Water Quality Investigations in the Historic Mining District of Chloride and Adjacent Areas in the Cerbat Mountains (Mohave County, Arizona)

by

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Table of Contents

Figures 2

Tables 2

Abstract 3

1 Background and Problem Statement 3

2 The Study Area 5

2.1 Physiogeography 5

2.2 Past and Present Use 6

3 Investigation Methods 7

4 Water Quality Standards 7

5 Results 9

5.1 Chloride and its Surroundings (I + II) 9

5.2 The Historic Mining Area southeast of Chloride (III) 12

5.3 The Historic Mining Area of Golconda and Cerbat (IV + V) 17

5.4 Cyprus Mineral Park Mine (VI) 19

6 Water Quality and Water Contamination due to Historic Mining 20

7 Recommendations 22

8 References 24

Appendix 26

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Figures

Fig. 1 Index map showing area of report (shaded) in Mohave County, Arizona

Fig. 2 EC values along Tennessee Wash (March 1995)

Fig. 3 Concentrations of As, Cd and Cr in the water samples and their relation to different numeric standards (roman numerals correspond to sections in table 7)

Fig. 4 Concentrations of Cu, Ni and Pb in the water samples and their relation to different numeric standards (roman numerals correspond to sections in table 7)

Fig. 5 Concentrations of Zn, Fe and Mn in the water samples and their relation to different numeric standards (roman numerals correspond to sections in table 7)

Fig. 6 Sampling sites and color of deposits in the Eureka Canyon

Fig. 7 Section of the Cerbat Mountains study area and sample locations (topographic base: Chloride Quadrangle) (see appendix)

Fig. 8 Section of the Cerbat Mountains study area and sample locations (topographic base: Cerbat Quadrangle) (see appendix)

Tables

Tab. 1 Heavy metal concentrations in groundwater of Tennessee Canyon and Tennessee Mine area exceeding DWS and HBGL standards (units are mg/L)

Tab. 2 Heavy metal concentrations in surface water of the Tennessee Canyon/Tennessee Mine mining area exceeding DWS and HBGL standards (units are mg/L)

Tab. 3 Heavy metal concentrations in surface water of the Golconda mining area exceeding DWS and HBGL standards (units are mg/L)

Tab. 4 Heavy metal concentrations of two Chloride wells after summer 1995 (units are mg/L)

Tab. 5 Radiochemical analyses of wells north of Chloride and at Big Wash (units are pCi/L)

Tab. 6 Site descriptions of the water samples listed in table 7 (see appendix)

Tab. 7 Water quality in the historic mining district of Chloride and adjacent areas (Cerbat Mountains, Mohave County, Arizona) (see appendix)

Abstract

Groundwater and surface water quality was analyzed in several watersheds of the historic mining district of Chloride and the southern adjacent former mining areas on the western slope of the Cerbat Mountains, northwest of Kingman, in Mohave County, Arizona. The investigations were carried out to characterize the general water quality, and particularly to ascertain, to what degree groundwater and surface water are contaminated due to the past mining activities.

Groundwater in the immediate vicinity of the large Tennessee Mine, where ore processing took place, was found to be seriously polluted by heavy metals. But neither the groundwater in the town of Chloride, nor the groundwater in the Cerbat Wash watershed, showed evidence of contamination by subsurface or surface water flow from the upstream mining areas. Independent of the historic mining nitrogen contamination was found in the Chloride wells, which could be attributed to improperly functioning private septic tanks.

In contrast to the groundwater almost all surface waters were contaminated by heavy metals and other contaminants due to the historic mining activities.

1 Background and Problem Statement

Located in the Sacramento Valley at the western foot of the Cerbat Mountains, 20 miles northnorthwest of Kingman, lies the little town of Chloride. Once it was a booming mining town, at the turn of the century, with almost 2,000 residents; today Chloride has approximately 420 citizens.

The section of the Cerbat Mountains east and southeast of Chloride (see fig. 1) was a heavily mined area in former times. Most of the small mines operated intermittently between the 1860's and the middle of this century, some of them still being worked until the 1970's. Today they are abandoned, but numerous tailings and waste rock dumps left from mining, milling, and leaching activities, as well as old mining shafts, building ruins, and rusted steam-engines still can be seen in the Cerbat Mountains canyons. In several streambeds of the canyons, especially below old tailings, strange colored deposits are easily recognized -- fine sediments washed out from the tailings and dumps during heavy rains.

Today the Cerbat Mountains and their foothills are predominantly used for cattle grazing.

Because of permanent water shortage problems, Chloride is now supplied with drinking water by a system which pumps water from Big Wash in the Detrital Valley basin. Only a few wells in town are still used -- mostly for garden irrigation. Water for livestock is pumped from aquifers at the base of the Cerbat Mountains or diverted from streams and springs in the mountains. On the open range cattle and horses drink directly from small streams and springs.

In years of water shortages such as 1990, always a possibility in arid regions, an additional exploitation of the local groundwater for domestic water supply and the use of surface water for agricultural livestock watering might become necessary (ADWR 1990).

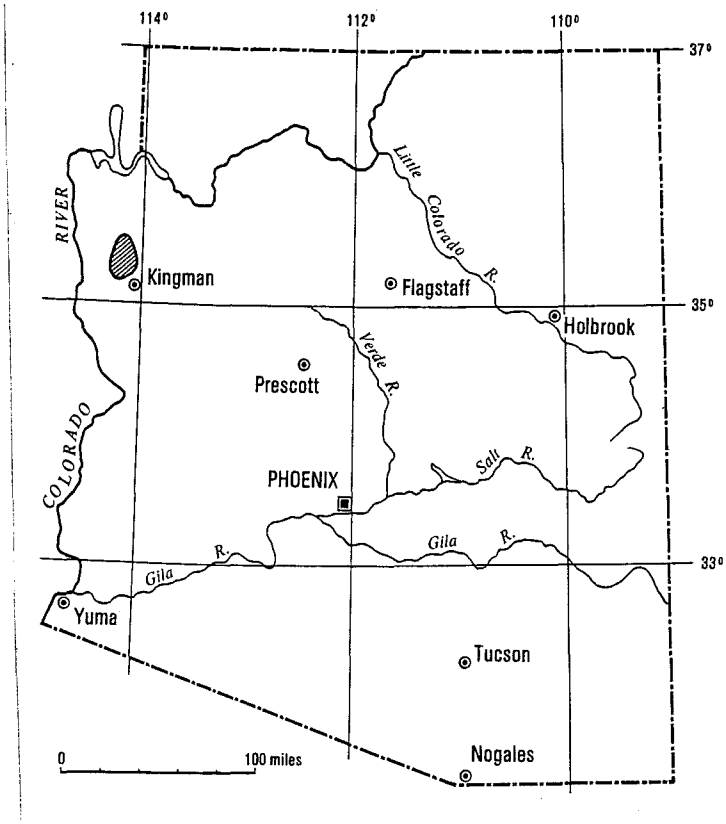

Fig. 1: Index map showing area of report (shaded) in Mohave County, Arizona

But considering the widespread former mining activities in this region, legitimate concerns arise about the groundwater and the surface water quality both in the former Chloride mining district and in the entire Wallapai Mining District. But only scant information on this subject is available. The first data concerning the Sacramento Valley were published by GILLESPIE et al. (1966) and GILLESPIE & BENTLEY (1971) and were integrated into the map of RASCONA (1991), which gives some information about the groundwater quality in the Sacramento Valley basin. RASCONA comes to the general conclusion that "... the groundwater of the Sacramento Valley basin is of good chemical quality." But only four samples in a 10-mile-radius around Chloride have been analyzed: three for electrical conductivity and fluoride; additional detailed chemical analyses (Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, alkalinity) were carried out on just one of the four samples. ADWR (1990) reports highly mineralized water in the immediate vicinity of Chloride and a radionuclide content (especially the most toxic Ra226) exceeding the maximum contaminant level set by the Environmental Protection Agency (ADWR 1990: 2, 5). No data were available for surface waters. And none of these reports contains information about heavy metals in groundwater or surface water. The only data concerning water contamination by heavy metals, due to historic mining activities in the Cerbat Mountains, were found in the study of HYDE (1994) about the American Legion, Stockton, and Neal watersheds on the east slope of the Cerbat Mountains, 10 miles north of Kingman.

The present study was therefore designed to answer the following questions about the water quality in Chloride, its surroundings, and the southern adjacent sections of the Cerbat Mountains:

1. How can the general water quality be characterized?
2. To what degree are the groundwater and the surface water contaminated by pollutants due to the historic mining activities?
3. What are the prospects for the future water use and water supply, given its quality?

2 The Study Area

2.1 Physiogeography

Geology and Geomorphology

The Cerbat Mountains start immediately north of Kingman and proceed in a northwesterly direction. The range is composed mostly of Precambrian igneous and metamorphic rocks (granite, gneiss, shist) containing younger dikes and of some Tertiary and Quaternary volcanics. Altitudes range from 4,000 to 6,500 feet. A rugged topography with precipitous slopes and numerous canyons is characteristic of the west side of the Cerbat Mountains (THOMAS 1953: 392).

On the west, the mountains are flanked by the Sacramento Valley, a typical alluvium-filled basin of the Basin and Range Provice. The alluvial deposits of the basin are underlain by Precambrian igneous and metamorphic rocks and have been divided by GILLESPIE & BENTLEY (1971: 1) into older (Tertiary age), intermediate (Pliocene to Pleistocene age), and younger (Holocene age) units. Altitudes of the basin floor range from 3,400 feet in the northern basin, southwest of Chloride, to about 460 feet near the town of Topock at the Colorado River. An abrupt transition separates the range from the Sacramento Valley Basin. Pediments, partially veneered with alluvial material, and valley fill surfaces slope away from the mountains with gentle gradients (see ADWR 1990: fig. 5).

The washs draining the mountains are oriented southwestward to the Sacramento Wash in the middle of the basin. Stream flow in the upper reaches of the Cerbats is intermittent -- flowing continually for several months -- whereas stream flow in the lower reaches of the Cerbats and on the pediments and the broad alluvial fans is ephemeral. Sacramento Wash itself is an ephemeral stream; it originates in the Cerbat Mountains north of Chloride, flows south, then west, and eventually discharges into the Colorado River at Topock (RASCONA 1991).

