HYDROGEOLOGY OF THE HUMBOLDT RIVER BASIN, IMPACTS OF OPEN-PIT MINE DEWATERING AND PIT LAKE FORMATION

June, 2015

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Prepared for: Progressive Leadership Alliance of Nevada and Great Basin Resource Watch

EXECUTIVE SUMMARY

The report summarized in this executive summary documents the deficit created in the groundwater of the Humboldt River basin by mine dewatering and qualitatively predicts the long-term or permanent effects of that deficit. The report considers the following aspects of the basin and deficit being created:

- Hydrogeology and conceptual flow model of the basin, including general discussion of recharge, discharge, and geologic properties of the basin
- Conceptual model of mine dewatering
- Volume of groundwater pumping for mine dewatering by mine, discussion of factors leading to the quantity of dewatering, and discussion of the disposition of that water including consumptive use where possible.
- Predicted volume of future pit lakes
- Long-term evaporation from the pit lakes
- Cumulative deficits created in the Humboldt River basin

The Humboldt River flows from east to west across northern Nevada and the Great Basin, from the Independence Range and Ruby Mountains to the Humboldt Sink. The Great Basin is an area of internal drainage, where no surface water flows to the ocean, and the Humboldt River basin is the largest river basin contained solely in Nevada.

Total recharge in the basin is about 223,000 acre-feet (af) per year (af/y). About two-thirds of this recharge occurs in the eastern half of the basin where precipitation is higher and the geology is more receptive to recharge. Groundwater discharges into wetlands, springs or streams near the middle of the valleys which provide baseflow to the river. Much of the river flow is runoff which also recharges the alluvium with an amount of water in addition to the mountain recharge. This is reflected in the sum of the perennial yield (PY) for all basins in the Humboldt River watershed, which exceeds 420,000 af/y. This is almost 50% higher than the

total river flow, and almost twice as much as the entire recharge. PY is the amount of groundwater that can be pumped from a basin without creating continued long-term drawdown. Pumping must ultimately divert a natural discharge of groundwater, which here is discharge to springs or to baseflow in the river. In order to develop the entire PY, most of the river flow would have to be induced to enter the alluvium as recharge.

Six mines within the Humboldt River basin have pumped almost 3,800,000 af of groundwater through 2014 to keep their pits or underground mines dry. Averaged over 25 years, the dewatering rate is about 152,000 af/y. About 22% of the dewatering has been discharged to surface water, primarily the Humboldt River or a nearby tributary. About 34% has been returned to the basin of origin either through reinfiltration to nearby aquifers or by replacing existing irrigation water supplies. About 12% of the dewatering is consumptively used, mostly in mining and milling operations. Table 1 summarizes the mine dewatering and its management.

The Goldstrike mine in Boulder Flat has pumped far more water for dewatering than other mines, at over 1,100,000 af since 1991, but also has returned more than 60% of the dewatering water to the local basin through replacing irrigation water and infiltration. The Goldstrike Mine dewatering has helped form a 40 by 15 mile drawdown cone along the Carlin Trend. Drawdown is the amount that the water table has lowered since dewatering began; in three dimensions it often resembles an inverted cone. There is also a large groundwater mound, or accumulation of water above the original water table, in the alluvium of Boulder Flat due to irrigation. Groundwater could flow to the pit once dewatering ceases if there is a hydraulic connection. If the mound does not replenish the deficit in the bedrock, groundwater to fill the pit and deficit in the bedrock will be drawn from further distances from the mine primarily from bedrock. The mound may provide irrigation water to Boulder Flat, and some may reach the Humboldt River and increase the baseflow until the mound dissipates.

The Lone Tree Mine, which closed in 2006, pumped the second largest amount of water at more than 780,000 af, with more than 57% being discharged to the river. A drawdown cone extended a long distance from the mine to the west, north, and east, including under the alluvium near the river. There is very little local recharge, other than from the Humboldt River. The drawdown was mostly in a confined aquifer and began to recover quickly, but groundwater levels also responded in the alluvial aquifer which indicates water could be drawn from the river. Dewatering discharge to the river had increased water levels in near-river shallow groundwater. Water levels in aquifers within a couple hundred feet of the ground surface increased as much as a couple tens of feet but have since lowered as groundwater drains back to the river. The Lone Tree Mine, being adjacent to the river and having dewatered alluvium, presents the most significant long-term threat to river flows.

