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# Drawdown: An Update on Groundwater Mining on Black Mesa

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# Executive Summary

For more than 40 years, billions of gallons of groundwater have been pumped out of the Four Corners region of Arizona by Peabody Western Coal Company before being mixed with pulverized coal to create a thick, black substance called slurry and piped more than 270 miles to a coal-fired power plant in Laughlin, Nevada. Mining of this potable, pristine groundwater—which serves as the primary source of drinking water for the area’s Hopi and Navajo residents—has been connected to a variety of groundwater-related problems. Peabody’s operations have had a range of environmental, cultural, and religious impacts on the region’s tribal communities that make their home in the Black Mesa plateau, and now Peabody is seeking to further erode protections for this vital water source.

The Navajo aquifer, known as the N-aquifer, is an underground water-bearing formation that provides the sole source of potable drinking water to many Hopi and Navajo on Black Mesa. Insulated by a barrier of mudstone and sandstone, it naturally satisfies Environmental Protection Agency (EPA) standards for drinking water—unlike the region’s other aquifers, whose contents are brackish or otherwise contaminated. The springs it feeds along its southern front are sacred to the Hopi people and essential to their religious practice.

In 2000, the Natural Resources Defense Council (NRDC) released a technical report entitled *Drawdown: Groundwater Mining on Black Mesa* (“Drawdown”), which assessed the conflict between the coal company using the Navajo aquifer for coal slurry operations and the people of the Black Mesa who rely on the aquifer for clean water. The 2000 report evaluated the data on groundwater depletion and made recommendations about what role the federal government should play in resolving the controversy. Six years later, *Drawdown: An Update* uses new data to update the hydrogeological evaluation of the impacts of Peabody’s massive water withdrawals on the health of the Navajo aquifer.

This 2006 update finds that not only are there signs of material damage to the aquifer, but that some of the government’s failure to adequately monitor the damage can be attributed to a flawed modeling system

that obscures on-site evidence of physical damage. Table 1 lists the criteria used to assess material damage. The changes that have occurred in the aquifer since 2000 paint the picture of a system still in decline.

<b>Table 1: Material damage to the N-aquifer since 2000</b>		
<b>Criteria used to assess material damage</b>	<b>Standard</b>	<b>Are indications of material damage still present?</b>
<i>Criterion 1:</i> Structural stability	“Maintain potentiometric head of 100 feet above top of N-aquifer at any point to preserve confined state of aquifer.”	<b>Yes.</b> Groundwater level, a key measure of structural stability, remains within 100 feet of the top of the aquifer in two monitored wells and has periodically dropped below the top elevation of the Navajo aquifer itself, indicating material damage.
<i>Criterion 2:</i> Water quality	“A value of leakage from D-aquifer not to exceed 10 percent from mine-related withdrawals.”	<b>Yes.</b> Leakage is not adequately assessed. Although the data needed for direct measurements are lacking, analysis of related data reveals increasing trends in chemical concentrations in some areas of the Navajo aquifer, threatening water quality and potentially causing material damage.
<i>Criterion 3:</i> Discharge to springs	“A discharge reduction of 10 percent or more caused by mine-related withdrawals based on results of N-aquifer simulation.”	<b>Yes.</b> Decline in discharge of 10 percent or more was indicated in three of four recently monitored springs and, if the model were updated and forced to calibrate, the conclusion that no material damage has occurred would not be supported.
<i>Criterion 4:</i> Discharge to washes	“A discharge reduction of 10 percent or more caused by mining.”	<b>Yes.</b> Material damage is indicated by a decline in discharge of 10 percent or more. Three of four continuously monitored wash gauging stations show decline of at least 50%, clearly indicating material damage; however, simulated modeling results do not calibrate with monitoring data.

The new data show that Peabody’s mining practice of drawing down the aquifer—sapping the water pressure that has taken many centuries to build—has already caused the aquifer material harm according to some of the U.S. government’s own criteria. Now, a permit request from Peabody seeks to potentially increase water withdrawals from the Navajo aquifer and loosen protections for this water source—despite signs of damage and continuing decline indicated by the physical monitoring data.

NRDC recommends a number of steps that must be taken to protect this critical water source:

- Peabody should permanently cease groundwater pumping from the N-aquifer, and the Office of Surface Mining Reclamation and Enforcement must deny Peabody’s request for increased access to these waters.
- The Department of the Interior should improve its monitoring of the N-aquifer and should ensure that the Hopi tribe and Navajo Nation have a viable, long-term source of water.
- With tribal consent, the Environmental Protection Agency should designate the N-aquifer a “sole source aquifer” that is granted government protection.
- Tribal sovereignty must be respected, and federal and tribal governments should work cooperatively to manage aquifer resources.

Full text of the original 2000 technical report can be accessed online at [www.nrdc.org](http://www.nrdc.org).

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# The Navajo Aquifer Shows Signs of Material Damage and Continuing Decline

**A**quifers are like sponges, holding their groundwater in sediment or in tiny pores, fissures, and fractures of rock such as sandstone and limestone. Water trickles through these spaces, pulled from high pressure areas to areas of lower pressure, but compared with surface water its flow is imperceptible: it moves just a few inches or feet in the course of a year. Beneath Black Mesa, water first flows south from the exposed Shonto plateau, then divides. Over the last few decades, however, Black Mesa and its springs have turned increasingly dry. The physical impacts to the Navajo aquifer have become even more pronounced since the release of the original *Drawdown* report.

In 2000, NRDC examined the Office of Surface Mining Reclamation and Enforcement's (OSMRE) own standards for assessing material damage to the N-aquifer's structural stability, its water quality, and its discharge to both springs and washes. *Drawdown: Groundwater Mining on Black Mesa* concluded that under the government's adopted criteria, material damage had clearly occurred to the N-Aquifer in at least one respect. *Drawdown* further concluded that physical monitoring data belied many of the Department of Interior's conclusions of no material damage, determinations which were often at odds with physical monitoring results. In fact, the government's results stemmed almost exclusively from the results of incomplete and inappropriately used models of the N-aquifer.

For *Drawdown: An Update*, NRDC undertook a thorough review of the most recent monitoring data and, additionally, commissioned LFR Levine-Fricke (LFR) to update its technical review of the Cumulative Hydrologic Impact Assessment (CHIA) criteria in light of the latest monitoring data (appended to this publication). This section revisits OSMRE's material damage criteria with the most current physical monitoring data and expert review available. The results are discouraging:

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- Material damage to the N-aquifer's structural stability is further indicated by new data, and the confined state of the N-aquifer has been potentially compromised;
  - Material damage to the N-aquifer's water quality is indicated by physical monitoring data, which shows localized increases in concentrations of sulfate, chloride, and total dissolved solids;
  - Simulated modeling results do not calibrate with physical monitoring data for spring discharge, with the latter indicating that material damage has already occurred for the three springs on the southwest side of the mesa;
  - Simulated modeling results do not calibrate with the physical monitoring data for wash discharge, with the latter once again indicating that material damage has already occurred.

## **Cumulative Hydrologic Impact Assessment Criteria Results Indicate Further Damage**

In 1989, the Department of the Interior established Cumulative Hydrologic Impact Assessment criteria to assess the material damage to the N-aquifer caused by Peabody pumping. Material damage was described as “any long-term or permanent change in the available quantity or quality of a water source that will preclude its use or reduce its utility to an existing water user.”<sup>1</sup>

In 2000, after reviewing the data from the U.S. Geological Survey (a sister agency of OSMRE's within the Department of the Interior) and Peabody's own reports, NRDC concluded that based on the government's own criteria, material damage had occurred. Six years later, the most recent data shows that the N-aquifer shows signs of continuing decline.<sup>2,3</sup> Water withdrawals on Black Mesa clearly violated at least one criterion for establishing material damage, with other criteria strongly indicating material damage was occurring. These findings are particularly important due to the possibility of renewed water withdrawals at increased levels over the next 20 years, as discussed in the following section.

### **CHIA Criterion One: Structural Stability**

**Criterion:** Maintain potentiometric head (the height to which confined liquid will rise when tapped by a well) of 100 feet above the top of N-aquifer at any point to preserve confined state of aquifer.

**2000 Findings:** OSMRE established material damage criterion to protect the structural stability of the N-aquifer. Peabody was to “[m]aintain potentiometric head 100 feet above top of N-aquifer to any point to preserve confined aquifer state.”<sup>4</sup> In 2000, NRDC reported that six of the fifteen wells (Rough Rock, 10T-258, 10R-111, Sweetwater Mesa, BM3, and Kayenta West) dipped below the 100-foot potentiometric threshold. Even if the first four sites are discounted for their proximity to the aquifer's unconfined portion, that still leaves two (Kayenta West and BM3) whose head fall within the signal 100 feet. As such, according to CHIA Criterion One, material damage continues to be indicated.

**2006 Findings:** Since 2000, water levels at most of the monitoring wells have continued to decline, supporting the findings of material damage made in *Drawdown*.<sup>5</sup> In addition, the latest monitoring data indicates that water levels in Kayenta West and BM3 have dipped below the top of the N-aquifer, potentially compromising the confined state of the aquifer. If, as OSMRE indicated, maintaining a potentiometric head 100 feet above the top of the N-aquifer is intended to provide a protective barrier in order to preserve the confined state of aquifer, then these continuing declines raise two serious concerns:<sup>6</sup>

- First, water levels at Kayenta West and BM3 have dipped far below the 100-foot criterion, which constitutes a violation of the CHIA requirements and an indication of material damage under OSMRE's adopted safety standards.
- Second, because water levels at Kayenta West and BM3 have dipped below the top of the N-aquifer itself and, therefore, have potentially compromised the confined state of the aquifer in those areas, the violation of CHIA Criterion One is especially serious.

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The monitoring data introduce a suite of concerns regarding material damage to the N-aquifer, including a reduction in permeability and loss of storage capacity in the area where the overdraft occurred, and raise serious concerns about the impact of any future mine-related aquifer withdrawals.

### **CHIA Criterion Two: Water Quality**

**Criterion:** A value of leakage from the Dakota Sandstone aquifer (known as the D-aquifer) not to exceed 10 percent from mine-related withdrawals.

**2000 Findings:** *Drawdown* reported that since data necessary for direct measurements is lacking, monitors have sought to indirectly gauge the magnitude of leakage from the D-aquifer by the amount of inorganic compounds, or total dissolved solids (TDS), in N-aquifer water. The USGS identified increased chloride and sulfate concentrations as important indicators of increased D-aquifer leakage.<sup>7</sup> *Drawdown* concluded that data from the previous 10 years had resulted in dramatic localized increases at certain wells that were discounted by OSMRE for sampling error, mislabeling, failure of individual well seals, or changes in pumping methods.<sup>8</sup>

**2006 Findings:** The latest physical monitoring data indicates that the trend of increased chemical concentrations has continued. The last 15 years have seen some dramatic localized increases, such as a spike in sulfate concentrations in a Chilchinbito well and a climb in TDS in a well at Forest Lake. Data collected at various monitoring springs that discharge from the N-aquifer also show a marked increase in chloride.<sup>9</sup> Recent monitoring data provide evidence of increasing trends in inorganic constituents in the N-aquifer, including chloride and total dissolved solids, particularly in the southeast portion of near Rough Rock, Pinon, and Keams Canyon.<sup>10</sup> Despite these trends and localized increases, OSMRE continues to conclude that material damage has not occurred.<sup>11</sup>

The sources of induced leakage have not been inadequately assessed. Leakage can occur for a number of reasons: a shift in the vertical gradients between the D- and N-aquifers from pre-development to post-development times, a shift in the horizontal gradient in the N-aquifer, or a combination of both.<sup>12</sup> With respect to the vertical gradient, OSMRE makes no attempt to estimate induced leakage through water-level monitoring of the D- and N-aquifers and changes in their vertical gradients.<sup>13</sup> With respect to the horizontal gradient, historic horizontal gradient in the N-aquifer was toward the south. However, it appears that horizontal gradient has reversed as a result of Peabody's pumping regime—leakage now appears to be providing a source of storage (or recharge) to offset those pumping stresses.<sup>14</sup> OSMRE has failed to adequately assess this shift in horizontal gradient.<sup>15</sup> In short, OSMRE has failed to provide quantitative estimates of either the vertical gradient between the D-aquifer and the N-aquifer from pre-stress to post-stress periods or the horizontal flux or vertical induced leakage based on observed changes in the horizontal gradient in the N-aquifer.

The CHIA criteria do not address the potential for man-made conduits that may effect water quality in the N-aquifer. In particular, wells in the Peabody well field are perforated or screened across multiple aquifers and, as such, when the wells are not pumping, a direct vertical conduit exists between the aquifers.<sup>16</sup> Because water quality in overlaying aquifers is worse than in the lower-lying N-aquifer, contamination conveyed through inactive wells is a possibility.<sup>17</sup> If the wells are not pumped for a significant period of time, water that is “injected” into the N-aquifer from overlying aquifers under non-pumping conditions could significantly impact water quality in the N-aquifer.<sup>18</sup> Peabody's massive water withdrawals coupled with its use of perforated well casings have created a situation in which damage to water quality may be occurring whether Peabody is pumping or not.

### **CHIA Criterion Three: Discharge to Springs**

**Criterion:** A discharge to springs reduction of 10 percent or more caused by mine-related withdrawals based on results of N-aquifer simulation.

**2000 Findings:** OSMRE designed its third criterion to assess damage to the springs, finding that damage was indicated if discharge fell by 10 percent or more as a result of Peabody's withdrawals. Unfortunately, as



reported in 2000, OSMRE linked this criterion to a U.S. Geological Survey (USGS) computer model of groundwater flow that is both outdated (the last computer simulation was in 1994) and inappropriate for the purpose of evaluation. Moreover, this model hardly reflects the on-site data reported by the USGS.<sup>19</sup> At the time of the original *Drawdown* report, not only had most springs experienced a discharge reduction in excess of 30 percent, but the majority of those appeared to have decreased by more than 50 percent (Rock Ledge, Moenkopi School, Many Farms, Whiskey, and Pasture Canyon).<sup>20</sup> Hence, regardless of the monitoring data deficiencies, OSMRE's conclusion that no material damage has occurred as a result of Peabody's pumping was strongly challenged by the data. It was unclear why the modeling simulations had not been adjusted (calibrated) to better represent observed decreases in spring discharges.