Climate

The average annual precipitation at the western foot of the Cerbat Mountains (altitudes of about 3,500 to 4,000 feet) is 6 to 10 inches. The mean annual air temperature is 56 to 67° F. In the mountains (above 4,000 feet) the average annual precipitation increases to 12 to 20 inches and the mean annual air temperature decreases to 47 to 57° F. One half of the precipitation occurs from December to

March. Because of the high evaporation rate humidity is very low, especially during the summer (RICHMOND & RICHARDSON 1974: 4 f., 13).

Hydrogeology

Generally the igneous and metamorphic rocks do not yield water except along fractures and in weathered zones. The principal aquifer in the Sacramento Valley region is the older alluvium. Depth to water ranges from less than 100 feet near Topock to over 1,050 feet below land surface in Golden Valley (RASCONA 1991). Wells located at the foot of the Cerbat Mountains in and around Chloride (in the sections 3, 4, and 9, T23N/R18W) are completed in Precambrian igneous and metamorphic rocks. They have reported depths between 19 and 115 feet below land surface, but dominantly between 30 and 40 feet (after data of ADWR 1995).

Recharging of the alluvium can mostly be attributed to infiltration of streamflow, whereas aquifers found in the fractured and weathered rocks -- like the aquifers of Chloride -- are recharged in direct response to precipitation events (ADWR 1990: 5, 6).

2.2 Past and Present Use

The study area belongs to the Wallapai mining district extending over the central part of the Cerbat Mountains northnorthwest from Kingman. It includes the historic mining camps of Chloride, Mineral Park, Cerbat, and Stockton as well as outlying and intermediate areas such as the Todd Basin. Many of the mines were discoverd between 1863 and 1900 by prospectors in quest of *silver* and *gold*. Later, improvements in transportation facilities and milling methods made the production of *lead* and then of *zinc and lead* much more profitable. Zinc-lead production reached its peak in the years 1915-17 under the stimulus of high metal prices (see DINGS 1951: 124 ff.). Compared to that, *copper* production was low in the first half of this century (DINGS 1951: tab. 1), but became very important when the Duval Mine at nearby Mineral Park (todays Cyprus Mineral Park Mine) and the Emerald Isle Mine started operation (BLM 1990: 96 and Appendix 31). Some of the mines did milling and leaching on site. For leaching usually sulfuric acid and arsenic acid was used. Also cyanide and mercury were sometimes used for processing operations (L. GITTINGS 1995, personal communications).

At the end of the 1940's mining had practically ceased to exist in Mohave County and all the camps were deserted except Chloride. Only the Cyprus Mineral Park Mine is still operating (the Emerald Isle Mine halted production in the early 1990's). Today several small leaching operations reprocess tailings of old mines for gold recovery (BLM 1990: 96).

As a visible sign of the once booming mining district, all Cerbat Mountain canyons are dotted with relics of abandoned mines.

At present, livestock grazing, wildlife habitat, recreation, and homesites are the principal land uses (BLM 1990).

3 Investigation Methods

Field work

The field work[1] lasted from March 4 to April 14, 1995. Water measurements and collecting of water samples were carried out between March 4 to 14 and on March 30 and 31. Important for the interpretation of the water analyses were the heavy rains that fell in March (3-5 and 3-11), which led to an increased flow even in usually dry sections of the washs. Temperatures mostly were in the sixties to low seventies.

Field measurements of pH values and electrical conductivity were made to get a general view of alkalinity and mineralization of groundwaters and surface waters (instruments: pH-meter 91 of WTW; conductometer LF 91 of WTW). At the same time water samples were collected from wells and streams; samples of streambed sediments were also collected (see footnote 1). One sample of the Chloride townwater (WP 4) was used as a background for drinking water quality; as a background for heavily contaminated water, the samples WP 9 and WP 10 from the discharge of the currently operating Cyprus Mineral Park Mine were used.

Laboratory Analyses

The water samples were submitted to McKenzie Laboratories, Phoenix, on March 16, 1995 (WP 1 to WP 25) and on April 3, 1995 (WP 26 to WP 28, EP 31).

4 Water Quality Standards

Water pollution is normally caused by anthropogenic raised concentrations of microorganisms and organic and inorganic chemicals. Some substances have unpleasant or nuisance effects, but some are poisonous in defined doses. Actually hazardous for human and animal health are elevated heavy metal concentrations, most of which are toxic; especially their compounds are toxic even when their elemental forms are not[2]. Heavy metals accumulate in the food chain because some of their compounds are very stable in the environment.

Any evaluation of the chemical quality of groundwater and surface water needs to refer to specific numeric standards for concentrations of their constituents.

The limits published in the Arizona Administrative Code (AAC) (ADEQ 1995) are the official and enforceable water quality standards for the state of Arizona. Different numeric standards for surface waters are assigned to seven designated uses:

1. DWS Domestic Water Source
2. FC Fish Consumption
3. FBC Full Body Contact
4. PBC Partial Body Contact

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1 Included was the sampling of soils and streambed sediments, the mapping of mining and prospecting sites and the mapping of soil erosion in selected areas. These data will be discussed in a subsequent paper.

2 Arsenic (As) -- a semimetallic element --is, strictly speaking, not a heavy metal, although it has a density of 5.72 g/cm^3. But in the ensuing discussion arsenic will be included with the heavy metals.

5. A&W Aquatic and Wildlife
6. AgI Agricultural Irrigation
7. AgL Agricultural Livestock Watering

Aquatic and Wildlife is divided into two types, acute and chronic, in each of the following four classes:

1. A&Wc Aquatic and Wildlife, cold water
2. A&Ww Aquatic and Wildlife, warm water
3. A&We Aquatic and Wildlife, ephemeral
4. A&Wedw Aquatic and Wildlife, effluent dominated water

Individual streams are then assigned official designated uses. Sacramento Wash and its tributaries (e.g. Tennessee Wash) are protected for Aquatic and Wildlife, ephemeral and Partial Body Contact uses. Because there are only a few A&We and PBC standards available, they were not listed in table 7. Below are shown the levels which have been exceeded by one or more of the samples (units are in mg/L):

Standards	As	Cd	Cu	Zn
A&We, acute	0.44			
A&We, chronic	0.23			
PBC		0.07	5.20	28.00

(units are mg/L)

The aquifer water quality standards apply to aquifers classified for the drinking water protected use (ADEQ 1995: 36) and correspond to the DWS standards.

The surface water and groundwater of the Cerbat Mountains probably met drinking water quality standards before mining activities, as can be seen by the analyses of some background samples (see samples WP 8, WP 11 and WP 17, tab. 7 in this study; see also HYDE 1994: tab. 4, samples #1 and #5). For that reason, not the A&We and the PBC standards, assigned to the Sacramento Wash drainage system, but the drinking water standards (**DWS**) are used as a comparison to characterize the water quality and to discuss the question about the influence of historic mining activities. Additionally the **AgL** standards are listed because of the widespread livestock grazing in this area (see tab. 7).

For some chemicals no numeric standards are available in the AAC (ADEQ 1995). Therefore three other standards are listed in table 7:

1. The health-based guidance levels (**HBGLs**) for drinking water and soil, developed by the Office of Risk Assessment and Investigation, Arizona Department of Health Services (ADHS). They represent human ingestion levels above which adverse health effects during long-termed exposure are likely. The HBGLs have no official status as cleanup standards. Rather they constitute levels that may be useful for reference in environmental work. (ADEQ 1992: 1).
2. The secondary maximum contaminant levels (**SMCL**) after U.S. EPA (1988).
3. The maximum allowed concentration (**MAC**) standards for drinking water, which are binding upper levels in the member states of the European Community (see HÜTTER 1994: 163 ff.).

5 Results

For study areas and location of the samples see figures 7 and 8, and for detailed sampling site descriptions see table 6. Complete analyses are listed in table 7, additionally heavy metal concentrations are shown in diagrams of figures 3 to 5.

5.1 Chloride and its Surroundings (I + II)

The surveyed area covers the sections 1 to 5 T23N/R18W and 32 to 36 T24N/R18W. Samples were collected in section 3, T23N/R18W and in sections 32 and 34 T24N/R18W.

The area includes the "Tennessee Wash watershed" northeast of Chloride whose headwaters begin near the divide between the Sacramento and the Hualapai Valley basin. Only one sample (WP 17) does not belong to the Tennessee Wash watershed (it belongs to the headwater system of the Sacramento Wash).

All canyons in this watershed have been heavily mined. Upstream of Chloride Tennessee Canyon contains numerous mines. The Tennessee Mine, situated about one mile east of Chloride and a quarter mile below the mouth of the Tennessee Canyon, was the largest producer in the entire Wallapai Mining District. According to statistical data (cumulative from 1901 through 1948) the Tennessee-Schuylkill Mine had the highest production of gold (42,383 oz.), silver (1,514,187 oz.), copper (839,837 lbs.), lead (59,897,096 lbs.) and zinc (66,805,907 lbs.) (DINGS 1951: 147). The Tennessee Mine milled and leached a large part of its ore on site. Several other mines did small scale processing, recognizable by the particle size distribution of the tailings (e.g. Elkhart and Schuylkill Mine) and/or by the dumps with leaching traces on the stones.

The mining in the Chloride area declined in the 1940's and never recovered. The Tennessee Mine closed down in 1948, probably not only as a consequence of financial problems but also because of water infiltrating the main shaft, which could never be pumped out (L. GITTINGS 1995, personal communication).

General Chemistry

Field measurements of *electrical conductivity* in the Tennessee Wash roughly characterize the waters leaving the mining area (see fig. 2). Starting upstream the last mine in the Tennessee Canyon, the EC values increase downstream (545, 610, 730, 830 µS/cm) and reach a maximum (1,050 µS/cm) below its confluence with an unnamed small wash flowing directly through the area of the Tennessee Mine tailings and the western adjacent mine. Further downstream, at the crossing with the old Chloride road, the value decreases again (830 µS/cm). This steady increase of EC values indicates that chemical substances are being washed out of the tailings and are entering the surface water.