The Cortez mine complex in Crescent Valley, including Pipeline, Cortez, and Mt Tenabo, has pumped the third highest amount of water at more than 620,000 af. Most of this this water is returned to a shallow groundwater aquifer within Crescent Valley through reinfiltration and irrigation. Crescent Valley naturally discharges very little water to the Humboldt River and because the mine is the southern portion of the valley, dewatering has little effect on the river.

Gold Quarry has pumped the fourth largest amount of water, at more than 460,000 af, and discharged more than 50% to the Humboldt River through Maggie Creek. Drawdown in the bedrock near Gold Quarry is part of the huge drawdown cone described for the Goldstrike Mine. Southeast of the mine, drawdown up to about fifteen feet in the bedrock reaches to the Humboldt River although it is poorly defined due to the lack of wells. Alluvial groundwater levels near the Humboldt River near Carlin have trended downward in connection with groundwater levels in underlying bedrock. However, there is an upward gradient from the siltstone to the alluvium, so groundwater flow from bedrock to alluvium is likely. Based on the drawdown beneath the river, the Humboldt River will not likely be the primary source of water to fill the bedrock deficit. However, once dewatering discharge ceases, the river will gain much less flow between Carlin and Palisade than at present. Maggie Creek and a reservoir have both seeped water into the Carlin Formation and created a significant groundwater mound. Seepage from this mound will likely temporarily make up some of the lost dewatering discharge in Maggie Creek when the dewatering ends.

The Twin Creeks Mine has pumped less than 200,000 af and is too far from the river to affect it. Much of this water is also returned to the basin. More than 250,000 af has been pumped for Leeville as part of the Goldstrike Mine water management system. The Meikle Mine is within the Goldstrike drawdown cone. The McCoy Cove Mine closed in 2001 after pumping 285,000 af, but it is a long distance from the river in the Reese River watershed.

Dewatering has caused substantial drawdown around the Humboldt River basin. The effect this drawdown has had or will have on stream or spring flows is less apparent. As dewatering lowers groundwater connected to surface water, either groundwater discharge to the surface water will decrease (for example a dried spring) or surface water will infiltrate to groundwater at higher than average rates in a process known as induced recharge. Changes in river flow caused by dewatering are difficult to ascertain because discharge to the river from three mines - Lone Tree, Gold Quarry, and Goldstrike (in 1998) - has exceeded the changes potentially caused by dewatering.

The basinwide deficit, if replenished wholly from surface water flow, will significantly decrease those flows. Most obvious decreases would be to river baseflow, which is primarily groundwater discharge, although some additional induced recharge could occur during high

flow and reduce the river flow. There is no avoiding these impacts – inflow equals outflow in a groundwater basin and dewatering is a new outflow which will eventually draw flow from natural groundwater discharges (flow to the river). Neither the lag time until river flow loss occurs nor the total amount that will be drawn from the river is known.

The total dewatering rate above the central part of the basin, approximately 150,000 af/y, is approximately equal to the total recharge above that point. Total pit lake volume, over a million af, with the Lone Tree and McCoy Cove pit lakes already forming, will draw groundwater from the basin. Based on a 50-year refill period, the pit lake refill rate for mines above the central part of the basin will be about 20,000 af/y or about 13.5% of total recharge above that point. Cumulative pit lake evaporation will exceed 9700 af/y or about 6% of the recharge above that point. Table 2 summarizes evaporation and pit lake volumes.

Pit lake evaporation will prevent pit lakes from recovering to pre-mining groundwater levels because the pits will effectively resemble a large diameter well pumping at the evaporation rate. Evaporation will cause a permanent drawdown and be a perpetual water lost. Unlike dewatering and pit lake formation, drawdown due to evaporation will approach steady state with time which means the evaporation loss will eventually draw water from other discharges in the basin, including discharges to the Humboldt River or nearby tributaries. Losses to evaporation will decrease flows to the river even from the Kelly Creek and Crescent Valley basins as the long-term water balance stabilizes between recharge, pit lake evaporation, and discharge from the basins.

