented in greater detail by Dollhopf et al. 1995.