**2006 Findings:** It remains unclear how a conclusion can be made that no material damage is evident based on simulated modeling results under both the USGS model (1994) and Peabody model (1999) while physical monitoring data suggest otherwise.<sup>21</sup> The USGS's most recent published monitoring data from four springs that discharge from the N-aquifer (Pasture Canyon, Moenkopi School, Burro, and an unnamed spring near Dennehotso) clearly shows an overall reduction in spring discharge for the three springs on the southwest side of the mesa (Pasture Canyon, Moenkopi School, and Burro). Discharge from the unnamed spring near Dennehotso has fluctuated over time, implying that some unknown change(s) may have occurred (e.g., new monitoring location, nearby construction), but the two lowest measured discharges over the last decade occurred within the last three years.<sup>22</sup> Looking at the annual data from Pasture Canyon, Moenkopi School, and Burro springs, physical monitoring data shows reductions that far exceed the 10 percent threshold: 24 percent at Moenkopi, 19 percent at Pasture Canyon, and 50 percent at Burro.<sup>23</sup> Moreover, if other historic spring discharge data were considered, observed discharge reductions would be much greater (70 percent at Moenkopi and 85 percent at Pasture Canyon).<sup>24</sup> All considered, if models used to support claims of no material damage were updated and forced to calibrate to the physical data that has been collected, material damage would likely be indicated. OSMRE's analysis of this criterion is severely limited by its reliance on computer modeling, but if physical monitoring data were given precedence over modeling, material damage would be evident.

OSMRE continues to disregard actual monitoring data and historical accounts from Hopi elders that the outflow from springs sacred to the tribe has been drying up.<sup>25</sup> Instead, OSMRE has created a "virtual" world that differs starkly from the reports on the ground in Black Mesa. It is not entirely clear how OSMRE could conclude that no material damage is evident based on simulated modeling results while physical monitoring data suggests otherwise. This finding of no material damage is particularly dubious since the groundwater

#### **Using water levels to better assess water quality**

A measure that should be used to supplement TDS sampling—one that was proposed by the Office of Surface Mining in 1988, but was bumped from the CHIA's final version—is water level. Under the proposed criterion, the aquifer's potentiometric head would be monitored for decline against a baseline altitude, which represents how high its water would have climbed before Peabody's operations began. Should its head drop below 100 feet of this baseline—suggesting a sharp fall in water pressure and the formation of a pressure gradient strong enough to pull lower-quality water from above—material damage would be indicated. (By contrast, under CHIA Criterion One, potentiometric head is monitored for its proximity to the aquifer's surface, not to a predetermined baseline, and material damage is indicated where the head drops within 100 feet of the aquifer itself.) If this proposed criterion were in use in 2000, there could be little question that water quality was threatened. In the intervening years, water quality has worsened to the point where three of the 11 monitored wells in the N-aquifer's confined portion (Pinon, Keams Canyon, and BM6) have dropped below the 100-foot mark and three additional wells (BM2, BM3, and BM5) are on the verge of crossing over. Moreover, in the areas where the N-aquifer has dipped below the top of the N-aquifer, the introduction of air can alter aquifer chemistry and result in damaging reactions such as the formation of iron and manganese oxide precipitates. Such impacts would be irreparable.



model used to make that determination is admittedly incapable of resolving significant changes in spring discharges at the level required by the CHIA criteria.<sup>26</sup> Physical monitoring data continue to show that material damage, as defined by the CHIA criteria, is occurring.

### **CHIA Criterion Four: Discharge to Washes**

**Criterion:** A decline in discharge to the N-aquifer washes by 10 percent or more, caused by mining.

**2000 Findings:** OSMRE designed its fourth criterion to assess damage to washes, finding that damage was indicated when discharge to the N-aquifer’s washes declined by 10 percent as a result of mine-related groundwater pumping. As noted in 2000, evaluation of this fourth criterion, like evaluation of the third, relies on a “virtual” world of modeling that does not conform to physical monitoring data. Unfortunately, OSMRE based its analysis of this criterion on the latest USGS N-aquifer model, which had last been updated by USGS in 1994. OSMRE continues to conclude that based upon that 1994 N-aquifer simulation, material damage has not occurred.

**2006 Findings:** Historical data do exist for flow in some area washes; however, the data are limited. According to the USGS, continuous discharge data have been collected at four streamflow gauging stations since the mid 1970s.<sup>27</sup> The average annual discharge at the four gauging stations varies during the period of record. Nonetheless, according to USGS monitoring data, since 1995 the median winter flows for Moenkopi Wash, Dinnebito Wash, and Polacca Wash have generally decreased.

For the four continuously monitored washes, the median winter flows in 2003 were 0.75 ft<sup>3</sup>/s for Laguna Creek, 0.25 ft<sup>3</sup>/s for Dinnebito Wash, 0.10 ft<sup>3</sup>/s for Polacca Wash, and 3.45 ft<sup>3</sup>/s for Moenkopi Wash. By comparison, the earliest measured median winter flows for Laguna Creek (1997), Dinnebito Wash (1994), and Polacca Wash (1995) were 1.8 ft<sup>3</sup>/s, 0.5 ft<sup>3</sup>/s, and 0.35 ft<sup>3</sup>/s, respectively. As such, flow reductions of 50 percent or more are evident since monitoring began in those three washes, which easily surmounts the 10 percent threshold identified in the CHIA criteria (see Table 2). For Moenkopi Wash, the period of record is much longer and shows a general decline since the highest measured value in 1988, except during the last two years where flow has increased.<sup>28</sup>

<b>Wash/Creek</b>	<b>Earliest Median Winter Flows</b>	<b>2003 Median Winter Flows</b>	<b>Change in Median Flow (percentage)</b>
Laguna Creek	1.8 ft <sup>3</sup> /s (1997)	0.75 ft <sup>3</sup> /s	- 58%
Dinnebito Wash	0.5 ft <sup>3</sup> /s (1994)	0.25 ft <sup>3</sup> /s	- 50%
Polacca Wash	1.8 ft <sup>3</sup> /s (1995)	0.10 ft <sup>3</sup> /s	- 94%
Moenkopi Wash	3.2 ft <sup>3</sup> /s (1977)	3.45 ft <sup>3</sup> /s	+ 8%

The physical monitoring data clearly indicates that base flow in a majority of the monitored washes have decreased by more than 10 percent since monitoring began. Material damage to the N-aquifer is evident; however, simulated modeling results do not calibrate with the physical monitoring data. Once again, OSMRE’s analysis of this criterion is severely limited by its reliance on computer modeling, but if physical monitoring data were given precedence over modeling, material damage would be evident.

As with spring discharge, to assess impacts of changes in base flow to washes this criterion depends on simulated groundwater modeling results rather than physical monitoring data. The physical monitoring data suggests that base flow in the majority of monitored washes have decreased by more than 10 percent since monitoring began. As such, in accordance with the CHIA criteria, material damage to the N-aquifer is evident; however, OSMRE continues to rely on simulated modeling results that do not calibrate with the physical monitoring data.

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# Flawed Modeling Obscures Evidence of Material Damage to the Navajo Aquifer

Since mining began on Black Mesa three decades ago, more than 44 billion gallons of pristine groundwater have been pumped from the Navajo aquifer to feed the Peabody pipeline. As shown in the original *Drawdown* report and again in this follow-up paper, data collected by the government often contravene the government’s own conclusion that material damage has not occurred. And yet, aided by flaws in the Interior Department’s criteria, holes in its monitoring program, and basic deficiencies in its hydrogeologic model, Peabody has been able to allege that the present use of water for slurry will not adversely affect the aquifer and those who depend on it.

*Drawdown* noted that perhaps the principal deficiency in the government’s program is its overreliance on modeling projections, which tend to obscure on-site evidence of material damage as described in *Drawdown* and this follow-up publication. For example, the third of OSMRE’s four material damage criteria, which assesses the aquifer’s discharge to springs, depends entirely upon modeling, regardless of what actual data may show. Simulations have also been used in application of criteria two and four, partly to distinguish Peabody’s impacts on water quality and washes from those of the tribes, although results there, too, fail to correspond with on-site trends or explain their divergence.<sup>30</sup> Relying on the U.S. Geological Survey model, OSMRE has found that material damage to Black Mesa’s springs has not occurred, noting how simulated flows “decreased [due to Peabody’s withdrawals] by less than 1 percent under all pumpage scenarios,” even though seven of nine monitored sites have already exhibited flow reductions well in excess of the government’s 10 percent ceiling.<sup>31</sup>

## Flaws in the U.S. Geological Survey’s Two-Dimensional Model

*Drawdown* outlined a number of flaws in the U.S. Geological Survey model (“USGS Model”). Besides being misapplied, the official model was based on assumptions about recharge and other hydrogeological features that have since been called into question. Recharge is the process by which aquifers are replenished with water,

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as rainfall infiltrates the ground and percolates downward. The physical characteristics of the soil, the extent of plant cover, the moistness of surface materials, the intensity of rainfall, the slope of the landscape, and the presence and depth of confining layers and storage basins can all influence the recharge rate of an aquifer, making calculation difficult.

Back in the early 1980s, the U.S. Geological Survey fixed the recharge rate of the N-aquifer at about 13,000 acre-feet per year; several later studies, including the crucial Cumulative Hydrologic Impact Assessment completed in 1989, relied on this estimate in formulating their conclusions.<sup>32</sup> But there were problems: the original researchers failed to provide full discussion or documentation of the aquifer's hydrodynamics, begging basic questions about the integrity of the USGS model, and they overestimated the region's annual precipitation, which colored the results.<sup>33</sup>

In response to an internal critique of the USGS model, *Drawdown* reported that the U.S. Geological Survey took steps to revise its original estimate: recharge to the exposed Shonto region at the northern end of Black Mesa, the region believed to account for much of the N-aquifer's recharge, has been downgraded on the basis of detailed geochemical and isotopic measurements to between 2,500 and 3,500 acre-feet per year, suggesting that actual recharge to the aquifer is but a fraction of the government's original estimate.<sup>34</sup> If this revised figure is correct, then Peabody's current withdrawals from the N-aquifer most likely surpass what hydrogeologists would call the aquifer's "safe yield,"—the difference between its annual rates of recharge and discharge.<sup>35</sup>

Safe yield is like a surplus in an accounting book; it is the amount left after all the year's credits (recharge) and debits (discharge) have been logged. What happens to an aquifer when its safe yield is exceeded? As the hydrologist C.V. Theis wrote in 1940, "a new state of dynamic equilibrium is reached only by an increase in recharge, a decrease in discharge, or a combination of the two."<sup>36</sup> If an increase in recharge is not forthcoming, a decrease in discharge to the washes and springs is to be expected.

Other criticisms of the USGS model have been made. The overarching issue concerning the USGS model is the fact that it is over a decade old and has not been run by USGS since 1994. LFR Levine-Fricke reports that if forced to update, the conclusion that no material damage has occurred would very likely not be supported. In addition, since a complete water budget (or allocation scheme) for the N-aquifer could not be calculated from available field data, researchers relied upon estimates in their original study; though revisions were made in subsequent years, fundamentals of this water budget were not reconsidered and related assumptions went unexplained.<sup>37</sup> As has also been noted, conclusions regarding the levels of potential leakage from the overlying D-aquifer are likewise based on insubstantial evidence.<sup>38</sup>

### **Peabody's 1999 Three-Dimensional Flow Model Is Fundamentally Flawed**

In 1999, HIS Geotrans and Waterstone prepared for Peabody A *Three-Dimensional Flow Model of the D and N Aquifers* ("1999 Flow Model") to develop estimates of N-aquifer water withdrawals. In 2002, at the behest of NRDC, LFR Levine-Fricke provided a technical review of the 1999 Flow Model and accompanying documentation and its application to predicting impacts on the D- and N-aquifers (appended to this publication). This review focused on whether the new model improved the ability to assess material damage and other disturbances to the hydrologic balance relative to CHIA criteria and whether it accurately simulated responses to Peabody pumping on such issues as groundwater elevations, aquifer discharge, induced leakage, and storage loss in the D- and N-aquifers.

The technical review concluded that the 1999 Flow Model is fundamentally flawed and fails to meet the regulatory requirements. Major flaws include the following:

1. The 1999 Flow Model is inadequate to address all relevant consequences of mining on the hydrologic balance (and associated, existing CHIA criteria).
2. the model is otherwise flawed in important ways that destroy its utility and credibility, including its theoretic postulation of a nearly unlimited supply of water to replace water pumped by Peabody and mask the effects of Peabody pumping.