Many uncertainties exist in the understanding of the hydrogeology of the basin and how dewatering will affect that hydrogeology. At least three future research projects could be completed to better predict and plan for the effects of mine dewatering on river flows. The first would be detailed analysis of the flows and water levels along the Humboldt River near Lone Tree to determine seepage along the reach and compare to water level changes. The second is a detailed analysis of the connections in the alluvium near Maggie Creek and the deeper bedrock to estimate how river flows could be affected. The third is to estimate the seepage times and rates for groundwater mounds in the Carlin Formation and Boulder Flat to reach the river and potentially supplement the flows. This research would provide an improved understanding of how the dewatering deficit connects to shallow groundwater and how shallow groundwater potentially connects to surface water in the Humboldt River watershed.

Table 1: Summary Table of Mine Dewatering Pumpage, Discharge to Surface Water, Infiltration and Irrigation, and Consumptive Use for the Seven Largest Dewatering Mines in the Humboldt River. Data through 2014.

Mine	Period	Total Pumped	Total Discharge	Total Infiltrated	Total Irrigation	Consumptive Use	Discharge %
Lone Tree	91-14	782,116	449,082	59,423		32,148	57.4
Twin Creeks	96-09	190,857	80,128	2,450		104,588	42.0
McCoy/Cove	89-01	285,000		N/A		N/A	0.0
Cortez/	97-14	621,197		445,905	94,185	60,653	0.0
Gold Quarry	96-14	464,437	239,469		52,340	127,581	51.6
Goldstrike	90-14	1,197,228	57,255		655,310	132,621	4.8
Leeville	2003-14	256,329					
Total		3,797,165	825,934	507,778	801,835	457,591	21.8
Most of the data from 1996 onward were provided by the NSE in spreadsheet form.							
The numbers may not balance because not all uses are reported. Also, early years water distributions other than the total dewatering are not known.							
For Lone Tree, the total discharge is actual from 1996 to 2015, and does not include an estimate for 1991							
For Lone Tree, the total consumptive use is actual from 1996-2014. It does not include 1991-95 or water sent to Marigold, Trenton Canyon or the Valmy Powerplant							
Twin Creeks infiltration only in 1998 and 1999							
Gold Quarry consumptive use is sum of total reported as consumptive use and mining.							
Discharge at Gold Quarry reported from 1999-2014 and estimated as proportion of 1999 pumpage for 1996-1998.							
Goldstrike total pumpage and consumptive is as reported to NDWR 1996-2009, and estimated from BVMP							
Goldstrike discharged to Humboldt R from January 1998 to February 1999; the BVMP total discharge to river value is 81,798 af							
Goldstrike irrigation is "delivered to ranch dam" and is likely an underestimate.							

Table 2: Pit lake volumes and Future Evaporation. The volume and area are based on data in the source column. The Volume (HCI, 1997) column shows an earlier projected volume. The evaporation is based on 3.9 ft/y.

	Volume When Full	Area When Full (ac)	Approximate Depth When full	Source	Volume (HCI, 1997)	Evaporation (af/y)
McCoy Cove	35,000	165.4		HCI, 2001		645.2
Goldstrike	360,000	710	1120	Schaeffer, 2007	580,000	2769
Gold Quarry[1]	175,000	371		HCI, 1997	175,000	1446.9
Lone Tree	129,900	400.2		WMC, 2008	93,000	1560.9
Twin Creeks	128,558	393	852	Geomega, 2007b	460,000	1532.7
Crossroad	143,220	269	870	Geomega, 2007a	44,000	1049.1
Cortez Hill	79,931	179	840	Geomega, 2007a		698.1
Total	1,051,609	2,488	3,682		1,352,000	9,702

1. The 2010 Leeville EIS references Gold Quarry pit lake development to the 1999 study, so for this analysis I consider this volume to still be accurate.