APPENDIX 11-OO

CHINDE WASH SURFACE WATER GAIN/LOSS REPORT

Chinde Wash Surface Water Gain/Loss Report

Introduction

In the 1997 annual hydrology monitoring report, BHP reported surface water losses (approx. 165 acre-feet) in Chinde Wash between the NAPI discharge point (up gradient of mining and CD-1A) and Navajo Mine surface water site CD-2A below the Bigfill, a distance of approximately nine miles. OSM requested (January 19, 1999 letter) that BHP characterize flow rates in several shorter sub reaches of Chinde Wash between the (NAPI) discharge point and Navajo Mine downstream surface water site CD-2A.

The gain/loss study plan is a product of discussions between OSM and BHP to address OSM's concerns about Chinde Wash and revise the portion of the Probable Hydrologic Consequences (PHC) that discusses Chinde Wash. The purpose of the gain/loss study is three fold: 1) characterize and document gains and/or losses of surface water flows along specified reaches of Chinde Wash, 2) revise the PHC section of the Navajo Mine Permit, and 3) address OSM's concern of surface water losses occurring across reclaimed lands.

Gains and/or losses were determined by measuring flow rates within discrete sub reaches of Chinde Wash. These flow measurements were then compared to determine if gains/losses are occurring and where. Quarterly data results were submitted to OSM.

Background

Chinde Wash flows from Navajo Agricultural Products Industry (NAPI) lands, east of the permit area, through the lease area to its confluence with Chaco River, west of the lease area. Chinde Wash traverses the Navajo Mine near the middle of the lease area, entering the lease area above Yazzie Pit and leaving the lease area at the Bigfill. The watershed area of Chinde Wash above the lease boundary is 9,532 acres; the total premine watershed size is 26,136 acres.

Under natural conditions, Chinde Wash is a dry, ephemeral drainage that would flow only in response to runoff from large precipitation events. Chinde Wash has artificially become an

intermittent drainage as a result of irrigation return flow and direct NAPI discharges. The attached Navajo Indian Irrigation Project (NAPI) information map, Exhibit 1, shows the extent of NAPI activities relative to Navajo Mine.

Springs and seeps occur along upper Chinde Wash, above the lease boundary; due to NAPI irrigation return flows. The source of water for the transient springs and seeps is extensive irrigation activity up gradient of Chinde Wash. The saturation of the regolith (eolian sand) and spring occurrence represents a distinct change from baseline conditions. No springs in the regolith would have been present prior to NAPI activities, and thus Chinde Wash would not have been an intermittent stream.

The springs are the result of excess, unused irrigation water migrating downward through a spatially extensive and permeable eolian sand that underlies the irrigated fields. When this water encounters the less permeable siltstones and shales of the underlying Fruitland Formation, it migrates laterally along a stratigraphic contact between the unconsolidated eolian sand and bedrock. As Chinde Wash progressively down cuts through the eolian sand and into the underlying bedrock, the water migrating along this stratigraphic contact discharges onto the surface and ultimately flows into the wash.

The springs are limited to the area of the sand bedrock contact along the banks of the wash. Downstream of the eolian sand deposits, Chinde Wash no longer receives spring discharges because the wash traverses a badlands area that is devoid of the eolian sand.

Monitoring Locations and Sub reaches

BHP determined where channel transmission losses were occurring by collecting one year of quarterly synoptic flow measurements from three additional flow monitoring sites (CD-3T, CD-4T, and CD-5T). The new monitoring sites were determined in the field by BHP and OSM representatives on February 24, 1999. The three additional temporary monitoring sites, in conjunction with CD-1A and CD-2A continuous flow measurement sites, allowed transmission gain/loss determinations for five sub reaches within Chinde Wash.

The location of the three additional flow monitoring sites is:

CD-3T - free flowing section of Chinde Wash above the vegetated area at the Yazzie highwall.

CD-4T - free flowing section in the temporary diversion immediately downstream of culvert CP-111.

CD-5T - free flowing section in the temporary diversion immediately downstream of culverts CP-31, 32, 33, and 34.

The five sub reaches defined by the flow monitoring locations are:

Reach 1 – Length - 15,190 feet. NAPI monitoring/discharge site downstream to BHP site CD-1A.

This reach begins at the headwaters of Chinde Wash and flows adjacent to thick sand (dune) deposits where extensive irrigation takes place, the channel is well defined, open and partially bedrock controlled. There are some contact springs along this reach.

Reach 2 – Length - 9,210 feet. CD-1A downstream to CD-3T

This reach is through badlands and the channel is well defined, deeply incised and dominantly bedrock controlled. Channel bottom deposits are likely thin and are underlain by bedrock. Low permeability rock units composed of mudstone and siltstone of the Kirtland Shale Formation dominate the bedrock. There are several contact springs between the eolian sand and bedrock units long this reach.