Groundwater in the Tennessee Wash watershed tends to be highly mineralized. With the exception of the background sample of the Chloride townwater, the values for *total dissolved solids* (*TDS*) range from 827 to 4,133 mg/L (Tennessee Mine main shaft). They are all far in excess of the SMCL standard of 500 mg/L and half of them

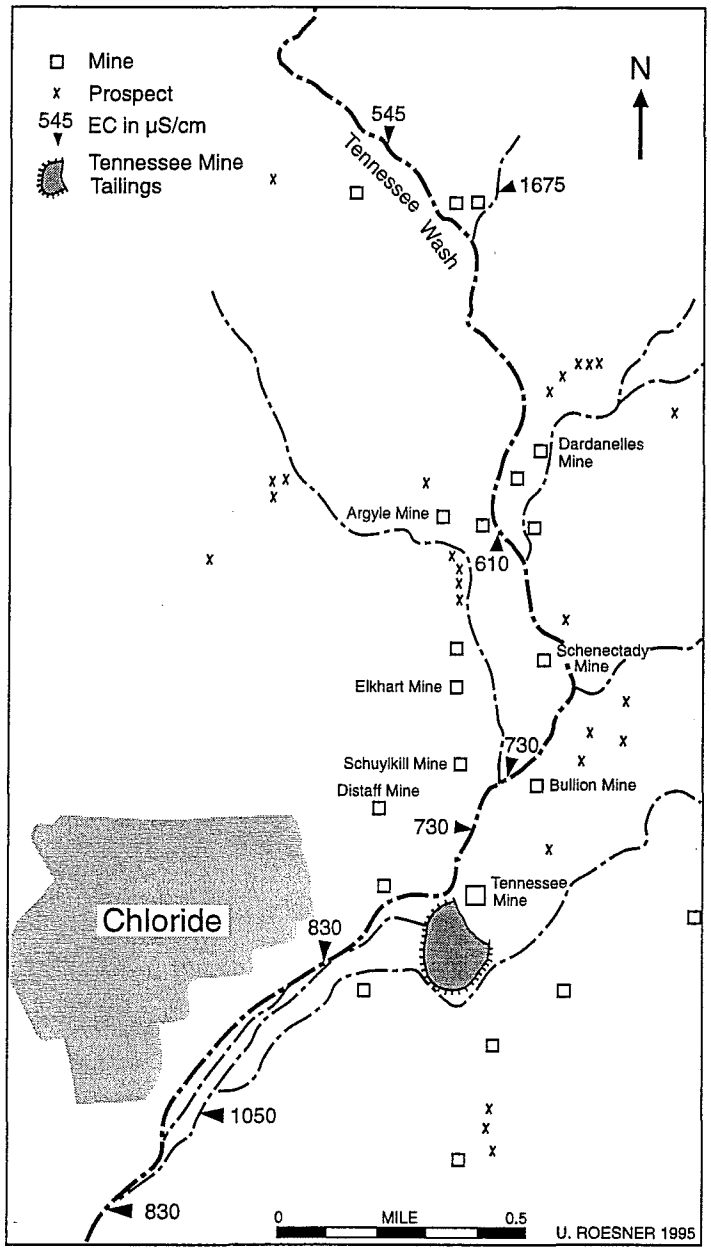

Fig 2: EC values along Tennessee Wash (March 1995)

would be categorized as brakish. But the high values in town groundwater samples cannot definitely be attributed to the mining area, because high TDS values might be natural for this area. That is shown best by the well above the Arizona Magma mine (WP 17): this groundwater has a TDS value of 2,735 mg/L, but no relics of mining operations have been found in the drainage system above.

In contrast to this the high surface water TDS values can be traced to the historic mining areas. The TDS values (WP 1, 5, 22, 23) exceed the SMCL standard in three of four cases, although the water was diluted by heavy rains on the days before the sampling. The highest values were found in the stream flows below the Tennessee Mine area.

No numeric standards are available for *alkalinity* and *bicarbonates*. But compared with HYDES (1994: tab. 4) background samples from the eastside of the Cerbat Mountains, the alkalinity values ranging from 200 to 370 mg/L appear normal.

The *chloride* values in the Fire Department well (WP 3) and in the well above the Arizona Magma mine (WP 17) are both far above the HBGL and the MAC standards. But, similar to the groundwater TDS values, high chloride concentrations don't indicate pollution, since the Tennessee Mine main shaft (WP 6) chloride value is not elevated.

Similiar reasoning applies to the major cations (*calcium, magnesium, sodium and potassium*): compared with the MAC standards, which are the only available ones, the cations in general have rather high concentrations in the groundwater samples, whereas the surface water samples meet all standards except one (WP 21 in the slow stream flow of a branch of the Tennessee Wash directly alongside the Tennessee Mine tailings).

All groundwater and surface water samples meet the standards for *fluoride*, whereas the *sulfate* values of the groundwater samples exceed in most cases by far the HBGL standard of 400 mg/L. But, as with TDS, the cations, and the anion chloride, no firm relationship can be established between the high sulfate values and the former mining activities in this area, assumptions notwithstanding.

Regarding the general quality of the Chloride aquifer the *nitrate-nitrogen* (NO_3-N) concentrations in the Fire Department well (WP 3), the NELSON well (WP 15), and the HERBST well (WP 21) are particularly remarkable. All samples exceed the HBGL standard of 7 mg/L and two of them (WP 3, WP 15) are far in excess of the DWS standard; water of the Fire Department well with 62 mg/L nitrate-nitrogen is more than six times above the 10 mg/L DWS limit. In contrast to this all other groundwater and surface water samples are either below the minimum reporting limit or far below both standards. Because nitrate is a typical disintegration product of nitrogen-bearing organic matter, the high nitrogen concentrations in Chloride can be attributed to domestic wastewaters (from septic tanks).

Heavy Metals

In three groundwater samples (WP 1, 6, 24) the *arsenic* concentration exceeds by 2.4 to 20 times the allowed DWS standard (see tab. 1). All three samples are from groundwater of the heavily mined Tennesse Canyon or from groundwater in the close proximity to the Tennesse Mine. In contrast to this the wells in town (HERBST well, NELSON well, and Fire Department well) are at or below the level.

ID	As	Cd	Pb	Zn	Fe	Mn
WP 1	0.122				0.35	
WP 6	0.999	0.0068	2.000	3.30	77.00	6.40
WP 24	0.491	0.0189	0.650	10.00	6.40	4.80
DWS	0.050	0.0050	0.050	5.00	NA	NA
HBGL	0.050	0.0035	0.005	1.40	0.30*	0.70

* SMCL standard, HBGL not available

Tab. 1: Heavy metal concentrations in groundwater of Tennessee Canyon and Tennessee Mine area exceeding DWS and HBGL standards (units are mg/L)

The samples from the Tennessee Mine main shaft (WP 6) and the well SSW of the Tennessee Mine tailings (WP 24) also show elevated concentrations of *lead*, *zinc*, *iron*, *manganese*, and *cadmium*; particularly the lead value of WP 6 is 40 times higher than the DWS standard.

In spite of these elevated concentrations the Chloride aquifer (see WP 3, 15, 22) has been unaffected.

This is in contrast with the increased heavy metal values in the surface waters (see tab. 2). The sample from Tennessee Wash at the mouth of Tennessee Canyon (WP 2) exceeds only the DWS standard for *arsenic* and *iron*. The other three samples from stream flow alongside and below the Tennessee Mine tailings (WP 5, 21, 23) also exceed the DWS standards for *cadmium*, *chromium*, *copper*, *iron*, *manganese*, *nickel*, *lead* and *zinc* (each sample with more or less different heavy metal combinations and proportions). Particularly sample WP 5 from the Tennessee wash just downstream of the big Tennessee Mine tailings stands out. These results prove that remarkable amounts of heavy metals - particularly arsenic - are washed out of the old tailings by heavy rains or are entering the surface water from polluted, shallow groundwater.

ID	As	Cd	Cr	Cu	Ni	Pb	Zn	Fe	Mn
WP 2	0.068					0.029		9.70	
WP 5	0.098	0.0195	1.10			0.170	5.90	4.20	
WP 21		0.6100		1.50	0.22	0.018	200.00	5.70	15.00
WP 23	0.080	0.0062						0.54	
DWS	0.050	0.0050	0.10	1.00	0.14	0.050	5.00	NA	NA
HBGL	0.050	0.0035	0.10	1.30	0.14	0.005	1.40	0.30*	0.70

* SMCL standard, HBGL not available

Tab. 2: Heavy metal concentrations in surface water of the Tennessee Canyon/Tennessee Mine mining area exceeding DWS and HBGL standards (units are mg/L)

5.2 The Historic Mining Area southeast of Chloride (III)

The surveyed area covers the sections 2, and 8 to 17 T23N/R18W. Samples were collected in the sections 2 T23/R18, 10, 11 and 14 T23N/R18W.

Included in this area are the headwaters of a southern tributary of Tennesse Wash, which runs parallel to the trunk stream for about three miles to the southwest before joining it. One part of the headwater system begins near the Lucky Boy Mine, the Samoa Mine, and the Cherum Peak; the other part starts further west at a lower elevation. The entire watershed was named "Falls watershed" because of the waterfall 2.2 miles eastsoutheast of Chloride. The southern adjacent watershed of an unnamed wash draining directly southsouthwest into the Sacramento Wash was called "Eureka Mine watershed".