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Each of these points is discussed in turn. First, Peabody relies heavily on the model to support its claims that impacts to the N-aquifer are minimal. However, Peabody admits that the model has insufficient resolution to address a critical issue: diminishment of flow at sacred and other springs in the area.<sup>39</sup> The impact of Peabody's activities on spring flow is, and has always been, a central hydrogeologic issue. For example, one of the four CHIA criteria established by OSMRE establishes a material damage threshold of 10 percent reduction in spring flow.<sup>40</sup> Yet, the 1999 Flow Model simply does not address this issue, thereby precluding OSMRE from assessing impacts to individual springs, many of which are religiously and culturally integral to the Hopi in addition to serving as sources of potable water.<sup>41</sup>

Second, the 1999 Flow Model is otherwise fatally flawed in important ways that destroy its utility and credibility. As documented in the attached report from expert hydrogeologists and modelers with LFR, the 1999 Flow Model has numerous inconsistencies and significant problems. Chief among them, the 1999 Flow Model artificially creates a nearly limitless supply of water residing in the D-aquifer that "replaces" water pumped from the underlying N-aquifer by the coal company for use in its operations. This element of the model fundamentally obscures impacts and minimizes Peabody's proportional role in those that are identified. In short, as more fully discussed in the attached LFR report, the 1999 Flow Model is inadequate to support the conclusions contained in Peabody's permit application, nor is it capable of supporting a finding by OSMRE that material damage or other disturbances to the hydrologic balance will not occur as a result of Peabody operations.<sup>42</sup>

It is instructive that an earlier 2002 permit application relying on the 1999 Flow Model contained significant caveats about the utility of the model. For example, Peabody acknowledged that the agreement between the model and observed water levels (alleged by Peabody) "does not necessarily mean that the predictions will be accurate."<sup>43</sup> Peabody also noted that "[e]arlier models produced reasonably good agreement with water-level change information available at the time of their calibration, but the agreement of measured and simulated water-level changes degraded with increasing time."<sup>44</sup>

### **The Significant Shortcomings of Peabody's 2005 Supplement**

In 2005, Peabody released a supplement to its *Three-Dimensional Flow Model of the D and N Aquifers* ("the 2005 Supplement"). The purpose of the 2005 Supplement was to simulate and evaluate five additional pumping scenarios, provide results of additional sensitivity testing, and evaluate whether the models originally presented in 1999 are able to accurately simulate water level changes from 1997 through 2003 in the Black Mesa monitoring wells. At the behest of NRDC, LFR reviewed the 2005 Supplement to determine its ability to address CHIA criteria and resolve outstanding shortcomings outlined in the 1999 Flow Model (appended to this publication).

Peabody's 2005 Supplement has three major flaws:

1. Previous concerns regarding the model and its ability to resolve specific CHIA criteria requirements remain unresolved, including a failure to resolve changes in spring discharge at the level necessary to evaluate CHIA criteria.
2. Essential statistics to support the supplement's conclusions and facilitate peer review are not made available; rather, only declaratory statements are provided.
3. The model fails to include D-aquifer water-level data necessary to quantify leakage from the D-aquifer to the N-aquifer.

Each of these issues is addressed in turn. First, the previous concerns regarding the model and its ability to resolve specific CHIA criteria requirements remain unresolved. As noted above, the 1999 Flow Model has insufficient resolution to address a critical issue: diminishment of flow at sacred and other springs in the area.<sup>45</sup> As noted earlier, this critical concern is a central hydrogeologic issue, one which the 2005 Supplement fails to address (as pointed out years ago by LFR). The supplement therefore fails to provide the necessary information for OSMRE to assess impacts to individual springs. For example, LFR noted that to assess discharge reductions at Pasture Canyon spring, a 10 percent reduction in spring discharge would require

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that the model accurately resolve changes in spring discharge of less than 5 gallons per minute or 8 acre-feet per year at a minimum. The 1999 Flow Model and 2005 Supplement fail to achieve this critical indicator. Furthermore, LFR notes, if the model were accurately calibrated, it would show a reduction in spring flow of over 19 percent at Pasture Canyon spring since 1995.<sup>46</sup>

Second, the 2005 Supplement fails to make available necessary information to support its conclusions and facilitate peer review. LFR notes that calibration statistics typically provided in model validation reports are not made available to the public, rather qualitative statements are provided with no statistical showing.<sup>47</sup> For example, the 2005 Supplement simply states that “[t]he four models match the observed water-level changes at the six BM monitoring wells quite well” without making available the information necessary to verify this statement. The 2005 Supplement acknowledges this shortcoming when, comparing additional pumping data and simulated model results to the updated pumping data, the report states: “[t]his evaluation, which is not presented here, indicated that there were only small differences between measured and simulated drawdown for the period 1997 through 2000” (emphasis added). The 2005 Supplement fails to conform to applicable industry standards for demonstrating model performance.

Third, neither the 1999 Flow Model nor the 2005 Supplement include water levels for the confined portion of the D-aquifer. In fact, Peabody does not even monitor water levels in the confined portion of the D-aquifer as part of its monitoring efforts. This information is necessary to directly evaluate the change in leakage from the D-aquifer to N-aquifer under the 1999 Flow Model for CHIA Criterion Three. Moreover, it would seem necessary to calibrate a model that incorporates the D-aquifer and is intended, in part, to quantify leakage from the D-aquifer to the N-aquifer.

Peabody’s 1999 Flow Model continues to suffer from the same fatal flaws that were left unaddressed in the 2005 Supplement. In fact, the 2005 Supplement raises a series of additional concerns that seriously undermine the utility and predictive accuracy of the 1999 Flow Model and 2005 Supplement for determining material damage to the N-aquifer.

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# Controversy Comes to a Head with Peabody's New Request for Increased Navajo Aquifer Access

The conflict is heating up between the coal company seeking to exploit the Navajo aquifer and the tribal communities who rely on the aquifer as a potable water source. Peabody has filed a request to extend its mining operations in Black Mesa and, despite the evidence to the contrary, claims that this invasive mining and accompanying water withdrawals will not damage the aquifer. But physical monitoring data as well as firsthand accounts tell a story of groundwater depletion that can be traced to Peabody's operations in Black Mesa.

## Mohave Generating Station Closure

Since the 1960s, the Black Mesa mine has produced coal and the N-aquifer has provided water so that the dirtiest remaining power plant in the Intermountain West, located 273 miles away in southern Nevada, could operate.<sup>48</sup> During this period, tens of billions of gallons of pristine water have been removed from the N-aquifer, causing material damage to the aquifer itself and threatening Hopi livelihood and the cultural practices that rely on it.<sup>49</sup> In 1997, environmental groups sued the co-owners of the Mohave Generating Station (MGS) to stop its repeated Clean Air Act violations.<sup>50</sup> According to available information, the 1,580-megawatt MGS plant was releasing an average of 19,000 tons of nitrogen oxide, 40,000 tons of sulfur dioxide, and 2,000 tons of fine particles a year into the air above Laughlin.<sup>51</sup> That plume of smog and soot pollution was contributing to the haze that diminished visibility at the Grand Canyon.<sup>52</sup> In 1999, MGS co-owners agreed to retrofit the plant, which supplied customers in California and in other states, with state-of-the-art pollution controls by January 1, 2006.<sup>53</sup> But when the MGS co-owners failed to retrofit the power plant and were forced to shut the plant down, most of Peabody's water withdrawals from the N-aquifer ceased indefinitely. To many tribal members, the shutdown of MGS and the cessation of mining activities at Black Mesa mine were necessary steps to preserve the N-aquifer and its springs.<sup>54</sup> But the threat to the tribes and to the balance of the N-aquifer remains.



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## Peabody's Current Request for Increased Access to the N-Aquifer

Peabody is moving forward to restart its N-aquifer withdrawals. In early 2004, Peabody submitted a permit application to OSMRE. In that application, Peabody sought regulatory authorization to extend mining operations on Black Mesa for an additional 20 years, while discounting any negative effects previous mining operations have had on the N-aquifer.<sup>55</sup> In its permit application, Peabody asserts that incontrovertible evidence supports the conclusion that potential hydrologic consequences of Peabody's "past, present, and potential future usage of the Navajo aquifer are negligible," despite the fact that this statement does not correlate with physical monitoring data.<sup>56</sup>

The conclusory statements in Peabody's latest permit application conflict with empirical data indicating that several of the criteria for material damage to the N-aquifer have already likely been exceeded. As noted in the *Drawdown* report and this publication, major impacts to the N-aquifer include:

- water levels in that have dipped below the 100-foot protective barrier and, in some locations, below the top of the N-aquifer;
- dramatic localized increases in total dissolved solids, as well as sulfate and chloride concentrations at a number of locations;
- diminishment of flow by more than 30 percent from seven of nine monitored N-aquifer springs, with spring flow reduction of 50 percent or more from three of four annually monitored N-aquifer springs; and
- substantial reductions in wash discharge of more than 50 percent in three of four monitored washes, as indicated by physical monitoring data, in excess of material damage criteria thresholds.<sup>57</sup>

In apparent response to the concerns of the harm to the N-aquifer that the permit application would raise, Peabody included a provisional plan to use an alternative water source: the Coconino Aquifer (or "C-aquifer"). Critically, Peabody fails to show that C-aquifer water can be withdrawn consistent with OSMRE regulations or that it is likely to be available to the mine.<sup>58</sup> Under Peabody's latest permit application, until C-aquifer water is available, if ever, Peabody requests increased access to the N-aquifer for all of its operations, including production and resultant transportation of coal and its new coal washing water requirements.<sup>59</sup> Essentially, under Peabody's latest permit application, if the C-aquifer never becomes available, is substantially delayed, or if Peabody decides it is not worthwhile to pursue, business as usual would continue on Black Mesa.

As noted earlier, Peabody's latest permit application suffers from at least two overarching shortcomings when it comes to issues related to the N-aquifer. First, Peabody's permit application discounts physical monitoring data, concluding that material damage is not occurring despite monitoring data indicating otherwise. Second, in addition to discounting physical monitoring data, Peabody crafted the permit application to continue its right to withdraw as much N-aquifer water as required for mining and transport operations through the life of the permit, while only making unsubstantiated assurances that it is *committed to seeking* an alternative water source, much less that it will be available.<sup>60</sup> These unsubstantiated assurances come in the face of a requested increase in the amount of water that Peabody would be allowed to withdraw—in excess of 6,000 acre-feet a year.

In short, Peabody's permit application, as drafted, would allow Peabody to increase water withdrawals from the N-aquifer for the next twenty years despite the serious concerns raised by physical monitoring data already evident at much lower levels of annual N-aquifer pumping.

Peabody's latest permit application to OSMRE is still being examined and will have to undergo environmental review under the National Environmental Policy Act of 1969—a process that will continue throughout 2006.



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# Recommendations for Preserving the Navajo Aquifer

**T**he U.S. government has an obligation to protect the Black Mesa water system from groundwater mining, a practice that virtually no one defends as an appropriate—let alone the best—use of a precious resource. To preserve the Navajo aquifer and the sacred springs and washes it feeds, NRDC concludes the following steps must be taken to protect the health of this vital water source.

■ **Peabody should *permanently* cease groundwater pumping from the N-aquifer.** As reported in 2000, there is ample evidence to suggest that Peabody’s annual withdrawal of more than a billion gallons of potable N-Aquifer water (which no one defends in principle) is endangering the ability of the Hopi and the Navajo to draw on groundwater for subsistence and other needs. Given the evidence—the substantial fall of water levels in the aquifer; mounting evidence that its recharge rates are substantially lower than originally forecast; evidence of water-quality degradation in at least some parts of the aquifer; declines in outflow from its springs; Peabody’s status as principal user; potential for severe, adverse consequences should pumping continue; and the protective principles that underlie the government’s trust relationship with the tribes—it should be the policy of the Department of the Interior that Peabody cease mining the N-aquifer and refuse Peabody rights to any continued access of the N-aquifer as posited in Peabody’s most recent permit application.

■ **OSMRE must deny Peabody’s life-of-mine permit application.** OSMRE cannot legally authorize a life-of-mine permit for the Kayenta and Black Mesa mines based on vague assumptions and future assurances that an alternative water source may one day be available.

■ **The Interior Department should renew its investigation of alternatives to the current pipeline system.** The Department of the Interior should update Phases 1 and 2 and conduct Phase 3 of the three-part study on coal transport alternatives that it began in the early 1990s. The Environmental Protection Agency identified a few of these alternatives in reviewing Peabody’s permit application 10 years ago: replacing water-based coal slurry with a methanol-based slurry; substituting low-grade water for the pristine drinking water of the N-aquifer; using reclamation technologies to reduce the total amount of water needed, regardless of the source;

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and developing an alternative vehicle for coal transport.<sup>61</sup> It remains for the Interior Department to update and complete its comparative analysis and determine which of the available options, singly or in combination, is the most environmentally and economically sound. This analysis can be performed within the context of the Environmental Impact Statement under the National Environmental Policy Act required for Peabody's latest permit application.<sup>62</sup>

The Department of the Interior should consider, in addition, at least one alternative that has not yet been named: the use of reclaimed water from existing treatment facilities as a replacement for all or part of the pristine N-aquifer groundwater used in Peabody's slurry. Recycling wastewater is generally considered sound environmental policy, supported by a wide range of interests in the southwestern United States, and NRDC's investigation has determined that recycling in this case may be technically feasible, once the needs of local farmers are met.<sup>63</sup>

■ **The Department of the Interior should adopt safe yield as its management goal.** Under the standard known as safe yield, users of an aquifer cannot take more than the aquifer's natural surplus; i.e., the difference between what the aquifer annually acquires through recharge and what it loses through discharge to springs and washes and other natural processes. Meeting this standard means developing policies and parameters that will ensure the availability of groundwater long into the future. Other standards—such as sustained yield, which sets a 100-year parameter for an aquifer's sustainability—provide neither a long-term solution to groundwater overdraft nor an appropriate way to ensure the viability of peoples that have inhabited the same land for many hundreds of years. With tribal consent, the Department of the Interior should adopt safe yield as its management goal for the N-aquifer.

■ **The Department of the Interior should improve its monitoring of the N-aquifer.** To ensure that safe yield standards are met and that washes, springs, community wells, and other features are protected in the long run, it is essential that the current monitoring regime be overhauled. The Interior Department should improve its metering of Moenkopi and other washes, take potentiometric measurements of the D- and N-aquifers for a more accurate assessment of contamination risk, and make whatever additional adjustments are necessary to address the potential impacts that OSMRE has identified. At the same time, it should open OSMRE's material damage criteria, which help define the parameters of its monitoring program, to a public process of reexamination and revision.