Reach 3 – Length – 11,640 feet. CD-3T downstream to CD-4T

This reach consists of the densely vegetated area above the Yazzie highwall and the diversion along the highwall. Because of the dense vegetation and low gradient (<0.5%), there is no defined channel and water sheet flows until it reaches the diversion. The vegetated area is approximately 3,500 feet long and 700 feet wide. Artificial, low flow seeps have developed at the top the Yazzie highwall immediately below the vegetated area. The seeps have developed because of the pooling of water in the vegetated area above the highwall and occur at the contact of Chinde Wash alluvial materials with the low permeability mudstones of the Fruitland Formation.

Reach 4 – Length – 4,770 feet. CD-4T downstream to CD-5T

This reach flows in the diversion entirely on spoil through a regraded area.

Reach 5 – Length – 5,924 feet. CD-5T downstream to CD-2A

Parts of this reach flows through the vegetated area upstream of the Bigfill. There is only a limited channel in the vegetated area, until flows reach an incised diversion that connects to the culvert through the Bigfill. The length of the vegetated area is approximately 2,000 feet.

The total length from the NAPI discharge point to CD-2A is 46,735 feet (8.85 mi.). The five sub reaches and the three quarterly monitoring sites are shown on Exhibit 1. The quarterly data allowed a determination of gains/losses by comparing flow measurements for the particular sub reach between monitoring points for that particular synoptic event.

Flow Data

Two types of flow data were collected and utilized as part of this study: synoptic quarterly measurements at CD-3T, CD-4T, CD-5T, and continuous flow measurements at CD-1A and CD-2A. The collection of flow data at CD-1A and CD-2A is detailed in Navajo Mine's Permit and is part of the permanent surface water-monitoring program at Navajo Mine.

Synoptic Data

The quarterly synoptic measurements consisted of a single instantaneous measurement of flow. Measurements were taken at the beginning of the quarter for four quarters during the year from April 1, 1999 through March 31, 2000. Specific dates when flow measurements were taken are April 15, 1999; July 13, 1999; October 12, 1999 and January 19, 2000.

A summary of the synoptic quarterly data is provided below in Table 1. The objective of the synoptic monitoring was to measure base flow at different points in the wash as close to the same point in time as possible to determine whether surface water flows were increasing or decreasing. Detailed data and methodology is provided in Appendix A.

Table 1. Quarterly Synoptic Flow Data (gpm)

Station	CD-1A (sensor)	CD-3T	CD-4T	CD-5T	CD-2A (sensor)
April 15, 1999	680	974	202	321	320
July 13, 1999	<200[2]	283	0	11	<200[2]
October 12, 1999	<200[2]	390	115	85	<200[2]
January 19, 2000	[1]	378	458	507	800

[1] Ice and backwater condition prevented accurate stage measurement at CD-1A.
[2] Estimates only; very low stage measurements (<0.1') recorded are approximating the accuracy of the sensor.

Continuous Discharge Monitoring Data

Stations CD-1A and CD-2A continuously recorded storm events and base flow caused by NAPI irrigation flows. Ultrasonic stage sensors were used to determine water levels and store this information in on-site data loggers. The stream stage data is converted to discharge by means of stage-discharge curves developed for each station. Both stage and discharge continuous hydrographs are then produced.

Data collected at Station CD-1A was impacted by weather, culvert maintenance and equipment problems, which are detailed in Appendix A, Data and Methodology. The cumulative result of these effects is that there are short blocks of time were the data is either inaccurate or the data is not available at station CD-1A. However, the majority of the data is still of high quality and allows for flow characterization between CD-1A and CD-2A.

Specifically, upstream-downstream comparisons of flows between CD-1A and CD-2A can be made for select time intervals to examine base flows, and high flows due to NAPI releases and precipitation events. Table 2 lists both peak flow measurements and flow volumes for selected events and time intervals for stations CD-1A and CD-2A. Hydrographs for selected events are in Appendix B.

Table 2. Continuous Flow Data and NAPI Operational Spills (cfs, ac-ft)