Like the Tennessee Wash watershed east of Chloride, this area was heavily mined and prospected. Particularly the Payroll, the Minnesota-Connor, the Copper Age, the

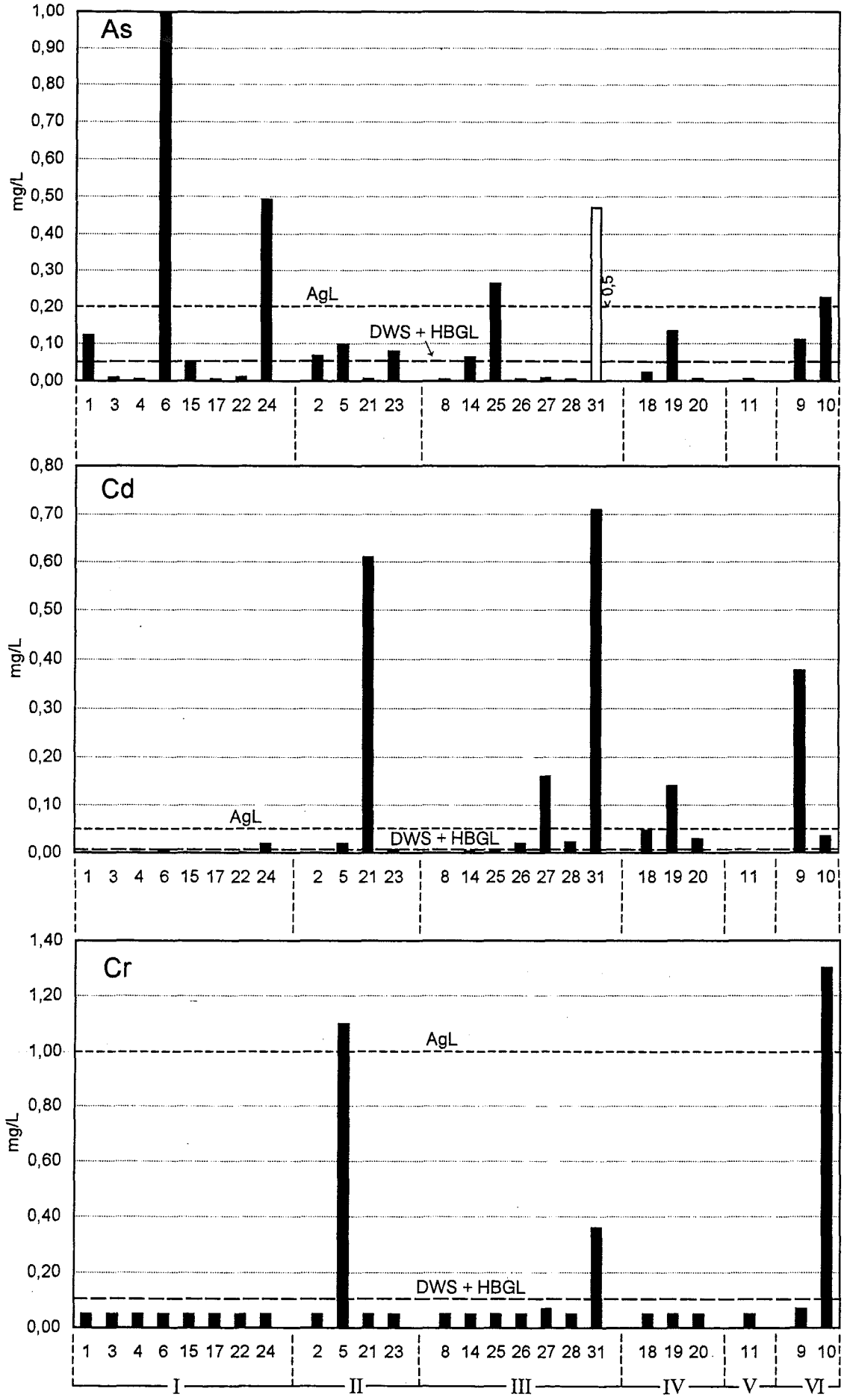

Fig. 3: Concentrations of As, Cd and Cr in the water samples and their relation to different numeric standards (roman numerals correspond to sections in table 7)

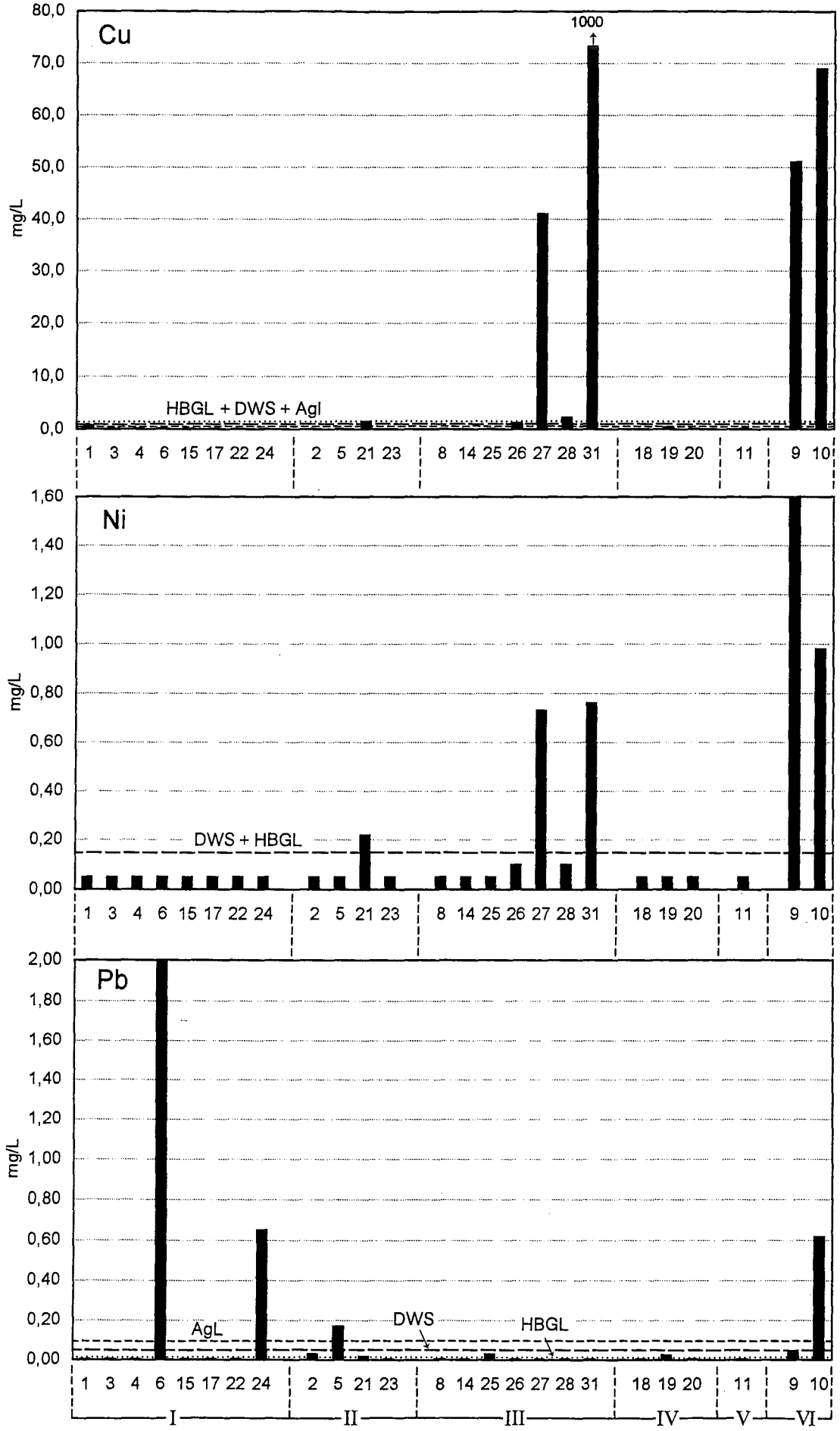

Fig. 4: Concentrations of Cu, Ni and Pb in the water samples and their relation to different numeric standards (roman numerals correspond to sections in table 7)

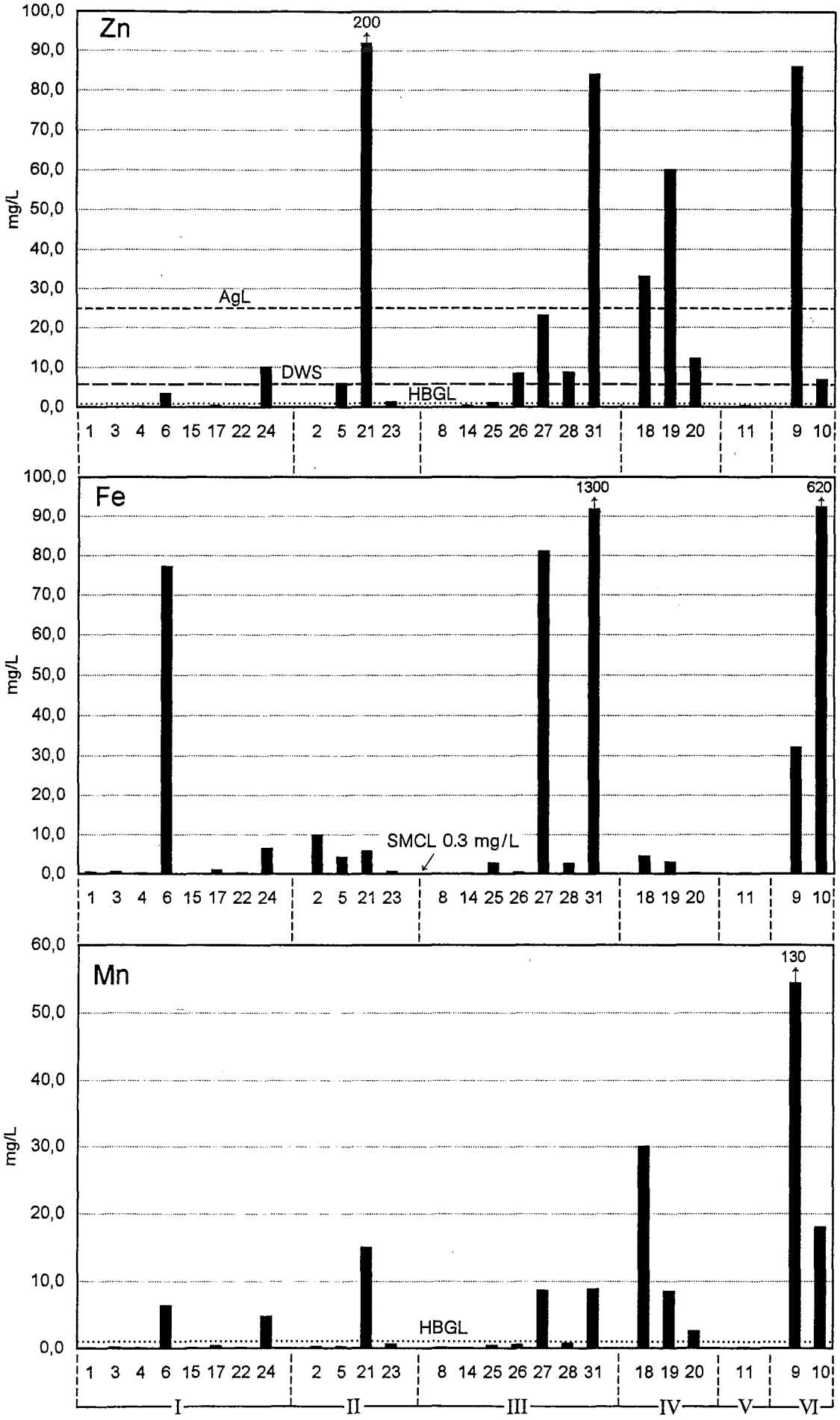

Fig. 5: Concentrations of Zn, Fe and Mn in the water samples and their relation to different numeric standards (roman numerals correspond to sections in table 7)