■ **The Department of the Interior should recalibrate its hydrogeologic model of the N-aquifer.** Data compiled by OSMRE and a reassessment of the aquifer's recharge rate undertaken by the U.S. Geological Survey suggest that the department's existing model does not reflect actual conditions. The department should revise its model accordingly. Of course, making these revisions to its modeling and monitoring programs should not delay the department in taking the precautionary steps we have recommended.

■ **With tribal consent, the Environmental Protection Agency should designate the N-aquifer a "sole source aquifer" pursuant to the Federal Sole Source Aquifer Protection Program.** The federal Safe Drinking Water Act recognizes that sole sources of regional drinking water, whose contamination "would create a significant hazard to public health," require special protection to ensure their long-term viability.<sup>64</sup> Once an aquifer has officially been designated a sole source under the program, no federal funding can be committed to any project that may result in its contamination. With the tribes' consent, the N-aquifer should receive this designation from the Environmental Protection Agency.

■ **Tribal sovereignty must be respected, and federal and tribal governments should work cooperatively to manage aquifer resources.** The federal government and the Hopi and Navajo tribes must work together to develop a viable policy of groundwater management applicable to reservation lands and modeled on the safe yield standard of zero net withdrawals. Fundamental to the plan should be self-governance for the tribes with respect to groundwater management, enforceable limits on withdrawals from the N-aquifer to ensure

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that progress associated with diminished industrial pumping is not offset or lost by increased pumping for other nonessential purposes, and regulations that recognize the environmental and cultural significance of the N-aquifer and the sacred springs it feeds. As the tribes make improvements to infrastructure in the coming decades, efforts should be made to incorporate acceptable usage levels into their water systems.

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# **Technical Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-aquifer, Black Mesa, Arizona**

This report has been prepared by LFR Levine•Fricke (LFR) at the request of the Natural Resources Defense Council (NRDC) for the purpose of updating our review of potential hydrologic impacts to the N-aquifer caused by groundwater withdrawals associated with Peabody Western Coal Company (PWCC) mining operations in the Black Mesa area of Northeastern, Arizona. In September 2000, LFR provided an assessment of potential impacts to the N-aquifer based on criteria established by the U.S. Department of the Interior Office of Surface Mining Reclamation and Enforcement (OSMRE), (LFR 2000). This report is intended to update LFR's findings based on more recently obtained monitoring data, including, but not limited to, the United States Geologic Survey (USGS) annual reports on Groundwater, Surface Water and Water Chemistry for the Black Mesa Area, Northeastern Arizona (Truini and Thomas, 2004; Truini and Porter 2005), and the USGS report on the Hydrogeology of the D-aquifer and Movement and Ages of Groundwater Determined from Geochemical and Isotopic Analysis, Black Mesa Area, Northeastern Arizona (Truini and Longworth 2003).

## **Executive Summary**

The objectives of this report are to determine whether material damage can be identified, based upon CHIA criteria established by OSMRE. To accomplish the objectives, LFR compared monitoring data contained in the annual USGS monitoring reports and other pertinent documents with the criteria as explained in the CHIA. Additional resource material was also reviewed to establish historic conditions and evaluate current trends.

To evaluate the impact of groundwater withdrawals on the N-aquifer, CHIA criteria were established to allow for comparison of future groundwater levels and surface water flows to baseline water levels and flows established in the CHIA. The hydrologic concerns addressed in the CHIA are primarily related to the diminution of the N-aquifer water resource related to potential adverse impacts on water quantity and quality.

The requirement of the first CHIA criterion is to maintain a potentiometric head 100 feet above the top of the N-aquifer at any point to preserve the confined state of the aquifer. Since the September 2000 report, water level declines have continued to be observed in most N-aquifer monitor wells. With respect to both the Kayenta West and BM3 wells, monitoring data show that the water levels in those wells have periodically dropped below not only the CHIA criteria level established to protect the aquifer, but the elevation of the top of the N-aquifer itself. This adds additional concerns regarding potential material damage to the N-aquifer. The failure of these wells to meet the criterion is dismissed by OSMRE as being the result of municipal pumping in the Kayenta community, even though the total municipal pumping at Kayenta represents less than 12 percent of the industrial pumping by PWCC a short distance south of Kayenta. Notwithstanding

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OSMRE's exception for the BM3 well, it appears that material damage to the hydrologic balance of the N-aquifer has occurred based upon CHIA Criterion 1.

The second CHIA criterion was established to prevent degradation of N-aquifer water quality due to induced leakage of poor quality groundwater from the overlying D-aquifer. To date, the CHIA criteria evaluation has relied on trends in inorganic water quality to assess whether material damage is occurring; however, such an analysis cannot provide a quantitative result to demonstrate that induced leakage from PWCC pumping is less than 10 percent of pre-stress leakage levels as required by the CHIA.

Documentation for a new groundwater model prepared on behalf of PWCC (GeoTrans 1999) included a water balance for each model layer under steady state conditions. For the steady state simulation, approximately 4,100 acre-feet per year of recharge to the upper N-aquifer layer is derived from vertical leakage from the overlying layer (Carmel Formation); however, no discussion was provided regarding the areal distribution of observed leakage or whether changes in vertical leakage are observed between pre-stress and post-stress model simulations. Recent model simulations for various future pumping scenarios indicate that the N-Aquifer southeast of Pinon represents a source of recharge (or storage) for pumping stresses to the north. This is the same area where vertical leakage has been documented by changes in inorganic water quality. While the CHIA criterion can not be quantitatively evaluated based on available data, indirect evidence of material damage associated with induced leakage exists.

The remaining two CHIA criteria were established to assess whether PWCC withdrawals would result in N-aquifer discharge reductions of 10 percent or more to springs or base flow in washes. OSMRE relies on groundwater modeling rather than physical monitoring to assess whether material damage is occurring, and has determined that material damage has not occurred. It remains unclear how a conclusion can be made that no material damage is evident based on simulated modeling results while physical monitoring data suggests otherwise. Both the USGS and PWCC groundwater models used to make that judgment are admittedly incapable of resolving significant changes in spring discharges at the level required by the CHIA criteria. The physical monitoring data suggests that base flow in many of the monitored springs and washes have decreased by more than 10 percent since monitoring began. If the model were updated and forced to calibrate to the physical data that has been collected, the conclusion that no material damage has occurred would not be supported. As such, in accordance with the CHIA criteria, material damage to the N-aquifer is evident; however, simulated modeling results do not calibrate with the physical monitoring data.

## Introduction

The Cumulative Hydrologic Impact Assessment (CHIA) criteria used were established by OSMRE in April 1989 to determine whether mine-related groundwater withdrawals resulted in material damage to the N-aquifer. On March 8, 1991, as part of a legal settlement, OSMRE agreed to review Black Mesa N-aquifer monitoring data against the CHIA criteria and thereafter report their findings to the Navajo Nation, Hopi Tribe, and PWCC in annual reports.

For the September 2000 report, LFR compared Black Mesa area monitoring data against the material damage criteria established in the 1989 CHIA. Based on our evaluation, LFR reported these findings:

- Based upon groundwater modeling performed for the CHIA, OSMRE concluded that none of the projected impacts associated with proposed mine operations exceeded the material damage criteria; therefore, OSMRE anticipated no material damage to the hydrologic balance within the study area.
- Flaws in the CHIA criteria and dependence of the criteria on an underlying groundwater flow model hindered evaluation. These flaws raise questions regarding OSMRE's conclusions.
- Three of the four material damage criteria may not necessarily be protective of N-aquifer water resources because they are either directly or indirectly dependent upon modeling results from a model not specifically designed to evaluate those criteria. OSMRE bases its analysis of CHIA Criteria 3 and 4 on the latest USGS N-Aquifer model or makes no evaluative attempt. Since the final CHIA was released in 1989, USGS has performed modeling simulations twice. The most recent modeling

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results are contained in the 1992-1993 USGS progress report released in 1995. Therefore, all OSMRE material damage analyses are based upon pre-1995 modeling results. Analysis of N-aquifer criteria as proposed in the 1990 CHIA has not occurred since 1994 data was evaluated.

- Modelers concede that the underlying model was not designed to evaluate impacts at individual springs or wells. As such, the model can not adequately simulate spring discharge with the level of precision necessary to evaluate CHIA criteria.
- Issues with the CHIA evaluation methods aside, groundwater elevation monitoring data show that material damage can be concluded based upon CHIA Criterion 1.
- If actual monitoring data were given precedence over predictions based on model output, a review of other CHIA criteria would likely support the conclusion that material damage has occurred. The Black Mesa monitoring data indicate that excessive pumping of the N aquifer has caused groundwater level declines and spring discharge reductions exceeding guidelines established in the CHIA. Data trends further indicate that additional material damage is imminent.

## **Objective**

The objectives of this report are to determine whether material damage can be identified, based upon Black Mesa CHIA criteria. To accomplish the objectives, LFR compared monitoring data contained in the annual USGS monitoring reports and other pertinent documents with the criteria as explained in the CHIA. Additional resource material was also reviewed to establish historic conditions and evaluate current trends. The scope of this evaluation is limited to impacts of pumping on the N-aquifer groundwater resource and does not address other pertinent criteria such as surface water quality.

## **Hydrogeology of the Black Mesa Area**

The Black Mesa region of northeastern Arizona is located in the Plateau Uplands Hydrogeologic Province and is characterized by high, isolated mesas and steep-walled canyons. The Black Mesa, with an area of approximately 5,400 square miles, is underlain by thick sequences of relatively flat-lying, well-lithified sedimentary rocks. The mesa land surface rises steeply on the East Side to more than 3,000 feet above the surrounding lowland, while it slopes gradually toward the lowland to the west.

A thin veneer of recent unconsolidated sediments covers the surface of the mesa with floodplain alluvial deposits generally occurring in narrow bands along major drainage channels. The underlying sedimentary rock sequence, Permian to Late Tertiary in age, is highly variable and consists of up to 10,000 feet of interbedded sandstone, mudstone, siltstone, limestone, coal, and gypsum deposits (Lopes and Hoffman 1996).

Several water-bearing zones (aquifers) underlie the Black Mesa area. The primary aquifer in the Black Mesa area is the Jurassic-age N-Aquifer, which includes the highly productive Navajo Sandstone and the underlying Wingate Sandstone (Cooley et al. 1969). The N-aquifer is more than 1,200 feet thick in the northwestern portion of the mesa and thins toward the southeast corner of the mesa. The N-aquifer is unconfined around the margins of the mesa where it is exposed and overlying sediments have been removed by erosion. Beneath approximately 3,500 square miles of Black Mesa, however, the N-aquifer is fully saturated and confined by sediments of the overlying D-aquifer and Carmel Formation (Lopes and Hoffman 1996). Recharge to the N aquifer occurs primarily in the area near Shonto, north and northwest of the mesa, where the N-aquifer is exposed at the surface (Lopes and Hoffman 1996).

The D-aquifer generally consists of isolated thin sandstone layers of the Morrison Formation and the Cow Springs Member of the Entrada Sandstone, separated by thick sequences of lower permeability mudstone and siltstone (Cooley et al. 1969). The thickness of the D-aquifer varies from less than 100 feet in the area northwest of the mesa to 1,300 feet in the central portions of the mesa (Lopes and Hoffman 1996). Groundwater occurs under both unconfined and confined conditions within the D-aquifer. Hydraulic heads in the D-aquifer are as much as 600 feet higher than those of the underlying N-aquifer, resulting in a significant potential downward gradient toward the N-aquifer. Recharge to the D-aquifer primarily occurs along the eastern slope of the mesa where the unit is exposed at higher elevations (Lopes and Hoffman 1996).



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The D- and N-aquifers are separated by a lower-permeability confining unit, or aquitard, consisting of the lower Entrada Sandstone and the Carmel Formation. This confining unit consists of generally less than 300 feet of mudstone and silty sandstone, which restricts the downward flow of poor quality water from the overlying D-aquifer into the underlying N-aquifer; however, recent studies have shown that leakage of poor quality water from the D-aquifer to the underlying N-aquifer is evident and has occurred in the southeast portion of the mesa (Truini and Longworth 2003).

Groundwater flow in the N-aquifer is generally from the recharge area north of the mesa, from surface elevations greater than 6,300 feet above sea level, toward the south-southeast beneath Black Mesa (Lopes and Hoffman 1996). Because the thickness of the N-aquifer decreases significantly in the southern portion of the mesa, the direction of regional groundwater flow beneath the central portion of the mesa generally diverges toward the northeast and southwest (Lopes and Hoffman 1996). Groundwater from the N-aquifer discharges to Laguna Creek and Moenkopi Wash, as well as to springs along the margins of the mesa where the N-aquifer outcrops. Water withdrawn from the N aquifer takes many years to be replenished through the recharge area; therefore, long-term impacts on springs may result from groundwater pumping.

Precipitation in the Black Mesa area ranges from 7 inches per year to 18 inches per year near Shonto and in the higher elevations of the mesa (Lopes and Hoffman 1996). Precipitation recharging the shallow unconsolidated sediments and the upper D-aquifer results in shallow flow outward toward the margins of the mesa and the occurrence of springs along surface drainage-ways.

## **Basis of Evaluation**

Pursuant to the Surface Mining Control and Reclamation Act of 1977, OSMRE performed a CHIA of PWCC's Black Mesa/Kayenta Mine in the Black Mesa Area of Northeastern Arizona. In January 1988, OSMRE issued a copy of their CHIA for the Black Mesa area. In April 1989, a revised CHIA for the Black Mesa was issued. Differences between the Draft and Final CHIA were discussed in Section 5.2 of LFR's September, 2000 report evaluating cumulative hydrologic impacts on the N Aquifer (LFR, 2000). The purpose of the Black Mesa CHIA was to determine whether Peabody's proposed extraction of approximately 4,000 acre-feet of water per year from the N-aquifer would cause material damage to the aquifer.