Station	Date	Peak Discharge (cfs)	Flow Volume (ac-ft)	Type of Event
NAPI 604+00	April 17, 1999	-	-	NAPI Discharge
CD-1A		8.8	4.8	
CD-2A		2.2	1.8	
NAPI 604+00	April 18, 1999	-	-	NAPI Discharge
CD-1A		14.5	8.0	
CD-2A		1.3	0.5	
NAPI 604+00	July 1, 1999	4.2	1.7	NAPI Discharge
CD-1A		33.50	11.11	
CD-2A		1.88	0.82	
NAPI 604+00	July 4-11, 1999	4.2	4.1	Base Flow and NAPI Discharge
CD-1A		23.9	28.0	
CD-2A		8.7	18.1	
NAPI 604+00	July 16-22, 1999	11.9	11.4	Base Flow and NAPI Discharge
CD-1A		23.8	19.8	
CD-2A		3.3	5.1	
NAPI 604+00	July 22, 1999	11.9	4.6	NAPI Discharge
CD-1A		23.8	14.5	
CD-2A		<1.0	0.1	
NAPI 604+00	July 23, 1999	4.2	0.7	NAPI Discharge
CD-1A		21.5	3.0	
CD-2A		5.9	5.3	
NAPI 604+00	July 27, 1999	4.2	0.7	NAPI Discharge
CD-1A		25.2	4.6	
CD-2A		<1.0	<0.1	
NAPI 604+00	August 3-4, 1999	-	-	Thunderstorm
CD-1A		308.1	38.9	
CD-2A		132.6	76.1	
NAPI 604+00	August 5-6, 1999	-	-	Thunderstorm
CD-1A		169.1	24.4	
CD-2A		117.4	64.2	

NAPI Data

NAPI tracks operational spills into Chinde Wash and the information for 1999 is provided in Appendix C. NAPI station 604+00 corresponds to the headwaters of one of the branches of Chinde Wash. According to the information provided by NAPI, the total volume of water released into the upper Chinde Wash during 1999 was 312 acre-feet. The information provided by NAPI is an *estimated total* (see letter from Michael Francis, Appendix C) and is not an absolute measurement of peak flow or volume. BHP data indicates that NAPI reported peak

flows and volumes are conservative when compared to data collected at CD-1A. Information for selective NAPI operational spills is listed on Table 2.

NAPI discharges are identified at stations CD-1 and CD-2A by information provided by NAPI and sudden increase in discharge recorded at CD-1A and CD-2A during periods when no precipitation was recorded at nearby Navajo Mine Meteorological Station MET II. Table 2 also assumes the occurrence of NAPI spills that were not documented in information provided to BHP based on CD-1A hydrographs from April 1999.

Discussion

Flow Characteristics

Chinde Wash storm flows are typical of ephemeral drainages in the semi-arid southwest. Storm flows are characterized by a rapid increase in discharge from a low base flow to peak discharge, followed by a recession to low discharge over several hours (see Appendix B for storm hydrographs of August 3-4, 1999 and August 5-6, 1999). Chinde wash is unusual because it has become perennial due to extensive agricultural return flows and direct discharges (operational spills) from NAPI. Synoptic monitoring records a base flow of approximately 0-2 cfs (see Table 1), with the lowest flow measured on July 13, 1999.

Peak flows decrease from CD-1A to CD-2A during storms and NAPI operational spills. This is particularly true for the thunderstorm of August 3-4, 1999 in which the peak flow decreased from 308.1 cfs at CD-1A to 132.6 cfs at CD-2A. NAPI operational spills also show a similar decrease in peak flow downstream, and in some cases, the NAPI operational spill is barely recorded at CD-2A. The reduction in the peak flow is due to the extensive vegetation in two vegetated areas between the stations. The vegetation restricts flow, which causes the flow to spread out and decrease the flow velocity. Furthermore, as discussed below, the vegetated areas cause increased infiltration, evaporation and have high transpiration rates.

Gain/Loss

The synoptic, NAPI and continuous surface water monitoring data for Chinde Wash records that during base flow and NAPI operational spills there is a net loss of surface water from the NAPI

discharge point to Navajo Mine monitoring station CD-2A. For example, on April 18, 1999, flow volume declined from 8.0 acre-feet at CD-1A to 0.5 acre-feet at CD-2A during a NAPI operational spill. Similar instances of flow volume decreases between CD-1A and CD-2A occurred throughout the year, such as on July 1, 1999 in which CD-1A recorded 11.11 acre-feet of volume and CD-2A recorded only 0.82 of volume for the same NAPI operational spill.

However, the synoptic flow measurement data collected documents that the majority of the declines in surface water base flow occur along Reach 3, from CD-3T to CD-4T. Identification of the loss along this reach is significant because it pinpoints that the loss of surface water is occurring upstream of reclaimed lands.

In contrast, during large storm events, the continuous monitoring data recorded that there is an increase in flow volume from CD-1A to CD-2A (Table 2). For example, on August 3-4, 1999 a large thunderstorm produced a flow volume of 38.9 acre-feet at CD-1A and a flow volume of 76.1 acre-feet at CD-2A. This increase is a result of increasing watershed size downstream and thus the contributions of additional flow from tributaries progressively produce an increasing volume of flow. Note also that the peak flow decreased from 308.1 cfs at CD-1A to 132.6 cfs at CD-2A during the same storm due to the effect of the vegetated area above the Yazzie highwall.