Jupiter, the Twentieth Century and the Eureka Mine deserve mention. At those mines the crushed and milled ore was leached on site (see also WILSON et al. 1934: 110).

Below the Minnesota-Connor Mine the tailings almost fill the upper canyon. This canyon joins the one of the Altata Mine where WP 25 was taken from a stream flow. The tailings of the Copper Age Mine further to the south have already been so heavily eroded that the fine sediments cover an extensive area west of the mine. Sample WP 14 was taken from a stream just below the eroded tailings. The tailings of the Jupiter Mine as well as the ones of the Eureka Mine to the south strech directly across a wash and have been eroded downstream. At several other smaller mines in the southern canyons the tailings are subject to similar erosional transport.

The streambed in the canyon below the Eureka Mine was totally covered with a strange, light blue, soft, and pudding-like deposit in the lower section; in the upper part of the canyon the color became white. Below the confluence of this stream flow with the rusty brown discharge of a tunnel, the color of the deposits changed into a greenish yellow. Three water samples were taken at this site (see fig. 6): one just above the confluence (WP 26), one from the tunnel discharge (WP 27), and one just below the confluence (WP 28). In the southern tributary of this stream a similiar soft, pudding like, greenish yellow streambed deposit was found. From this deposit sample EP 31 was taken 0.15 miles above its confluence with the Eureka Canyon.

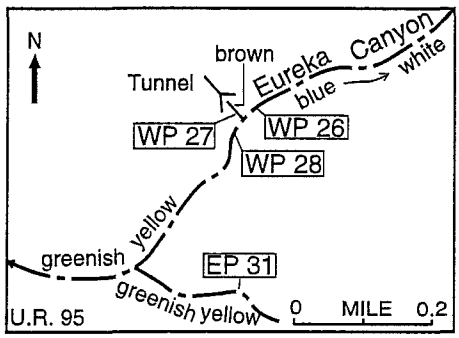

Fig. 6: Sampling sites and color of deposits in the Eureka Canyon

General chemistry

In the following discussion, keep in mind that sample EP 31 represents the chemical precipitations on the streambed and therefore has much higher concentrations than the water samples. EP 31 offers a comparison but will not be included in the discussion of the water samples.

The *electrical conductivity* shows downstream decreasing values: e.g. from the Petroglyphs area with 1,100µS/cm 1.25 miles to the southeast with 610µS/cm or from 0.35 miles below the Minnesota Connor Mine with 3,150µS/cm 0.15 miles down to the canyon mouth with 2,850µS/cm. These findings can be explained by the fact that there are no further tailings downstream whose discharges might affect the flowing water as in the Tennessee Canyon (see above).

Except for sample WP 8 from the northern part of this watershed, all surface waters are highly to extremely mineralized; the *TDS values* range from 1,333 mg/L to 3,562 mg/L. The highest concentrations are in the stream flows below the Copper

Age Mine and the Minnesota Connor Mine, a proof of the negative effects of the historic mining on the water quality.

Compared with the available standards and with the background samples of HYDE (1994: tab. 4) from the east slope of the Cerbat Mountains, all waters show normal values for *alkalinity*, *chloride*, *fluoride*, and *nitrate-nitrogen* except the tunnel discharge (WP 27), which is extremely acidic with a *pH value* of 3.0.

Samples WP 14 and WP 25 with their very high *sulfate* concentrations (2,300 resp. 1,400 mg/L) show a strong affect of the mining as does sample WP 27 (1,600 mg/L) from the tunnel discharge. But just below the confluence with the stream flow of the Eureka Canyon the sulfate content of this tunnel discharge is promptly diluted.

Regarding the major cations (*calcium*, *magnesium*, *sodium*, *potassium*) only the values of the samples from the immediate vicinity of the Copper Age Mine and the Minnesota Connor Mine show increased concentrations.

Heavy metals

The samples taken in the stream flows below the Copper Age Mine (WP 14) and the Minnesota Connor Mine (WP 25) have elevated *arsenic* values. The arsenic concentration in WP 25 appears critical: it exceeds the DWS standard more than five times and is also above the AgL standard. But with exception of the moderately higher *cadmium* and *iron* values in WP 25, these two water samples meet all other DWS standards for heavy metals.

In contrast to that all samples of the Eureka Canyon (WP 26, 27, 28) meet the DWS standard for *arsenic*, but have elevated concentrations of *cadmium*, *copper*, and *zinc*. Additionally the tunnel discharge (WP 27) shows elevated *nickel*, *iron*, and *manganese* values.

The "sludge" sample (EP 31) is far in *excess of all above mentioned heavy metal standards except arsenic*. Its extremely high concentrations of copper and iron might explain the strange greenish yellow color.

5.3 The Historic Mining Area of Golconda and Cerbat (IV + V)

The surveyed area covers the sections 36 T23N/R18W; 6 T22N/R17W and 1, 2, 11, 12 T22N/R18W. Samples were collected in three sections: 6 T22N/R17W, 1 and 2 T22N/R18W.

The area extends east- and southeastward of the huge Cyprus Mineral Park Mine tailings (see chap. 5.4). Two streams flow together east of the tailings. The trunk stream ends in the water damed on top of the tailings not far downstream of the confluence. One of the headwater streams heads upstream of the Todd Basin with the historic town of Golconda (in the following discussion this canyon is called Golconda Canyon) and into the southern adjacent canyon with the Paymaster Mine at its head. The other stream drains the area of the Cashier Mine east of the Cyprus Mineral Park Mine tailings.

The most productive mine in this district was the Golconda Mine in the Todd Basin. After the Tennessee Mine it was the second-largest producer of gold (20,752 oz.), silver (510,180 oz.), copper (354,703 lbs.), and zinc (56,226,020 lbs.) and the third-

largest producer of lead (2,031,719 lbs.) in the Wallapai district from 1901 through 1948 (DINGS 1951: 147). Almost the entire production occured from 1908 to 1917. In 1917 a fire destroyed the mill and the other surface equipment. Only a few small-scale attempts to resume operations have been made.

In the upper part of the Golconda Canyon are the ruins of the historic town of Golconda. At the end of the last century about 1,200 miners are believed to have lived here. Golconda was also a station along the stage coach route which lead from Chloride over the Cerbat Mountains into the Hualapai Valley (L. GITTINGS 1995, personal communication). Several building ruins, mines, and tailings are left in the upper part of the canyon. One sample (WP 19) was taken in the discharge just below the largest tailings in the upper canyon. Water flows from at least two tunnels. The water of the lower tunnel (sample WP 18) crosses the big tailings at the canyon mouth leaving a coating of rust-red sticky deposits on the streambed. A third sample (WP 20) was taken at the road crossing below the confluence of the Golconda Canyon stream and the stream from the southern adjacent canyon.

No well was found in the watershed of the Golconda Canyon. As a substitute one groundwater sample (WP 11) was taken in the Cerbat Wash watershed, which experienced similiar mining activities, to gain some general information about a possible threat to the groundwater. The Cross-H-Ranch well, supplying drinking water for the ranch, is situated just at the mouth of the Cerbat Canyon.

General chemistry

The *EC values* increase as long as the water runs through the mining area and begin decreasing again as soon as the water has left the mining area (390 - 1,900 - 1,250 - 1,100µS/cm; all measurements from the same day). This dependence of the EC value on the flow alongside or through a heavily mined district is comparable with the findings in the above discussed sections of Chloride and its eastern and southeastern surroundings (I, II + III).

In general the waters are not as highly mineralized as in the areas discussed above except the tunnel discharge (WP 18) with a *TDS value* of 1,503 mg/L.

The same sample contains *sulfate* more than twice the HBGL value, whereas the other two samples have normal sulfate concentrations.

The sample from the tailings discharge (WP 19) shows a very low *pH value* of 4.9. A low pH is obviously characteristic for mining discharges, because all waters which have been in direct contact with tailings or mine waters have pH values far below the normal level in this area (e.g. WP 9: 3.2; WP 10: 2.6). The normal pH values in this section of the Cerbat Mountains are 7.0 to 8.4.

Heavy metals

The heavy metals *arsenic*, *cadmium*, *zinc*, *iron* and *manganese* have been found in the three samples (see tab. 3). As expected, the most contaminated water is the tailings discharge (WP 19): the cadmium concentration of 0.14 mg/L is 28 times higher than the DWS standard, the zinc concentration of 60.0 mg/L exceeds the standard 12 times and arsenic is 2.7 times higher. In the tunnel discharge (WP 18) arsenic meets the DWS standard but cadmium is almost 9 times higher and both zinc and manganese are far above the level. In contrast to this the lower heavy metal

values of sample WP 20, which was taken below the confluence with the surface water flow from the south, clearly show the decrease of the heavy metal concentration from the dilution of cleaner waters. But in spite of this dilution the cadmium concentration in the water is still 5.7 times above the DWS level and more than 8 times above the HBGL level. Zinc and manganese as well are above the save range of DWS levels.