To evaluate the impact of groundwater withdrawals on the N-aquifer, CHIA criteria were established to allow for comparison of future groundwater levels and surface water flows to baseline water levels and flows established in the CHIA. Within the CHIA, pertinent baseline years are listed as January 1, 1980 through December 31, 1984 for surface water quantity evaluations, and 1985 for groundwater level evaluations. The hydrologic concerns addressed in the CHIA are primarily related to the diminution of the N-aquifer water resource related to potential adverse impacts on water quantity and quality.

## **Discussion**

Table 1 lists the Black Mesa CHIA criteria standards that are specifically pertinent to N-aquifer groundwater resources. The status of each of those criteria as reported in LFR's September 2000 report and this report are included for reference. Below is a summary of Black Mesa CHIA criteria along with associated observations from our evaluation.

### **Criterion 1: Maintain potentiometric head 100 feet above top of N-aquifer at any point to preserve confined state of aquifer.**

This criterion was established to protect the structural stability of the N-aquifer due to a reduction of potentiometric head and water stored within the aquifer. Confined aquifers are typically dependent upon water pressure contained within the matrix pore space to retain structural integrity; without the additional support of pore space water pressure some aquifers can compact, causing a permanent loss of storage capacity and, in some cases, surface land subsidence. Because the N-aquifer in the Black Mesa Area is comprised primarily of cemented sandstone, the likelihood of aquifer compaction occurring is lessened. This likelihood of N-aquifer compaction is recognized on pages 5 6 of the CHIA; however, "as an added insurance" the criterion is retained.



**Appendix Table 1: The CHIA criteria<sup>1</sup>**

	<b>Standard</b>	<b>Status in 2000</b>	<b>Status in 2006</b>
<i>Criterion 1:</i> Structural stability	“Maintain potentiometric head of 100 feet above top of N-aquifer at any point to preserve confined state of aquifer.”	Groundwater level is within 100 feet of top of N-aquifer in two monitored wells.	Groundwater level is within 100 feet of the top of N-aquifer in two monitored wells and has periodically dropped below the top elevation of the N-aquifer itself.
<i>Criterion 2:</i> Water quality	“A value of leakage from the D-aquifer not to exceed 10 percent from mine-related withdrawals.”	Leakage is not directly measured; analysis of related data suggests that water quality is threatened in some areas.	Leakage is not adequately assessed; analysis of related data reveals increasing trends in inorganic constituents in the N-aquifer in some areas.
<i>Criterion 3:</i> Discharge to springs	“A discharge reduction of 10 percent or more caused by mine-related withdrawals based on results of N-aquifer simulation.”	Seven of nine monitored springs show a decline in excess of 10 percent, according to available field data.	Three of four monitored springs continue to show a decline in excess of 10 percent; if the model were updated and forced to calibrate, the conclusion that no material damage has occurred would not be supported.
<i>Criterion 4:</i> Discharge to washes	“A discharge reduction of 10 percent or more caused by mining.”	Moenkopi Wash shows a decline of approximately 25 percent; status of other washes is difficult to ascertain.	Three of four continuously monitored wash gauging stations show decline of at least 50%; material damage is evident however simulated modeling results do not calibrate with monitoring data.
<small><sup>1</sup>The criteria listed here were established by OSMRE in its Cumulative Hydrologic Impact Assessment of the Peabody Coal Company Black Mesa/ Kayenta Mine (1989), pp. 6-20 to 6-45 and 7-3 to 7-5. Assessments made in the column marked “status” are based on the analysis presented below.</small>			

### Results of the September 2000 Assessment

In the September 2000 report, LFR located measuring point elevations for the N-aquifer wells listed in the USGS progress reports and evaluated measured water levels based upon this criterion. Of the 15 wells listed as existing within the confined portion of the N-aquifer in the USGS progress reports, six had a potentiometric head within 100 feet of the top of the N-aquifer. Three of those six wells (10T-258, 10R-111, and Sweetwater Mesa) are located near the aquifer boundary between confined and unconfined portions of the N-aquifer and behave more like wells existing in the unconfined portion of the aquifer. A fourth well, the Rough Rock well, is located in the unconfined portion of the N-aquifer.

Of the 11 wells monitored that were known to be installed in the confined portion of the aquifer, two (Kayenta West and BM3) were found to have a potentiometric head less than 100 feet above the top of the N-aquifer. The groundwater elevation in the Kayenta West well was reported in 1996 to be more than 11 feet below the approximated top of the N-aquifer and in 1998 to be approximately 0.2 feet above the top of the N-aquifer. The groundwater elevation at BM3 was reported in 1996 to be within approximately 1 foot of the top of the N-aquifer and in 1998 to be approximately 1.6 feet above the top of the N-aquifer.

OSMRE acknowledged this criterion failure at BM3 in their material damage reviews. However, since the static water level in this well was 99 feet above the top of the N aquifer when it was first installed (1959) OSMRE concludes that “material damage to the hydrologic balance of the N-aquifer, caused by mining, with respect to maintaining the potentiometric head above the top of the N-aquifer, has not occurred.” Monitoring data indicate a water level decline in the BM3 well more than 93 feet since the pre-stress (or pre-mining) period.

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OSMRE did not include a discussion of the Kayenta West well in its material damage reviews nor do they include any explanation for the exclusion of Kayenta West data from their reviews. Monitoring data collected from the Kayenta West well were included in the USGS progress reports; however, these data were omitted from the OSMRE reviews. The USGS monitoring data indicated a water level decline in the Kayenta West well of more than 69 feet since the pre-stress period.

### **CHIA Criterion 1 Update**

Since the September 2000 report, water level declines have continued to be observed in most N-aquifer monitor wells. Still, only monitor well BM3 is identified by OSMRE as not meeting the CHIA Criterion 1 objective of having a groundwater elevation of at least 100 feet above the top of the N-aquifer in the confined portion of the aquifer. The failure of this well to meet the criterion is dismissed by OSMRE as being the result of municipal pumping in the Kayenta community. OSMRE states in their 2004 Annual Hydrologic Data Report that 516 acre-feet were withdrawn from the N-aquifer at Kayenta, accounting for 38% of all non-industrial pumping from the confined portion of the aquifer. They don't mention that the total municipal pumping at Kayenta represents less than 12% of the industrial pumping by PWCC a short distance south of Kayenta. Furthermore, OSMRE does not include a discussion of the Kayenta West well in its material damage reviews because the USGS reported that the well had recently been pumped and water level measurements were not considered representative. Nevertheless, historical monitoring data collected from the Kayenta West well show that this well would not meet the CHIA Criterion 1 objective, and it appears that material damage to the hydrologic balance of the N-aquifer has occurred based upon CHIA Criterion 1.

For the BM3 well, water levels have fluctuated (both up and down) by approximately 10 feet from the levels reported in the September 2000 report. The most recent monitoring data indicate that for the year 2004, groundwater elevations are approximately 2.3 feet above the top of the N-aquifer. As such, this monitor well continues to fail CHIA Criterion 1. Notwithstanding OSMRE's exception for the BM3 well, it appears that material damage to the hydrologic balance of the N-aquifer has occurred based upon CHIA Criterion 1.

With respect to both the Kayenta West and BM3 wells, monitoring data show that the water levels in those wells have periodically dropped below not only the CHIA criteria level established to protect the aquifer, but the elevation of the top of the N-aquifer itself. This adds additional concerns regarding potential material damage to the N-aquifer. The 100 foot threshold for CHIA Criterion 1 was intended as a buffer to protect the confined state of the aquifer. As the water levels drop below the confining layer, the aquifer begins to dewater and air enters the previously saturated pore spaces. Even if water levels rebound, air can become entrained in the pore spaces and can reduce the permeability and storage capacity of the aquifer in the area where the overdraft occurred. In addition, the introduction of air can alter aquifer chemistry and result in damaging reactions such as the formation of iron and manganese oxide precipitates. Such impacts may be irreparable.

### **Criterion 2: A value of leakage from the D-aquifer not to exceed 10 percent from mine-related withdrawals.**

Continued stresses on the N-aquifer and associated water level declines, as observed, will increase vertical gradients and potentially induce vertical leakage of poor quality water from the overlying D-aquifer. This criterion was established to prevent degradation of N-aquifer water quality due to induced leakage of poor quality groundwater from the overlying D-aquifer.

In order to quantify leakage from the D-aquifer to the N-aquifer, water level elevations for both aquifers and the vertical hydraulic conductivity of the confining unit separating the aquifers are needed. However, since D-aquifer water level data is not regularly monitored, other approaches must be used. Other methods of evaluating D-aquifer leakage to the N-aquifer include inorganic water quality monitoring from the D- and N-aquifers and groundwater flow and transport modeling.

To establish and evaluate this criterion for the CHIA, OSMRE used the USGS N-aquifer model. Specifically, the CHIA evaluated the model's simulation of predicted changes in the annual volume of leakage from the D-aquifer to the N-aquifer attributable to mine-related withdrawals. The CHIA predicted no significant change in volume of D-aquifer leakage to the N-aquifer for the simulated period.

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## Results of the September 2000 Assessment

In its annual material damage reviews, OSMRE used inorganic water quality monitoring to analyze for induced leakage. This approach was dependent upon historical inorganic water quality data for the area of study. In the Black Mesa area, the N aquifer generally has lower inorganic constituent content, including major ions and cations such as chloride and sulfate, than the D-aquifer. One measure of the presence of inorganic constituents is the amount of Total Dissolved Solids (TDS) expressed in milligrams per liter. In OSMRE's analysis, where induced leakage from the D-aquifer is occurring, an increase in TDS would be anticipated in the N-aquifer. Yet, where increases in TDS have been observed for N-aquifer wells, some justification was made to minimize the increasing values. While increasing TDS trends were observed for multiple monitoring locations, the trends were noted to be "small" or "statistically insignificant." OSMRE concluded that "material damage to the hydrologic balance of the N-aquifer, caused by mining, with respect to leakage from the D-aquifer to the N-aquifer, has not occurred." OSMRE based its conclusion upon inorganic water quality analysis only; other methods of analysis were not attempted. No attempt was made to correlate the trends of increasing TDS with the material damage criterion.

If leakage to the N-aquifer were estimated as proposed in the draft CHIA by evaluating the magnitude of N-aquifer water level declines and associated changes in the vertical gradient between the D-aquifer and the N-aquifer, a conclusion of material damage to the N-aquifer water quality would be more likely. The N-aquifer potentiometric head was more than 100 feet below the baseline altitude in at least two of the monitored wells (Pinon and Keams Canyon). Additionally, data trends for at least four additional wells (BM2, BM3, BM5, and BM6) indicate that groundwater levels would soon be more than 100 feet lower than the baseline altitude in those wells. Ultimately, six or more of the eleven monitored wells would likely exhibit groundwater level declines more than 100 feet before mining operations cease.

## CHIA Criterion 2 Update

The CHIA criteria set a 10 percent increase in induced leakage attributed to mine-related withdrawals as the basis for determining material damage to the N-aquifer. While physically quantifying the amount of induced leakage associated with mine-related withdrawals may not be possible, estimates could be based on the fact that the amount of leakage induced by groundwater withdrawals would increase proportionally to the increased vertical gradient resulting from those withdrawals [i.e., from Darcy's Law:  $Q$  (flux) =  $K$  (hydraulic conductivity)  $\times$   $I$  (gradient)  $\times$   $A$  (area)]. In other words, everything else being equal, an increase in the vertical gradient by 10 percent would increase the vertical flux of leakage by 10 percent. However, rather than attempting to estimate induced leakage through water-level monitoring and changes in vertical gradients or using water balance results from groundwater modeling, OSMRE looks at inorganic water quality as an indirect indicator of induced leakage to make the conclusion that material damage has not occurred.

Recent monitoring data provide evidence of increasing trends in inorganic constituents in the N-aquifer, including chloride and total dissolved solids, particularly in the southeast portion of Black Mesa near Rough Rock, Pinon, and Keams Canyon. Induced leakage resulting from groundwater withdrawals does not necessarily occur in the immediate vicinity of the pumping stresses, rather it can occur at some distance away where resistance to vertical flow is reduced and leakage can provide a source of recharge to offset those pumping stresses. As such, evidence of induced leakage from the D-aquifer to the N-aquifer in the southern portion of Black Mesa may potentially be related to groundwater withdrawals by PWCC further to the north.

In 2003, the USGS issued a report on the Hydrogeology of the D-aquifer and Movement and Ages of Groundwater Determined from Geochemical and Isotopic Analysis, Black Mesa Area, Northeastern Arizona (Truini and Longworth 2003). That report included a discussion on groundwater leakage from the D-aquifer to the N-aquifer based on geochemical and isotopic data analysis and concluded that leakage has occurred from the D-aquifer to the N-aquifer for thousands of years, and most likely occurs in the southern part of Black Mesa. Unfortunately, the report avoids any quantitative discussion of the change in vertical gradients between the D- and N-aquifers from pre-development to post development times. A separate USGS report (Thomas 2002) states that groundwater monitoring of the N-aquifer has shown that vertical drawdowns have increased the differences between the potentiometric surfaces of the D- and N-aquifers by greater than one-

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third in the area of most apparent leakage.

The 2003 USGS report suggests that a more quantitative answer to observed changes will require additional information on the Carmel Formation (the aquitard separating the D-aquifer and the n-Aquifer) and simulation modeling. Historically, the CHIA evaluation relied on the original USGS N-aquifer groundwater model and concluded that no significant change in leakage was evident for the simulation period. Since then, PWCC has developed a new model that incorporates both the D-aquifer and the N-aquifer. Documentation for the new model included a water balance for each model layer under steady state conditions. For the steady state simulation, approximately 4,100 acre-feet per year of recharge to the upper N-aquifer layer is derived from vertical leakage from the overlying layer (Carmel Formation); however, no discussion was provided regarding the areal distribution of observed leakage or whether changes in vertical leakage is observed between pre-stress and post-stress model simulations. This would seem like a logical and necessary evaluation to include considering the specific requirements of the CHIA criteria.