Reach 1

Due to the conservative nature of the data provided by NAPI, changes in flow were not identified in this reach.

Reach 2

Synoptic and continuous monitoring data record an increase in surface water flow during all three measurements along Reach 2. The average gain along this reach of 189 gpm is attributed to the addition of flow from springs caused by irrigation return flows. Surface water in this reach flows dominantly on top of low permeability bedrock that limits surface water infiltration.

Reach 3

Synoptic monitoring recorded a decrease in flow of surface water during three measurements along Reach 3 for the first three quarters of 772 (974 to 202), 283 (283 to 0) and 275 (390 to 115) gpm, respectively. The decreases are primarily due to a densely vegetated area and to a lessor extent, the proximity of the Yazzie highwall to the diversion.

The vegetated area upstream of the Yazzie highwall is responsible for significant losses of surface water in Chinde Wash. The effect that the large vegetated area has on surface water flows is two-fold: 1) reduces peak flows, and 2) enhances surface water loss. Surface water losses occur due to the flows spreading out, creating a larger surface area for infiltration and evaporation. Flows spread out and peak flows are reduced due to the low gradient and the silt fence effect produced by the dense vegetation. The extensive and densely vegetated area will also consume water by transpiration during the majority of the year. In addition, un-quantified seeps have been observed on the Yazzie highwall face beneath the Chinde temporary diversion confirming that surface water is infiltrating in the vegetated area. The cumulative effects of these processes, without an additional source of incoming water, is to reduce the amount of available water for downstream flows

During the fourth quarter, on January 19, 2000, an increase in flow of 80 gpm was recorded. The increase is likely due to no evapotranspiration and limited infiltration during frozen conditions present during the winter months. This measurement supports the conclusion that a majority of surface water losses from the diversion are due to the vegetated area above the highwall.

Reach 4

Synoptic monitoring identified that flow increased during three measurements by 119 (202 to 321), 11 (0 to 11) and 49 (458 to 507) gpm and decreased during one measurement by 30 (115 to 85) gpm along Reach 4 (Table 1). Surface water in this reach flows in the diversion entirely on spoil through a regraded area. The data documents that surface water flows are dominantly increasing slightly when flowing across spoil.

The small amounts of change in flow rates are attributed to the naturally low permeabilities in spoil at Navajo Mine. The spoil is derived from dominantly sodic mudstone and siltstones that when disturbed produce fine-grained material and swelling clays that have inherent low permeabilities. Pit run spoil permeability was determined in the Leach Study (Chapter 11, Appendix K) to be 10^{-6} cm/sec (four samples that ranged from 1.66×10^{-6} to 5.4×10^{-6} cm/sec), which is a similar permeability to that of a compacted soil liner. The low measured permeability values indicate that spoil material has the ability to minimize vertical infiltration of surface water. Furthermore, the low permeability lab values measured in spoil independently support the field flow measurements that surface water losses are not occurring across reclaimed lands.

Reach 5

Synoptic monitoring recorded that flow was constant or increased slightly during four measurements along Reach 5 (Table 1). Some of this reach is comprised of a vegetated area upstream of the Bigfill. There is a poorly defined channel through the vegetated area until flow reaches an incised diversion that connects to the culvert through the Bigfill.

The July 13, 1999 and October 12, 1999 continuous flow estimates at CD-2A during the synoptic measurements are approximating the accuracy of the sensor. Nevertheless, the very low stage measurements (<0.1') recorded at CD-2A indicate that the very low flows are similar to the low synoptic flow measurements.

Conclusion

Synoptic flow measurements and continuous flow data have adequately characterized and documented gains and losses of surface water flows along specific reaches of Chinde Wash. Specifically, the data collected support the conclusion that future reconstructed channels built in spoils will not significantly alter surface water flows due to vertical infiltration. The data also record that flow volume increased from CD-1A to CD-2A during large, high intensity storm events.

Surface water losses occur during base flows and NAPI operational spills from the NAPI discharge point to CD-2A. However, by dividing this nine-mile reach into smaller reaches and

measuring flow between these reaches, Reach 3 was identified as losing a significant amount of flow. Thus, the decrease in surface water flows is occurring upstream up the lease area in the vegetated area.

Synoptic monitoring also identified that that surface water flows are dominantly increasing slightly when flowing across regraded spoil in Reach 4. The small amounts of change in flow rates across a spoil area are attributed to the naturally low permeabilities in spoil at Navajo Mine that have been measured at 10^{-6} cm/sec. Thus, surface water flow data collected along the temporary diversion demonstrate that impacts to surface water flows across reclaimed lands will be minimal.

The conclusions and the supporting documentation presented in this report are the basis for characterizations of Chinde Wash presented in the PHC.