ID	As	Cd	Pb	Zn	Fe	Mn
WP 18	0.023	0.0462		33.00	4.40	30.00
WP 19	0.134	0.1400	0.025	60.00	2.90	8.50
WP 20	0.006	0.0286		12.00		2.60
DWS	0.050	0.0050	0.050	5.00	NA	NA
HBGL	0.050	0.0035	0.005	1.40	0.30*	0.70

* SMCL standard, HBGL not available

Tab. 3: Heavy metal concentrations in surface water of the Golconda mining area exceeding DWS and HBGL standards (units are mg/L)

WP 11, taken at the mouth of the Cerbat Wash canyon, was selected to assess the potential for groundwater contamination from the mining operations further up the canyon. None of the values exceeds a single standard, indicating that this groundwater has been unaffected by the mining.

5.4 Cyprus Mineral Park Mine (VI)

The surveyed area extends over the sections 21 to 24, 26 to 27, 34 to 35 and 2, 3 T23N/R18W.

The Cyprus Mineral Park Mine (former Duval Mine) was one of the latest to start operations, but it has become the largest in Mohave County. It is still in operation and is now the largest copper producer in Mohave County (BLM 1990: 96). In former times turquoise was also mined in the open pit copper mine (MALACH 1977: 8).

The Cyprus Mineral Park Mine tailings are about 1.2 miles long, almost half a mile wide, and 40 to 50 feet high. The area is drained by several washs with ephemeral stream flow, running for some miles parallel to each other in a southsouthwestward direction before reaching the Sacramento Wash.

Two samples were taken: one represents the stream flow just below the Cyprus Mineral Park place (section 24 T23N/R18W) and the other reflects the quality of water seeping through a dam at the southwest end of the tailings. These heavily contaminated samples serve as a comparison for all other water samples in the study area.

General chemistry

Both samples show extremely low *pH values* (3.2, 2.6), extremely high *TDS values* (5,549 and 6,625 mg/L) and extremely high *sulfate* contents (4,500 and 6,000mg/L). The values for the major *cations* are moderate to high.

Heavy metals

In both samples *arsenic*, *cadmium*, *chromium*, *copper*, *nickel*, *lead*, *zinc*, *iron*, and *manganese* are in most cases very high to extremely high above the DWS standards. To cite only a few examples: the cadmium concentration of the stream flow just downstream the Cyprus Mineral Park Mine place (WP 9) is 75.4 times higher then the standard, copper exceeds the standard 51 times, and zinc 17.2 times.

The discharge from the tailings ran down the washs until about two years ago, when the dam around the tailings was built. In years with very heavy rains the water could eventually reach the Sacramento Wash.

6 WATER QUALITY AND WATER CONTAMINATION DUE TO HISTORIC MINING

Groundwater along the western slope of the southern Cerbat Mountains *is highly mineralized.* None of the groundwater samples meets the SMCL standard of the U.S. EPA (1988) for total dissolved solids (TDS). That can be attributed to the very *high sulfate concentrations*, because a proportional relationship between high sulfate values and high (measured) TDS values can be recognized; the same correlation applies to the surface waters. These elevated SO_4 concentrations explain why the TDS values calculated on the basis of electrical conductivity (EC) are constantly low: usually it is presupposed that the dissolved solids concentration in mg/L may be approximated by multiplying the EC values with 0.6, the approximate ratio of TDS in mg/L to EC in S/cm (RASCONA 1991). But the electrical conductivity of a hydrous solution is controlled by the different coductivities of the individual electrolytes (e.g. sulfate) and their different ratios. That is most likely the reason why the assumed relation between EC values and TDS values does not apply to groundwaters and surface waters of this area. Consequently any evaluation of water quality in this section of the Cerbat Mountains based solely on EC-calculated TDS values must be viewed critical.

The *high groundwater mineralization cannot be traced to groundwater flow from the heavily mined upper watershed or to infiltration of contaminated surface waters.* The investigations have shown that the groundwater in the studied area is naturally highly mineralized. For example the well above the Arizona Magma Mine, west of Chloride, has a TDS value of 2,735 mg/L (EC is 4,000 S/cm), and surface water upstream of the heavily mined Tennessee Canyon shows an EC value of 1,675 S/cm. The wells downstream of the mining areas do not have significantly higher TDS and EC values. Therefore it is nearly impossible to clearly separate natural and anthropogenic mineralization.

The *groundwater of Chloride is almost devoid of heavy metals*, whereas the *groundwater in the immediate vicinity of the historic mines is highly polluted with arsenic, cadmium, lead, zinc, iron, and manganese.*

Three explanations are possible for the lack of heavy metals in the Chloride groundwater:

The first explanation would be that there is no groundwater flow from the nearby mining district east of Chloride to the towns aquifer. That seems to be the most likely

explanation, because the groundwater in the proximal mountain footzone is found in the fractured/weathered zone of the Precambrian igneous and metamorphic rocks (ADWR 1990: 6). For that reason no uninterrupted groundwater aquifer may exist; rather, different groundwater systems, separated from each other, may be present. The hypothesis of interrupted groundwater systems in the Tennessee Canyon/Tennessee Mine area and the Chloride area is also supported by two facts: firstly the water level in the Tennessee Mine main shaft (at 4,160 feet) is much higher than the groundwater table in Chloride (e.g. 3,970 feet at the Fire Department well). Secondly the wells in the higher Tennessee Mine area did not run dry during hot summers as some wells in Chloride did (L. GITTINGS, personal communication).

The second explanation for the lack of heavy metals in the groundwater could be a possible dilution effect after the groundwater recharge during winter time, so that no heavy metal load is detectable. To clarify the last question two additional water samples, from the HERBST well and from the Fire Department well, have been taken in September 1995 after the dry summer period (see tab. 4). The heavy metal concentrations show no remarkable difference to the results of the same wells sampled in March 1995 (see tab. 7, WP 3 and WP 22). Therefore the dilution-explanation can be excluded.

ID	As	Cd	Cr	Cu	Hg
WP 29 (Fire Dept. well)	< 0.013	< 0.0005	< 0.05	< 0.05	< 0.0002
WP 30 (HERBST well)	< 0.005	< 0.0005	< 0.05	< 0.05	< 0.0002
DWS	0.050	0.0050	0.10	1.00	0.0021
HBGL	0.050	0.0035	0.10	1.30	0.0021
ID	**Ni**	**Pb**	**Zn**	**Fe**	**Mn**
WP 29 (Fire Dept. well)	< 0.05	< 0.005	< 0.05	< 0.05	< 0.05
WP 30 (HERBST well)	< 0.05	< 0.005	< 0.05	< 0.05	0.24
DWS	0.14	0.050	5.00	NA	NA
HBGL	0.14	0.005	1.40	0.30*	0.70

(No analyses for Ag and Se, because both metals never occurred in any of the previous samples)
* SMCL standard, HBGL not available

Tab. 4: Heavy metal concentrations of two Chloride wells after summer 1995 (units are mg/L)

A third explanation could be the influence of solubility and mobility of heavy metals in groundwater on their transport. The metal ion transport in groundwater can be affected by different soil parameters like pH, redox potential, organic content, and the particle size distribution of the soil (e.g. BRÜMMER et al. 1986, HORNBURG & BRÜMMER 1990, SCHEFFER & SCHACHTSCHABEL 1992, HÜTTER 1994). So it could be possible that the heavy metals are being immobilized in the soil by chemical reactions and adsorbtion. But considering the high concentrations of heavy metals in the immediate vicinity of the mines (e.g. WP 6, WP 24) and the relatively short distance to the Chloride wells (0.5 to 0.8 miles), that explanation appears questionable. Only further

detailed physical and chemical investigations of soils in the concerned area could prove or unprove this hypothesis.

In contrast to the groundwater samples *almost all surface waters are contaminated by arsenic, cadmium, chromium, copper, nickel, lead, zinc, iron, and manganese*, some of which even exceed the AgL standards. Additionally one has to keep in mind the increased flow from the heavy rains the days before, which diluted the load of pollutants. And one has to consider also, that summation of heavy metals (e.g. Cd/Zn) might result in toxic effects before a single standard is reached (HÜTTER 1994: 192).

The *surface water contamination can be attributed to the historic mining areas*, firstly because of the downstream decrease of various pollutants (shown for example by the decrease of cadmium and zinc concentrations in the Golconda canyon) and secondly because of the presence of cadmium which is a co-element of the zinc production, the dominant historic production in the Wallapai District. The surface water sample from the Petroglyphs area east of Chloride (WP 8), which is free of heavy metals, can be used as naturally clean background sample.

Besides the surface water affection, a contamination of the streambed sediments is to be expected, because of the heavy metal load of the stream flow. This hypothesis will be discussed in a subsequent article (see footnote 1).

To characterize the *water quality of the Chloride aquifer*: the water might have a salty taste because of its chloride content, it might have a laxative effect because of the high sulfate content, and it might damage engines, boilers, and pipes because of its rather high content of cations, but no contamination due to the nearby historic mining activities could be proven. Yet the water is actually not acceptable for drinking water use for two reasons:

1. The natural radionuclide content in this area (especially the most toxic isotope of radium, Ra226) exceeds the maximum contaminant levels set by the Environmental Protection Agency for radionuclides as shown by analyses of the Chloride Water Corporation (now: Chloride Domestic Water District) (see tab. 5).
2. The nitrate-nitrogen content exceeds the DWS standard or at least the HBGL standard, which could be traced to pollution by domestic wastewater. Chloride does not have a municipal septic system, but domestic wastewater is purified by private septic tanks, which apparently do not work like they should.

In contrast to the local groundwater quality the water from the townwater system (WP 4), which is currently provided by the Chloride Domestic Water District, is actually reaching bottled drinking water quality.