Regardless of the modeling and water-quality monitoring efforts that have been done to date, there have been no attempts to provide quantitative estimates of either horizontal flux or vertical induced leakage based on observed changes in the horizontal gradient in the N-aquifer or the vertical gradient between the D-aquifer and the N-aquifer from pre-stress to post-stress periods. Horizontal groundwater gradients in the N-aquifer have changed significantly in the southern portion of Black Mesa since the introduction of PWCC withdrawals. The most recent model simulations indicate that groundwater flow in the N-aquifer southeast of Pinon is to the north and represents a source of storage (or recharge) for pumping stresses to the north. This area is also where vertical leakage has been documented by changes in inorganic water quality. While the CHIA criteria cannot be quantitatively evaluated based on available data, indirect evidence of material damage associated with induced leakage exists. In short, based upon the information provided, the impact of increased vertical gradients on the potential for increased induced leakage from the D-aquifer as a result of PWCC withdrawals from the N-aquifer has not been adequately assessed.

In addition to concerns about induced leakage, available reports do not address the potential for man-made conduits that locally may impact water quality in the N-aquifer. In particular, wells in the PWCC well field are screened across multiple aquifers and, as such, when the wells are not pumping a direct vertical conduit exists between the units. If the wells are not pumped for a significant period of time, water that is “injected” into the N-aquifer from overlying aquifers under non-pumping conditions could significantly impact water quality in the N-aquifer.

### **Criterion 3: A discharge (from N-aquifer springs) reduction of 10 percent or more, caused by mine-related withdrawals based on results of N-aquifer simulation.**

This criterion was established to protect the natural springs in the Black Mesa area. Well capture generally results in reduced discharge from the aquifer, induced leakage to the aquifer, or some combination of those two.

OSMRE used the N-aquifer groundwater model to establish and evaluate this criterion for the CHIA. They base the criterion on present and future N-aquifer simulations. Apparently, when model updates are unavailable this criterion is based upon the most recent model results or no material damage evaluation is attempted. Within the CHIA, only one spring area (Pasture Canyon) appears to have been evaluated. The CHIA predicted “outflow to the springs in Pasture Canyon would not be affected by the duration of pumping at the mine.” However, later in the same paragraph (page 6-39) OSMRE states that the simulated outflow numbers for Pasture Canyon “should be used with caution because the model does not adequately represent important details of the local geology in this area.” They also state “reliable estimation of changes in flow of the Pasture Canyon springs would require detailed study and modeling of that local area.”

### **Results of the September 2000 Assessment**

In its annual material damage reviews, OSMRE based its analysis of this criterion on the latest USGS N-aquifer model or made no evaluative attempt. Since the final CHIA was released in 1989, the USGS had performed modeling simulations twice. The most recent modeling results were presented in the 1992-1993 USGS progress report released in 1995. Therefore, all OSMRE material damage analyses were based upon

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pre-1995 modeling results. OSMRE concluded either that based upon “the most recent N aquifer computer model simulation, material damage to the hydrologic balance of the N-aquifer, caused by mining, with respect to N-aquifer discharge has not occurred” or that it “could not determine whether or not material damage to the hydrologic balance of the N-aquifer has occurred” due to a lack of modeling results. Either way, analysis of this criterion as proposed in the 1990 CHIA had not occurred since 1994 data was evaluated.

Discharges for multiple springs located in the Black Mesa area have been monitored and the USGS progress reports contain some of this data. LFR searched the progress reports and other USGS water use reports to obtain spring discharge data for analysis. Of the nine springs for which discharge data were available, seven showed a decline of 30 percent or more. Flows had apparently increased in two springs (Dennehotso, Hard Rocks); however, original flows at Hard Rocks were only estimated, and the magnitude of change in flow from the spring near Dennehotso tended to imply that some unknown change(s) may have occurred (e.g., new monitoring location, nearby construction). Some of the monitoring data were questionable due to variable monitoring locations and the lack of any attempt by the USGS to correlate them. Not only had most springs experienced a discharge reduction in excess of 30 percent, but the majority of those appeared to have decreased by more than 50 percent (Rock Ledge, Moenkopi School, Many Farms, Whiskey, and Pasture Canyon). Hence, regardless of the monitoring data deficiencies, material damage appeared obvious based upon actual conditions. It was unclear why the modeling simulations had not been adjusted (calibrated) to better represent observed decreases in spring discharges.

### **CHIA Criterion 3 Update**

The USGS report “Ground-Water, Surface-Water, and Water Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-2004” (Truini and Porter 2005) contains recent data for four springs that discharge from the N-aquifer. Of the four springs, three are located on the southwestern side of Black Mesa (Pasture Canyon, Moenkopi School, and Burro) and the other is on the northeastern side of Black Mesa (unnamed spring near Dennehotso). Annual discharge data dating back to at least the early 1990s are provided. Some historic discharge data (pre-development) are also provided. A graph showing trends in discharge for all four springs is presented, although the data is plotted on a logarithmic scale making interpretation difficult. A closer look at the data clearly shows an overall reduction in spring discharge for the three springs on the southwest side of the mesa. Discharge from the unnamed spring near Dennehotso has fluctuated over time making a definitive analysis of the overall trend more difficult; however, the two lowest measured discharges observed since annual measurements commenced in 1992 occurred within the last three years. Using only the annual data collected at the same location for each spring, estimates of discharge reduction since monitoring began are 24 percent at Moenkopi, 19 percent at Pasture Canyon, and 50 percent at Burro. Considering that industrial pumping at PWCC represents the single largest stress on the N-aquifer (roughly 75 percent of withdrawals from the confined portion of the N-aquifer in 2003), monitoring data shows that material damage has occurred based on the CHIA criteria (a reduction of discharge of 10 percent or more). If other historic spring discharge data were considered, observed discharge reductions would be much greater (70 percent at Moenkopi and 85 percent at Pasture Canyon).

It remains unclear how a conclusion can be made that no material damage is evident based on simulated modeling results under both the USGS model and PWCC model while physical monitoring data suggests otherwise. The groundwater model used to make that judgment is admittedly incapable of resolving significant changes in spring discharges at the level required by the CHIA criteria. Physical monitoring data continue to show that material damage, as defined by the CHIA criteria, is occurring. If the model were updated and forced to calibrate to the physical data that has been collected, the conclusion that no material damage has occurred would not be supported.

### **Criterion 4: A discharge (from N-aquifer to washes) reduction of 10 percent or more, caused by mining.**

This criterion was established to prevent excessive reduction of flow in the Black Mesa area washes due to reduction of N-aquifer discharge to the washes. When a stream is in communication with an aquifer and the



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hydraulic head of the aquifer is greater than the relative elevation of the stream, water will discharge from the aquifer into the stream (gaining stream). As head potentials within the aquifer decrease, the discharge to the gaining stream will diminish. If the head potential within the aquifer decreases below the relative elevation of the stream channel, the stream will begin to lose water to the aquifer (losing stream).

Within the CHIA, the N-aquifer model was again used to evaluate the potential for material damage due to reduced baseflow discharge from the N-aquifer to area washes. Predicted baseflow discharges along Moenkopi wash and Laguna Creek are discussed. By using various pumping scenarios in multiple model simulations, the USGS was able to attribute approximate baseflow discharge reductions to industrial and/or municipal withdrawals. The CHIA concluded that mine-related withdrawals would have a minor impact on baseflow discharges in some instances based upon model results, but never to exceed the material damage criterion.

### **Results of the September 2000 Assessment**

As with Criterion 3, OSMRE based their analysis of this criterion on the latest USGS N aquifer model, which had last been updated in 1994. OSMRE again concluded that based upon “the most recent N-aquifer computer model simulation, material damage to the hydrologic balance of the N-aquifer, caused by mining, with respect to N-aquifer discharge has not occurred” or that it “could not determine whether or not material damage to the hydrologic balance of the N-Aquifer has occurred” due to a lack of modeling results.

Historical data do exist for flow in some area washes; however, the data are limited. For the baseline years (1980-1984), data were only collected for the Moenkopi and Laguna Creek washes. The Dinnebito wash had a monitoring station established in June 1993. Prior to establishing the 10 percent reduction criteria, the CHIA noted that the Moenkopi gauge had been rated as having poor accuracy. As such, the margin of error in measurement of more than 15 percent exceeds the criterion range of 10 percent.

The USGS monitoring reports use low-flow data for comparing wash flows. Low-flow data are based upon daily stream discharges for the months of November through February of a water year. Discharge data collected during these months are considered representative of low flow because the effect of stream loss due to evapotranspiration (losses due to evaporation and transpiration, or the transfer of water to the atmosphere by vegetation) and gain from snowmelt and rainfall (which generally occurs during temperate months) is minimized.

The Dinnebito wash had a mean daily discharge (as low-flow) of approximately 0.50 cubic feet per second (ft<sup>3</sup>/s), based upon 1994-1997 continuous-record data. The Dinnebito wash gauging station became operational in June 1993. In 1998, the low-flow discharge measurements for the Dinnebito wash ranged from 0.32 ft<sup>3</sup>/s to 0.44 ft<sup>3</sup>/s, a reduction of at least 12 percent. The average mean daily discharge (as low-flow) for the baseline years on Moenkopi wash was reported to be about 3.2 ft<sup>3</sup>/s. From 1992 through 1998, the average mean daily discharge (as low-flow) on Moenkopi wash was reported to be about 2.4 ft<sup>3</sup>/s. Therefore, there had been a discharge reduction of approximately 25 percent in the Moenkopi wash according to the USGS progress reports. The Laguna Creek monitoring station had been moved to a new location since readings were taken for the baseline years making evaluation of that data difficult.

### **CHIA Criterion 4 Update**

According to the USGS report “Ground-Water, Surface-Water, and Water Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-2004” (Truini and Porter 2005), continuous discharge data have been collected at four streamflow gauging stations since the mid-1970s. The average annual discharge at the four gauging stations vary considerably during the period of record and no long-term trends are apparent. Groundwater discharge to the washes is assumed to be constant throughout the year, and the median winter flow is assumed to represent the constant annual groundwater discharge. According to the report, since 1995 the median winter flows for Moenkopi Wash, Dinnebito Wash, and Polacca Wash have generally decreased and there is no consistent trend in flows for Laguna Creek.

For the four continuously monitored washes, the median winter flows in 2003 were 3.45ft<sup>3</sup>/s for Moenkopi Wash, 0.75ft<sup>3</sup>/s for Laguna Creek, 0.25 ft<sup>3</sup>/s for Dinnebito Wash, and 0.10 ft<sup>3</sup>/s for Polacca Wash. By comparison, the earliest measured median winter flows for Laguna Creek (1997), Dinnebito Wash (1994),

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and Polacca Wash (1995) were 1.8 ft<sup>3</sup>/s, 0.5 ft<sup>3</sup>/s, and 0.35 ft<sup>3</sup>/s, respectively. As such, flow reductions of 50 percent or more are evident since monitoring began in those three washes: 58 percent reduction at Laguna Creek; 50 percent reduction at Dinnebito Wash; and 71 percent reduction at Polacca Wash. For Moenkopi Wash, the period of record is much longer and shows a general decline since the highest measured value in 1988, except during the last two years where flow has increased.

As with spring discharge, the CHIA criteria depends on simulated groundwater modeling results rather than physical monitoring data to assess impacts of changes in base flow to washes and creeks. The physical monitoring data suggest that base flow in the monitored washes have decreased by more than 10 percent since monitoring began. As such, in accordance with the CHIA criteria, material damage to the N-aquifer is evident; however, simulated modeling results do not calibrate with the physical monitoring data.

## Summary

Of the four N-aquifer groundwater resource criteria identified in the Black Mesa CHIA, only one (Criterion 1) is written such that material damage can be readily determined through physical monitoring data. The other three criteria are written such that material damage can only be determined if attributed to mine-related groundwater withdrawals through hypothetical modeling efforts. While municipal withdrawals have grown over time, mine-related withdrawals still represent the single largest consumptive use of groundwater at Black Mesa, accounting for about 62 percent of the total groundwater withdrawals and about 77 percent of the groundwater withdrawals from the confined portion of the N-aquifer (Truini and Porter 2005). Compounding the issue, most mine-related withdrawals are used to transport coal as slurry to Nevada. As such, extracted groundwater is exported from the region, precluding any potential for conservation measures that might be employed, such as treatment and re-use, if the water were used locally.

Evaluation of Criterion 3 is based solely on computer groundwater modeling simulations and Criteria 2 and 4 are directly dependent upon the modeling results. Since the modeling simulations are not performed regularly, OSMRE does not annually review the criteria based upon the simulation results, making it impossible for them to ascertain whether material damage has occurred. Concluding material damage is therefore problematic based upon the final CHIA criteria irrespective of data evaluation. However, in light of available monitoring data, it is not possible to support OSMRE's conclusion that material damage has not occurred, made in its annual analyses of Peabody and USGS hydrological data monitoring reports. With respect to physical monitoring data for the N-aquifer, an evaluation of the more recently collected data shows that the concerning trends previously observed and reported by LFR in September 2000 continue to persist. The median average annual decline in groundwater elevations in the confined portion of the N-Aquifer was reported to be approximately 2 feet per year since 1983. The median overall decline in water levels in the confined portion of the aquifer from pre-stress period (1965) to 2004 is 72 feet with a maximum decline of more than 205 feet at one location. Spring monitoring data show reductions in discharge of between 19 percent and 50 percent in three of the four monitored springs since around 1990, and by more than 70 percent if historical (pre-development) data are considered. Similarly, the USGS concluded that median winter flows in washes, used to approximate base flow attributed to groundwater discharge, have been observed to be decreasing in excess of the CHIA criterion threshold for material damage in at least three of four washes that have been monitored since 1995. Since a majority of groundwater withdrawals from the N-aquifer are industrial and associated with the mine (particularly in the confined portion of the aquifer) the observed impacts must be attributed in large part to those mine-related withdrawals and, therefore, physical monitoring data confirms that material damage is still occurring as a result of Peabody withdrawals.

## Technical Review of “A Three-dimensional Flow Model of the D- and N-aquifers” and “A Three-dimensional Flow Model of the D- and N-aquifers Supplement 1”

LFR provided a review of the model developed by PWCC for the combined D-aquifer and N-aquifer and determined that:



- The model, because of its nature, resolution, and data density, is not well suited to the task of assessing potential material damage or other disturbance to the hydrologic balance as it was intended to do.
- A surface boundary condition putting, in effect, an infinite amount of water on top of the aquifer system is inappropriate in an arid to semi-arid climate setting.
- The model includes both the D- and N-aquifers. The CHIA has been developed for the N-aquifer only. By including groundwater storage of the D-aquifer to the model, more than 43 percent of stored water is added to the system. By adding storage to a system where “most of the groundwater pumped is released from storage,” the effects of withdrawals are effectively diluted.

Overall, the new model provided for recharge levels that greatly exceed the latest estimates provided by the USGS. In the PWCC model, approximately 11,000 acre-feet per year of recharge is applied in the unconfined portion of the N-aquifer. In addition, an estimated 5,400 acre-feet per year of recharge is derived from the river recharge boundary condition applied to the upper surface of the model as an initial condition (pre-pumping). The upper boundary condition represents an infinite supply of water, thus aquifer withdrawals will yield additional recharge from the river recharge boundary condition due to increased vertical gradients. It is estimated that more than 15,000 acre-feet per year of recharge could be derived from the theorized river recharge boundary condition if pumping stresses lowered groundwater elevations to the top of the N-aquifer. The impact of the river recharge boundary condition was not assessed in the sensitivity analysis.

The PWCC model did not address the resolution problems that have precluded modeling as an accurate method to assess material damages in the form of reduced discharge from the N-aquifer. The PWCC model is unable to resolve changes in spring discharge from the N-aquifer or reduced flow in washes at the 10 percent level specified by the CHIA criteria. Actual monitoring data regarding spring discharges continue to contradict predictions based on modeling.

In July 2005, Supplement 1 of the Three-Dimensional Flow Model of the D- and N-aquifers was released. The purpose of the supplement was to simulate and evaluate five additional pumping scenarios, provide results of additional sensitivity testing, and evaluate whether the models originally presented in 1999 are able to accurately simulate water level changes from 1997 through 2003 in the Black Mesa monitoring wells. Based on our review of the supplemental report, LFR concludes as follows:

- Previous concerns regarding the model and its ability to resolve specific CHIA criteria requirements remain unresolved.
- Calibration statistics typically provided in model validation reports (e.g., American Society for Testing and Materials [ASTM] guidance for documenting and calibrating groundwater flow model applications) are not made available, but rather qualitative statements are provided. For example, the supplement simply offers us this evaluation: “The four models match the observed water-level changes at the six BM monitoring wells quite well.” The report further states that the model was updated to include additional pumping data and simulated model results were compared to the updated pumping data. The report states, “This evaluation, which is not presented here, indicated that there were only small differences between measured and simulated drawdown for the period 1997 through 2000.” Subjective and unsupported narrative does not constitute technical support for the conclusion reached. It would be more appropriate to provide quantitative analyses of model validation that demonstrate model performance within applicable industry standards.
- For the additional pumping scenarios, the report states that “predicted impact on discharge to streams was almost negligible, and would not be measureable.” The question that more appropriately should be addressed is whether the model would be able to resolve changes in spring discharge at the level necessary to evaluate the CHIA criteria. For example, to assess discharge reductions at Pasture Canyon Spring, a 10 percent reduction in spring discharge (CHIA Criterion 3) would require that the model accurately resolve changes in spring discharge of less than 5 gallons per minute or 8 acre-feet per year at a minimum. Furthermore, if the model were accurately calibrated, it would show a reduction in spring flow of more than 19 percent at Pasture Canyon Spring since 1995 (Truini, Macy, and Porter 2005).

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- It is reported that neither the USGS nor PWCC monitors water levels in the confined portion of the D-aquifer as part of its monitoring effort. D-aquifer water level information would be needed to directly evaluate the change in leakage from the D-aquifer to the N-aquifer under CHIA Criterion 2 (OSM 2005). D-aquifer water level data would also be necessary to calibrate a model that incorporates the D-aquifer and is intended, in part, to quantify leakage from the D-aquifer to the N-aquifer.

## Conclusions

To determine whether Peabody's extraction of more than 4,000 acre-feet of water per year from the N-Aquifer would cause material damage to the aquifer, OSRME prepared a CHIA report dated April 1989 (4,000 acre-feet is typically used for estimation of mine-related groundwater withdrawals). Actual annual withdrawals have ranged from 2,520 acre-feet to 4,740 acre-feet since mine-related withdrawals began in earnest in the early 1970s. The average mine-related withdrawal over that same period has been approximately 3,950 acre-feet. In the CHIA, OSRME established specific criteria used to determine whether material damage would occur. Based upon groundwater modeling performed for the CHIA, OSRME concluded that none of the projected impacts associated with proposed mine operations exceeded the material damage criteria; therefore, it anticipated no material damage to the hydrologic balance within the study area.

In September 2000, LFR evaluated groundwater, surface water, and water quality data from the Black Mesa monitoring program contained in USGS Progress Reports to determine if material damage to the N aquifer could be detected or appeared imminent. Flaws in the CHIA criteria and dependence of some criteria on an underlying model that was not specifically designed to evaluate those criteria made the evaluation difficult. It was determined that while the model may reasonably predict regional N-aquifer groundwater conditions in the Black Mesa vicinity, the model does not adequately represent geologic detail to enable conclusions regarding vertical leakage, spring discharge, and base flow in washes at the scale required by the final CHIA criteria. LFR concluded that, issues with the final CHIA aside, material damage was evident based upon CHIA Criterion 1. Additionally, if monitoring data were given precedence over modeling predictions, it could be determined that excessive pumping of the N aquifer has caused groundwater discharge reductions to springs and washes that exceed the guidelines established in CHIA Criterion 3 and CHIA Criterion 4. The most recent physical monitoring data indicates that the 2000 LFR Report conclusions are still valid.

Since LFR's September 2000 report, physical monitoring data show excessive drawdown in many Black Mesa area groundwater monitoring wells and continued declines in discharge to springs and washes. Based on the latest physical monitoring data, LFR concludes that additional negative impacts resulting in material damage have occurred and further material damage to the N-aquifer is imminent. Material damage is still indicated under CHIA Criterion 1 and, if physical monitoring data is given precedence over hypothetical modeling results, material damage is also clearly indicated for CHIA Criteria 3 and 4. With respect to CHIA Criterion 2, leakage is not adequately assessed but indirect evidence of material damage associated with induced leakage exists. LFR continues to believe that the Black Mesa CHIA criteria are not necessarily protective of the N-aquifer water resources due to their dependence upon simulated computer modeling results and disregard of actual monitoring data. Damage to the hydrologic balance of the N-aquifer may be compounding over time due to the lack of protection provided based upon the CHIA criteria and the disregard of actual monitoring data. Nevertheless, groundwater modeling results, rather than actual monitoring data, remain the primary tool for assessing material damage to the N-aquifer. As such, a detailed and quantitative analysis of model performance, based on standard industry practices for model calibration and documentation, and considering the rigorous requirements of the CHIA criteria, is needed.

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## SELECTED REFERENCES

GeoTrans, Inc. 1999. *A Three-Dimensional Flow Model of the D and N Aquifers*, Black Mesa, Arizona. September.

GeoTrans, Inc. 2005. *A Three-Dimensional Flow Model of the D and N Aquifers, Black Mesa, Arizona, Supplement 1*. July.

LFR Levine•Fricke. 1997. *Evaluation of Impacts of Groundwater Pumping from the N Aquifer, Black Mesa Area, Arizona*. August.

LFR Levine•Fricke. 2000. *Evaluation of Cumulative Hydrologic Impacts on N-Aquifer, Black Mesa, Arizona*. September.

LFR Levine•Fricke, 2002. Technical Review of “A Three-Dimensional Flow Model of the D and N Aquifers” Prepared by HIS Geotrans and Waterstone for the Peabody Western Coal Company, September 1999. April.

The Office of Surface Mining Reclamation and Enforcements. 2004. Report on its Review and Analysis of Peabody Western Coal Company’s 2003 “Annual Hydrological Data Report” and the U.S. Geological Survey’s “Ground-Water, Surface-Water, And Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2002-03.” September.

The Office of Surface Mining Reclamation and Enforcements. 2005. Report on its Review and Analysis of Peabody Western Coal Company’s 2004 “Annual Hydrological Data Report” and the U.S. Geological Survey’s “Ground-Water, Surface-Water, And Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04.” August.

Thomas, B.E. 2002. “Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona-2000-2001, and Performance and Sensitivity of the 1988 USGS Numerical Model of the N Aquifer.” U.S. Geologic Survey Water Resources Investigations Report 02-4211.

Truini, M. and S.A. Longworth. 2003. “Hydrogeology of the D Aquifer and Movement and Ages of Ground Water Determined from Geochemical and Isotopic Analysis, Black Mesa Area, Northeastern Arizona.” Water Resources Investigations Report 03-4189\_Version 1.1.

Truini, M. and T.J. Porter. 2005. “Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona-2003-2004.” U.S. Geologic Survey Open File Report 2005-1080.

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# **Technical Review of “A Three-Dimensional Flow Model of the D and N Aquifers” Prepared by HIS Geotrans and Waterstone, for the Peabody Western Coal Company, September 1999**

April 24, 2002 (LFR 014-10002-00)

## **Introduction**

Three-dimensional flow models of the N Aquifer in the Black Mesa Basin of Arizona have been developed and used to evaluate effects from Peabody Western Coal Company (PWCC), and Navajo Nation and Hopi Tribe community pumping centers on the N Aquifer. Those modeling efforts have been applied to assess potential impacts to the N Aquifer.

The Department of Interior has previously established Cumulative Hydraulic Impact Assessment (CHIA) criteria to assess the presence of material damage to the N Aquifer caused by PWCC pumping. The four main CHIA criteria included:

1. Maintain potentiometric head of 100 feet above the top of N Aquifer at any point to preserve confined state of aquifer.
2. A value of leakage from the D Aquifer not to exceed 10% from mine related withdrawals.
3. A discharge to springs reduction of 10% or more caused by mine-related withdrawals based on results of N Aquifer simulation.
4. A decline in discharge to the N Aquifer washes by 10% or more caused by mining.

Evaluation of the four CHIA criteria relies heavily or almost entirely on model simulation results. In fact, the very terms of some of the criteria directly refer to a modeling analysis. Unfortunately, available models generally lack the necessary resolution and/or were not developed for the specific purpose of evaluating CHIA criteria. Thus there has been a large degree of uncertainty in conclusions derived from model predictions.

In September 1999, PWCC issued a report summarizing the development of a new three-dimensional flow model that simulated aquifer conditions and groundwater flow in both the D and N aquifers. One stated objective of this modeling effort was to help assess probable hydrologic consequences of the life- of-mine mining plan upon the quality and quantity of surface and groundwater for the proposed permit and adjacent areas. More specifically, the model was used to estimate future impacts of PWCC and tribal pumping on the D and N aquifers.

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LFR was asked to provide a technical review of the model and accompanying documentation, and its application to predicting impacts on the D and N aquifers. This review focused on whether the new model improved the ability to assess material damage and other disturbances to the hydrologic balance relative to CHIA criteria and whether it accurately simulated responses to PWCC pumping on such things as groundwater elevations, aquifer discharge, induced leakage, and storage loss in the D and N aquifers.

## **Model Review**

The results of our review of the most recent model developed by PWCC are summarized in the following comments. Major technical issues and other inconsistencies are discussed with reference to the model documentation, where available. Overall, LFR's comments can be condensed into the following three statements:

- i. The model, because of its nature, resolution, and data density, is not well suited to the task of assessing potential material damage or other disturbance to the hydrologic balance as it was intended to do.
- ii. A surface boundary condition putting in effect an infinite amount of water on top of the aquifer system is inappropriate in an arid to semi-arid climate setting.
- iii. The model includes both the D and N aquifers. The CHIA have been developed for the N Aquifer only. By including groundwater storage of the D Aquifer to the model, over 43% of stored water is added to the system. By adding storage to a system where "most of the groundwater pumped is released from storage," the effects of withdrawals are effectively diluted.

## **Major Issues**

### **A. Surface boundary condition**

The model consists of seven layers, the top three representing various members of the D Aquifer. Layer four represents the thin Carmel Aquitard, and layers five through seven represent members of the N Aquifer. Peabody states that water budgets provided in the model documentation are based on the combined inflows and outflows of both the D Aquifer and N Aquifer. In the Black Mesa Area, the Mancos shale and other unconsolidated deposits overlie the D Aquifer. Those units are not explicitly defined in the model because they are thin and usually unsaturated (page 5-1). On page 5-12, it is stated that "Water primarily moves into the Dakota aquifer from leakage of water through the Mancos shale overlying the Dakota sandstone." This leakage is simulated in the model by a river boundary condition which, in effect, places an infinite amount of water on top of the model. A "riverbed" conductance of 0.00026 ft/d and a thickness of 600 feet is used for the Mancos shale, and a "river stage" is assumed to be 100 feet above the top of the Mancos, or 700 ft above the top of the D Aquifer (p. 513). This vertical conductance, albeit small, is theorized to yield a significant amount of inflow when considered over the area of the aquifer system modeled. When combined with data on the aerial extent of the D Aquifer (Surface statistics, Table 4.3-1) and evaporation (section 5.4.2, page 5-16), this simulated "river recharge" yields an estimated 5,400 acre-feet/year or more to the combined aquifer systems, or nearly the equivalent of the documented withdrawals (Peabody mine and Indian Communities are estimated to withdraw 4,000 and 2,800 ac-ft/yr, respectively). Note that this boundary condition influx is an initial (pre-pumping) source of recharge in addition to the precipitation recharge of 11,000 ac-ft/year in the unconfined areas, discussed in the recharge boundary condition, section 4.6.9, and used extensively as a variable in calibration runs (ES-3 and page 4-36).