7 RECOMMENDATIONS

Water from the wells in Chloride should not be used as drinking water even in dry years with water shortages in the townwater system. Before an additional domestic water supply from the wells in town is considered, each well should be tested again for radionuclides, and the septic tanks should be controlled and reconstructed if necessary.

Location*	Gross Alpha	Radium 226	Gross Beta
Comb. well # 1, 2, 3; 0.8 mi. NNE of Chloride B (24-18) 34 (1991)	11.0 ± 4.0	10.6 ± 1.4	
Townwater well at Big Wash *before* filtration; B (24-18) 30 (1992)			
at 200 feet	161.0 ± 11.0	8.0 ± 0.4	98.2 ± 3.7
at 340 feet	36.0 ± 3.1	12.2 ± 0.4	26.8 ± 1.5
at 440 feet	28.0 ± 2.9	11.6 ± 0.6	30.3 ± 1.6
at 475 feet	35.9 ± 3.3	15.6 ± 0.7	41.1 ± 1.9
Well head, new well *after* filtration (1994)	1.4 ± 0.3		
MCL standard**	15.0	5.0	5.0

* Data gratefully received in 1995 from H. OLSON, President of the Chloride Domestic Water District

** MCL = Maximum Contaminant Level; enforceable EPA standard (see ADEQ 1992)

Tab. 5: Radiochemical analyses of wells north of Chloride and at Big Wash (units are pCi/L)

In this heavily mined area of the Cerbat Mountains it is not easy to supply livestock with unobjectionable water. It is economically unfeasible to clean up the hundreds of historic mining sites to prevent surface water from contamination. But at least a few measures should be implemented to minimize the threat of water contamination to animals and to human end-consumers:

1. Livestock should be prevented from drinking water from streams which drain tailings of active or historic mines. A distance of at least one half mile below the last tailings is suggested. An even greater distance is recommended, if there are extensive tailings in a drainage system.
2. In any case, livestock should not be allowed to drink water from tunnel discharges.
3. To prevent further surface water contamination at least the largest tailings (e.g. the Tennessee Mine tailings, Cyprus Mineral Park Mine tailings etc.) should be recultivated and covered such, that water cannot infiltrate and dissolve chemical substances. Tailings stretching across a streambed (e.g. the Payroll, New Jersey, Jupiter Mine, etc.) should be completely removed from the streambed and its closest vicinity. The remaining tailings must be fixed to reduce further erosion of fine sediments.

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APPENDIX

Tab. 6: Site description of the water samples listed in table 7

I) Groundwater samples in Chloride and its surroundings

WP 1 Distroyed well at the exit of the Tennessee Wash Canyon right above the confluence of the trunk stream with a tributary (waterless at time of sampling). A: 4,200 ft., D: 5 ft..

WP 3 Fire Department well in the center of Chloride. The well is situated north of the centerline between the Tennessee Wash and an unnamed northern tributary. The tributary (waterless at time of sampling) comes from the west slope of the ridge which borders the Tennessee Wash on its east side. A: 4,020 ft., D: 50 ft..

WP 4 Townwater of Chloride - provided by the Chloride Water Corporation - which comes from a well located at the Big Wash north of the Calico Peak Range, north of Chloride. Background sample for drinking water quality.

WP 6 Groundwater, main shaft of the Tennessee Mine, east of Chloride. A: 4,200 ft., D: 39 ft..

WP 15 NELSON well at the east end of Chloride. The well is situated south of the centerline between the Tennessee Wash and an unnamed northern tributary. The tributary (waterless at time of sampling) comes from the west slope of the ridge which borders the Tennessee Wash on its east side. A: 4,100 ft., DW: 180 ft..

WP 17 Well north and above the Arizona Magma Mine (2 mi. westnorthwest of Chloride) in the northern part of the Sacramento Wash watershed. Headwater streams begin north in the Calico Peak Range. A: 3,960 ft., DW: unknown.

WP 22 HERBST well at the northeast end of Chloride. Well is situated north of the centerline between the Tennessee Wash and an unnamed northern tributary. The tributary (waterless at time of sampling) comes from the west slope of the ridge which borders the Tennessee Wash on its east side. A: 4,120 ft., DW: 200 ft..

WP 24 Distroyed well of an unnamed mine 0.1 mi. (160 m) southsouthwest of the Tennessee Mine tailings, east of Chloride. A: 4,120 ft., D: 10 ft..

II) Surface water samples in the surroundings of Chloride

WP 2 Stream flow at the exit of the Tennessee Wash Canyon above the confluence of the trunk stream and the tributary (waterless at time of sampling). Both streams drain the heavily mined Tennessee Canyon.

WP 5 Stream flow of the Tennessee Wash just below the confluence with a short, unmapped tributary (waterless at time of sampling), draining the the Tennessee Mine tailings east of Chloride. The Tennessee Wash drains the heavily mined Tennessee Canyon.

WP 21 Slow stream flow of a branch of the Tennessee Wash just alongside the northern edge of the Tennessee Mine tailings.

WP 23 Stream flow around the southern edge of the Tennessee Mine tailings; sampling 0.4 mi. (640 m) southwest of the tailings. Headwaters reach the former mining area of the Hercules and New Jersey Mine.

III) Water samples in the historic mining area southeast of Chloride

WP 8 Water tank. The water comes from the Petroglyphs area eastsoutheast of Chloride.

WP 14 Stream flow draining the area of the Copper Age Mine tailings 1.7 mi. (2.7 km) southsoutheast of Chloride. Sampling little above the road bifurcation to the old Pinkham Mine.

WP 25 Stream flow of an unnamed wash draining the Minnesota Conner Mine area, 1.3 mi. (2 km) southeast of Chloride.

WP 26 Stream flow at the exit of the Eureka Canyon just <u>above</u> the <u>confluence</u> with the discharge from a tunnel (see sample no. WP 27).

WP 27 Discharge from a tunnel at the exit of the Eureka Canyon just above the confluence with the flow from the upper canyon (see sample no. WP 26).

Tab. 6 (continued): Site description of the water samples listed in table 7

WP 28 Stream flow at the exit of the Eureka Canyon just below the confluence with the flow from a tunnel (see sample no. WP 26, 27).

EP 31 "Sludge": soft, pudding-like, watery, greenish yellow streambed deposits, canyon north of the Cyprus Mineral Park Mine.

IV) Water samples in the historic mining area of the old town of Golconda

WP 18 Discharge from a tunnel below the town of Golconda.

WP 19 Discharge from the tailings in the old town of Golconda.

WP 20 Stream flow just below the confluence of the stream draining the Todd Basin (with the town of Golconda) and the stream draining the southern adjoining canyon.

V) Groundwater sample in the historic mining area of the old town of Cerbat

WP 11 Cross H Ranch well at the exit of the Cerbat and Charrcoal Canyon watershed (near the Cerbat Wash). The headwater streams of the Cerbat Canyon drain a heavily mined area east of the old mining town of Cerbat. A: 3,720 ft., DW: 140 ft..

VI) Surface water samples from the Cyprus Mineral Park Mine (former Duval Mine)

WP 9 Stream flow of the trunk stream of the Cyprus Mineral Park watershed just downstream of the Cyprus Mineral Park Mine (C.M.P.M.). The name Cyprus Mineral Park watershed is given to a watershed whose headwater streams begin north, northeast and east of the C.M.P.M. and flow through a heavily mined area before reaching the trunk stream near the C.M.P.M..

WP 10 Discharge from the C.M.P.M. tailings. The water was seeping through a dam at the southern (lowest) end of the tailings.

Explanations to table 6:

A = Altitude in feet above mean sea level.

D = Depth to water in feet below land surface.

DW = Depth of well in feet below land surface by owners record.

Notes to table 7:

1) EC: Electrical coductivity in S/cm (microsiemens per centimeter).
2) TDS: Total dissolved solids. TDS = 0.6 (Alk) + Na + Ca + Mg + Cl + SO_4 + NO_3-N + F in mg/L.
3) Alk.: Alkalinity, total as $CaCO_3$.
4) NO_3-N: Nitrate/nitrite as N.
5) Hardness: (Ca x 2.497) + (Mg x 4.116) = total hardness as $CaCO_3$.
6) "Sludge": Analized like the water samples.
7) C.M.P.M.: Cyprus Mineral Park Mine (former Duval Mine).
8) Domestic water source (DWS) means the use of navigable water as a potable water supply. Treatment may be necessary to yield a finished water suitable for human consumption. Numeric water quality criteria after Arizona Administrative Code (AAC) (ADEQ 1995).
9) Health-Based Guidance Level (HBGL): Levels for chemical contaminants in drinking water. The HBGLs are not to be construent as cleanup standards. Rather, they constitute a set of consistently derived health-based levels that may be useful for reference in environmental work. HBGL values after ADEQ (1992).

   If there is neither a HBGL standard nor an AAC standard available, the EPA secondary maximum contaminant level (SMCL) is listed in this line and marked by *. SMCL standards after U.S. EPA (1988).
10) Agricultural livestock watering (AgL) means the use of navigable water for consumption by livestock. Numeric water quality criteria after AAA (ADEQ 1995).
11) Maximum allowed concentration (MAC): Standards for drinking water which are binding upper levels in the member states of the European Community (see HÜTTER 1994: 163 ff.).

NA No numeric standard available.

Table 7 (I): Water quality in the historic mining district of Chloride and adjacent areas (Cerbat Mountains, Mohave County, AZ)

(units are mg/L except pH and EC)

ID	Location	General Chemistry													
		pH	EC[1]	TDS[2]	Alk[3]	HCO_3	Cl	F	NO_3-N[4]	SO_4	Hardn.[5]	Ca	Mg	Na	K
I) Groundwater samples in Chloride and its surroundings															
WP 1	well, end of Tennessee Canyon	7.2	1300	968	350	430	92	1.40	0.72	360	588	130.0	64.0	110.0	2.4
WP 3	Chloride Fire Department well	7.5	3000	2198	210	260	400	1.30	62.00	930	1157	300.0	99.0	280.0	3.5
WP 4	townwater of Chloride	7.0	150	97	24	29	32	< 0.10	< 0.10	19	22	4.2	2.7	25.0	< 1.0
WP 6	Tennessee Mine (T.M.), main shaft	5.8	4400	4133	330	400	85	0.35	< 1.00	2800	2921	560.0	370.0	120.0	32.0
WP 15	NELSON well, Chloride	7.4	520	1421	220	270	50	0.40	19.00	810	861	180.0	100.0	130.0	7.1
WP 17	well above Arizona Magma Mine	7.9	4000	2735	140	170	900	0.70	0.37	950	1716	440.0	150.0	210.0	12.0
WP 22	HERBST well, Chloride	7.0	1225	827	320	390	120	0.60	7.90	230	585	160.0	45.0	71.0	4.6
WP 24	well SSW of T.M. tailings	6.9	2500	1932	350	430	160	1.90	< 0.10	920	1367	300.0	150.0	190.0	4.4
II) Surface water samples in the surroundings of Chloride															
WP 2	Tennessee Wash above T.M.	8.4	400	288	150	180	24	0.68	< 0.10	81	178	40.0	19.0	33.0	4.2
WP 5	Tennessee Wash below T.M.	7.6	830	643	220	270	56	0.98	< 0.10	260	402	87.0	45.0	62.0	3.2
WP 21	T.W. alongside north T.M. tailings	6.2	2800	2685	130	160	73	< 0.10	0.62	1900	1705	320.0	220.0	93.0	10.0
WP 23	SW of T.M. tailings	8.4	1150	711	270	330	96	1.70	< 0.10	220	425	91.0	48.0	92.0	3.3
III) Water samples in the historic mining area southeast of Chloride															
WP 8	water tank, Petroglyphs area	7.9	1100	847	260	320	64	1.20	< 0.10	360	625	130.0	73.0	63.0	2.8
WP 14	below Copper Age Mine tailings	7.8	4000	3562	200	240	130	2.10	< 0.10	2300	1931	460.0	190.0	360.0	5.0
WP 25	canyon below Minnesota Connor M.	7.8	3150	2358	260	320	100	1.70	< 0.10	1400	1665	370.0	180.0	150.0	6.9
WP 26	Eureka M. Cany., above confluence	7.0	1625	1359	80	98	57	1.90	< 0.50	860	912	220.0	88.0	84.0	7.2
WP 27	Eureka M. Canyon, tunnel	3.0	2600	2035	< 10	< 10	39	< 0.10	< 0.50	1600	868	150.0	120.0	65.0	2.9
WP 28	Eureka M. Cany., below confluence	6.5	1675	1333	74	90	55	1.70	< 0.50	840	912	220.0	88.0	84.0	7.9
EP 31[6]	"sludge", canyon N of C.M.P.M.[7]	n.a.	n.a.	6678	6000	7300	79	15.00	0.93	1900	2763	810.0	180.0	93.0	43.0
IV) Water samples in the historic mining area of the old town of Golconda															
WP 18	tunnel, below Golconda	6.6	1800	1503	120	150	23	0.40	0.78	930	1228	360.0	80.0	37.0	5.4
WP 19	tailings discharge, Golconda	4.9	590	393	16	20	< 50	0.13	2.60	280	279	72.0	24.0	4.8	6.9
WP 20	below confl., Golconda area	7.4	1250	834	120	150	26	0.64	0.85	450	680	180.0	56.0	49.0	4.1
V) Groundwater sample in the former mining area of the old town of Cerbat															
WP 11	Cross-H-Ranch well, Cerbat	7.4	1400	1080	340	410	130	1.20	0.14	380	642	150.0	65.0	150.0	4.1
VI) Surface water samples from the Cyprus Mineral Park Mine															
WP 9	just downstream the C.M.P.M.	3.2	4700	5549	< 5	< 6.1	85	0.11	0.99	4500	2883	380.0	470.0	110.0	7.7
WP 10	tailings discharge, C.M.P.M.	2.6	5300	6625	< 5	< 6.1	< 50	< 0.10	1.20	6000	1960	340.0	270.0	11.0	110.0
Standards															
Domestic water source (DWS)[8]		5.0-9.0	NA	NA	NA	NA	NA	4.00	10.00	NA	NA	NA	NA	NA	NA
Health -Based Guidance Level (HBGL)[9]		NA	NA	500*	NA	NA	250*	0.42	7.00	400	NA	NA	NA	NA	NA
Agricultural livestock watering (AgL)[10]		6.5-9.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Maximum Allowed Concentration (MAC)[11]		9.5	NA	1500	NA	NA	NA	NA	NA	250	NA	NA	50.0	150.0	12.0

Table 7 (II): Water quality in the historic mining district of Chloride and adjacent areas (Cerbat Mountains, Mohave County, AZ)

(units are mg/L except pH and EC)

ID	Location	Heavy Metals											
		As	Ag	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	Fe	Mn
I) Groundwater samples in Chloride and its surroundings													
WP 1	well, end of Tennessee Canyon	0.122	< 0.005	< 0.0005	< 0.05	0.65	< 0.0004	< 0.05	< 0.005	< 0.005	< 0.05	0.35	< 0.05
WP 3	Chloride Fire Department well	0.008	< 0.005	< 0.0005	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	0.005	< 0.05	0.47	0.15
WP 4	townwater of Chloride	< 0.005	< 0.005	< 0.0005	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	< 0.005	0.15	0.06	< 0.05
WP 6	Tennessee Mine (T.M.), main shaft	0.999	< 0.005	0.0068	< 0.05	0.08	0.0011	< 0.05	2.000	< 0.005	3.30	77.00	6.40
WP 15	NELSON well, Chloride	0.052	< 0.005	< 0.0005	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	< 0.005	< 0.05	< 0.05	< 0.05
WP 17	well above Arizona Magma Mine	< 0.005	< 0.005	< 0.0005	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	0.005	0.38	0.96	0.38
WP 22	HERBST well, Chloride	0.011	< 0.005	< 0.0005	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	< 0.005	0.09	0.18	< 0.05
WP 24	well SSW of T.M. tailings	0.491	< 0.005	0.0189	< 0.05	< 0.05	< 0.0004	< 0.05	0.650	< 0.005	10.00	6.40	4.80
II) Surface water samples in the surroundings of Chloride													
WP 2	Tennessee Wash above T.M.	0.068	< 0.005	< 0.0005	< 0.05	< 0.05	< 0.0004	< 0.05	0.029	< 0.005	0.06	9.70	0.22
WP 5	Tennessee Wash below T.M.	0.098	< 0.005	0.0195	1.10	< 0.05	< 0.0004	< 0.05	0.170	< 0.005	5.90	4.20	0.20
WP 21	T.W. alongside north T.M. tailings	0.006	< 0.005	0.6100	< 0.05	1.50	< 0.0004	0.22	0.018	< 0.005	200.00	5.70	15.00
WP 23	SW of T.M. tailings	0.080	< 0.005	0.0062	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	< 0.005	1.30	0.54	0.63
III) Water samples in the historic mining area southeast of Chloride													
WP 8	water tank, Petroglyphs area	< 0.005	< 0.005	< 0.0005	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	< 0.005	< 0.05	< 0.05	< 0.05
WP 14	below Copper Age Mine tailings	0.064	< 0.005	0.0028	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	< 0.005	0.30	0.12	0.05
WP 25	canyon below Minnesota Connor M.	0.264	< 0.005	0.0068	< 0.05	0.07	< 0.0004	< 0.05	0.029	< 0.005	0.98	2.70	0.44
WP 26	Eureka M. Cany., above confluence	< 0.005	< 0.005	0.0190	< 0.05	1.20	< 0.0004	0.10	< 0.005	< 0.005	8.40	0.29	0.56
WP 27	Eureka M. Canyon, tunnel	0.009	< 0.005	0.1600	0.07	41.00	< 0.0004	0.73	0.005	< 0.005	23.00	81.00	8.60
WP 28	Eureka M. Cany., below confluence	< 0.005	< 0.005	0.0220	< 0.05	2.20	< 0.0004	0.10	< 0.005	< 0.005	8.60	2.50	0.75
EP 31[6]	"sludge", canyon N of C.M.P.M.[7]	< 0.005	< 0.250	0.7100	0.36	1000.00	< 0.0200	0.76	< 0.500	< 0.005	84.00	1300.00	8.80
IV) Water samples in the historic mining area of the old town of Golconda													
WP 18	tunnel, below Golconda	0.023	< 0.005	0.0462	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	< 0.005	33.00	4.40	30.00
WP 19	tailings discharge, Golconda	0.134	< 0.005	0.1400	< 0.05	0.35	< 0.0004	< 0.05	0.025	< 0.005	60.00	2.90	8.50
WP 20	below confl., Golconda area	0.006	< 0.005	0.0286	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	< 0.005	12.00	0.13	2.60
V) Groundwater sample in the former mining area of the old town of Cerbat													
WP 11	Cross-H-Ranch well, Cerbat	0.006	< 0.005	< 0.0005	< 0.05	< 0.05	< 0.0004	< 0.05	< 0.005	< 0.005	0.24	0.07	< 0.05
VI) Surface water samples from the Cyprus Mineral Park Mine													
WP 9	just downstream the C.M.P.M.	0.110	< 0.005	0.3770	0.07	51.00	< 0.0004	1.60	0.036	< 0.005	86.00	32.00	130.00
WP 10	tailings discharge, C.M.P.M.	0.225	< 0.005	0.0345	1.30	69.00	< 0.0020	0.98	0.615	< 0.005	6.80	620.00	18.00
Standards													
Domestic water source (DWS)[8]		0.050	NA	0.0050	0.10	1.00	0.0021	0.14	0.050	0.050	5.00	NA	NA
Health -Based Guidance Level (HBGL)[9]		0.050	0.050	0.0035	0.10	1.30	0.0021	0.14	0.005	0.050	1.40	0.30*	0.70
Agricultural livestock watering (AgL)[10]		0.200	NA	0.0500	1.00	0.50	0.0100	NA	0.100	0.050	25.00	NA	NA
Maximum Allowed Concentration (MAC)[11]		0.050	0.010	0.0050	0.05	NA	0.0010	0.05	0.050	0.010	NA	0.20	0.05