The river boundary condition on top of the model domain in itself contributes an inflow of equal magnitude as the groundwater withdrawals. With increasing drawdown in the underlying aquifers, the surface boundary condition, as theorized in the model, will yield more water due to increased vertical gradients. As such, the impact of the surface boundary condition is that sufficient water is always available as vertical leakage to the D and N aquifers to offset pumping stresses applied in the simulations. Impacts to spring discharge and baseflow in washes are minimized, the boundary between the confined and unconfined portion of the N-Aquifer is unaffected, and the confined portion of the N-Aquifer remains fully saturated. Yet, the

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modelers conclude that “Because of the limited flow through the Mancos and the further isolation from the N Aquifer provided by the D Aquifer and Carmel Formation, more extensive characterization was not believed to be worthwhile for the objectives of the model. Further, these parameters [river conductance and river stage] were not adjusted during the calibration.”

### **B. Horizontal and vertical resolution**

The horizontal cell dimensions of the finite difference grid range from 500 to 4,200 meters (1,640 to 13,780 feet). This spatial resolution is not adequate to evaluate impacts at individual washes and springs (CHIA 3 and 4). This is because MODFLOW treats streams (a line feature) and wells and springs (point features) as three-dimensional cells or cell blocks. For example, the lateral dimensions of one drain cell at Moenkopi School is 3,000 by 2,100 meters (9,840 by 6,890 feet) while in the actual scenario is a spring area approximately 50 feet wide discharging anywhere between 12 to 40 gpm only. Such discrepancy in representation of a drain feature will effect the calibration that can either be aimed at water levels or discharge, but not both. This is an inherent and well-known problem of MODFLOW and finite different models in general. The alternative would be the use of a finite element model.

In the vertical dimension, the report states that the contact elevations of the seven hydrostratigraphic units (HSUs) is generally accurate within 100 feet in moderately sloping terrains and up to 300 feet in steeper areas (Appendix F, page F-2 and F-6). This too, precludes an accurate representation of springs and intersects of HSUs by streams which are critical to the natural drainage of the aquifer system. These shortcomings related to grid resolution have been recognized by the authors on page 1-5: “The model grid, although optimized to address flow issues [stream discharge, recharge, leakance], was not designed to evaluate impacts at individual springs or wells.” Yet, the impact on springs is acknowledged to be a significant issue of concern, and is exactly the goal of CHIA criterion #3.

### **C. Confined and unconfined storage**

The model combines the water budget (Table 5.8-4) for the D and N aquifers, thereby obscuring the CHIA that have been developed for the N Aquifer only. The combined volume of the two aquifers increases the predicted amount of groundwater in storage by 43% (Table 4.3-1). Because most of the groundwater pumped is released from storage (page ES-6), the effects of withdrawals on the N Aquifer are diluted.

When unconfined storage is depleted, air enters the pore space to replace the extracted groundwater. When the groundwater is confined, storage depletion results in pressure drops that extend over very large distances (in the order of miles) to draw replacement water from the surrounding aquifer over long periods of time (decades).

Under unconfined conditions the amount of storage is determined by the storage coefficient which equals the specific yield ( $S_y$ ), or drainable porosity at the water table. For confined conditions the storage coefficient is expressed as specific storativity ( $S_s$ ) and is described as the volume of water released per unit volume of aquifer per unit change in head. Both these coefficients, and the respective condition that the groundwater in a HSU is exposed to, have a significant effect on the amounts of water recharged, stored and pumped.

However, from the nine calibration steps, only one (step 6, page 5-36) adjusted the specific storage while the remaining steps controlled the hydraulic conductivity and flow rates, specifically recharge. This does not agree with the conclusion that the hydrologic system is “only mildly” sensitive to recharge (page 8-4). In the transient model run, a large contrast exists between the values of  $S_y$  (0.1) and  $S_s$  (3.05·10<sup>-7</sup> ft<sup>-1</sup>). These values are assumed constant throughout the vertical layering and the lateral extent (page 5-39, and Table 5.6-1). This is puzzling, since over 50 pumping tests have been performed over the area and storage coefficient is an output from such analyses. Furthermore, a change from confined to unconfined condition results in the release of large amounts of water, albeit irreversible. Once air enters a previously confined aquifer, its recovery will not be complete because of air entrapment and possible settling. The scenario shown in Figure 5.6-3 with the new 3-D model showing a larger confined area than the 2-D model and virtually no effect on the confined/unconfined boundary by the year 2033 cannot be justified with the storage data used.



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Other inconsistencies:

- Page 1-1: reads that the projected recovery of the water levels, 20 years after pumping ceases, is 94%. The same recovery appears in the conclusions, page 8-4, to be 70%.
- Page ES-3: “Model calibration was intended to be used to improve basin-wide recharge”. Section 5.4 (page 5-12), on the other hand, reads: “The plan to estimate the recharge rate using the model was not successful because of uncertainty in the discharge rates”. Model calibration, as defined by ASTM, should focus on the match between model simulation and observed data.
- Page ES-4: The values of “full” and “half” recharge stated here differ more than by round-off errors from those listed in Table 5.8-4. It is unclear which values were input and which were “calibrated to improve estimates of recharge”. It does not appear that a recharge rate representative of Lopes and Hoffman’s work was used.
- Page ES-4: It is unclear why four models had to be calibrated in order to estimate the effects of PWCC and community pumping on the D and N aquifers. If the difference between these four models is only in recharge and discharge rates, one calibrated model and three “what-if” scenarios would seem more appropriate.
- Page 5-33: The standard guide to model verification (ASTM, 1994), is referenced but does not appear in Section 9, References and Bibliography. It is also unclear from the mass balance, Table 5.8-4, how this verification relates to stream discharges which, in Tables 6.3-7 to 6.3-9, show no effect to pumping whatsoever.
- Page 5-38: The units used in the model are meters and days, while the report is written in, and the figures of contours show, units of feet. Reason for this inconsistency is unclear and it makes comparisons of calculations to reported graphs difficult.
- Figures 5.6-4 and 5.5-5: An anomalous geological feature with a contrasting hydraulic conductivity connecting wells BM-1, BM-2 and BM-3 is shown in the three lowermost formations, but its origin is not explained.
- Figure 6.1-1: First part of the curve, historical pumpage, is different in the presented scenarios. If based on existing data, the six curves from 1960 to 1998 should be identical.
- Figures 6.3-14, 6.3-21, 6.3-28, and 6.3-41. Problem in the legend of the drawdown contour: the subtraction is not that of scenario A – E, shown in Figure 6.3-7.

## **Summary of the Model’s Applicability to N Aquifer Issues**

LFR has reviewed previous reports and modeling applications used to assess potential impacts to the N Aquifer from mine-related groundwater withdrawals. The most significant issues previously identified by LFR that are relevant to the current model review include:

- Most recharge to the N Aquifer occurs in the Shonto area north of the mesa where the N Aquifer is unconfined.
- The quantity of recharge to the N Aquifer has been overestimated in previous modeling exercises. Many early models included as much as 13,000 ac-ft/yr of N-aquifer recharge. More recent studies conducted by the U.S. Geological Service (USGS; Lopes and Hoffman, 1996) incorporating detailed geochemical and isotope measurements suggest that the average rate of recharge to the N Aquifer during the past several thousand years may be as low as 3,100 ac-ft/yr in the primary recharge area along the northern margin of the mesa.
- USGS studies by Brown and Eychaner (1988) estimate that only 3% of the N Aquifer water budget is attributed to leakage from the overlying D Aquifer.
- CHIA criteria were developed by the Department of Interior, Office of Surface Mining Reclamation and Enforcement to establish if material damage to the N Aquifer has or may occur as a result of mine-related withdrawals. Those criteria may not be protective because many depend either directly or indirectly on simulations using ground water models that were not specifically designed to evaluate those criteria.



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- Monitoring data indicate that excessive pumping of the N Aquifer has caused groundwater level declines and spring discharge reductions exceeding guidelines established in the CHIA.

The latest model developed by PWCC does little, if anything, to resolve the previously identified issues associated with the N Aquifer, and incorporates the D Aquifer, which is generally of poor quality and not a drinking water source.

Overall, the new model provides for recharge levels that greatly exceed the latest estimates provided by the USGS. In the PWCC model, approximately 11,000 acft/yr of recharge is applied in the unconfined portion of the N-aquifer. In addition, an estimated 5,400 ac-ft/yr of recharge is derived from the river recharge boundary condition applied to the upper surface of the model as an initial condition (pre-pumping). The upper boundary condition represents an infinite supply of water, thus aquifer withdrawals will yield additional recharge from the river recharge boundary condition due to increased vertical gradients. It is estimated that more than 15,000 ac-ft/yr of recharge could be derived from the theorized river recharge boundary condition if pumping stresses lowered groundwater elevations to the top of the N Aquifer. The impact of the river recharge boundary condition was not assessed in the sensitivity analysis.

The PWCC model does not address the resolution problems that have precluded modeling as an accurate method to assess material damages in the form of reduced discharge from the N Aquifer. The PWCC model is unable to resolve changes in spring discharge from the N Aquifer or reduced flow in washes at the 10% level specified by the CHIA criteria. Actual monitoring data regarding spring discharges continue to contradict predictions based on modeling.

It does not appear that changes incorporated in the PWCC model improve the ability to assess the CHIA criteria or to assess any similar criteria that may be developed. The N Aquifer was the primary subject of the CHIA because, among other things, it represents a sole-source drinking water supply for the Hopi Tribe and many members of the Navajo Nation. Water quality in the D Aquifer is generally too poor for human consumption.

## **Applicability of the Model to Other Groundwater Issues**

PWCC used their model to assess a broader range of impacts as defined by their report on Probable Hydrologic Consequences, Chapter 18 of Peabody's Revised Mining Application. Previous reports in defense of PWCC groundwater withdrawals include community withdrawals when discussing potential damages to the N Aquifer. However, the community wells are not used for calibration in the PWCC model due to "a lack of detailed information on pumping in community wells". Considerable information has been collected by the USGS on annual pumping and/or water use, and on water levels in wells used by the various communities and it is not apparent why simulation results were not calibrated to available community pumping center data.

The reports provided by PWCC suggest that past (45+ years) as well as future groundwater extraction (an additional 20+ years) at the mine will only capture water from aquifer storage (rather than recharge). Water is captured from aquifer storage under transient conditions when wells are initially pumped. Equilibrium conditions are reached when the cone of influence extends to (and captures) some source of recharge. This will result in reduced discharge from the aquifer (as springs or baseflow in washes) and/or an inducement of additional recharge as leakage from overlying units to offset the withdrawals. If withdrawals exceed available recharge, then transient conditions persist and groundwater again is removed from aquifer storage. Under that scenario, groundwater elevations will continue to decline and dewatering of the aquifer can occur. PWCC suggests that the process of reaching equilibrium with groundwater withdrawals never occurs over the 65+ years of continuous pumping from the aquifer.

In contrast to previous studies that suggest only 3% of the N Aquifer water budget is attributed to leakage from the overlying D Aquifer, the inclusion of the D Aquifer and use of a river recharge boundary in the model provides far greater aquifer storage and recharge to offset mine-related withdrawals. It is not surprising that impacts to N Aquifer discharges are minimized in the model.

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## Conclusions

Based on our review of the PWCC model documentation the following conclusions are provided:

- The new PWCC model attempts to characterize a broader range of impacts of groundwater withdrawals by incorporating the D Aquifer in addition to the N Aquifer. However, the PWCC model does not resolve problems identified with previous models used to evaluate potential impacts to the N Aquifer.
- Previously established CHIA criteria focus on impacts to the N Aquifer primarily because it is a sole-source drinking water supply and spiritual resource for the Hopi Tribe. The D Aquifer is generally not suitable for human consumption.
- Incorporation of the D Aquifer and river recharge boundary condition, along with N Aquifer recharge in the unconfined areas, results in recharge assumptions that are substantially higher than any other known estimate and are inconsistent with recharge evaluations in both unconfined and confined portions of the N Aquifer provided by the USGS and others.
- The inclusion of the D Aquifer and use of a river recharge boundary in the PWCC model inappropriately provides far greater aquifer storage and recharge to offset mine-related withdrawals. As such, conclusions regarding impacts to N Aquifer cannot be substantiated.
- The model, because of its nature, resolution, and data density, is not well suited to the task of assessing potential material damage or other disturbance to the hydrologic balance as it was intended to do.

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## ABOUT THE AUTHORS

**LFR Levine Fricke (LFR)** is an environmental consulting and engineering firm headquartered in the San Francisco Bay Area with approximately 400 employees in 20 offices nationwide. LFR provides assessment, visualization, and practical solutions to engineering and environmental problems associated with resource management, infrastructure development and improvement, and hazardous waste management.

**Dr. Vit Kuhnel, Ph.D.**, has over 15 years of experience in environmental engineering and water resource management on projects throughout the United States, Europe, and the Middle East. His expertise in hydrogeology and geochemistry includes groundwater exploration and modeling, contaminant fate and transport modeling, remedial systems analysis, and design and implementation of corrective actions. Dr. Kuhnel's primary focus is on the acquisition, interpretation, trend analysis, and presentation of hydrologic data using groundwater flow and transport models ranging from simple analytical codes to sophisticated, three-dimensional, multi-phase and transient models. Dr. Kuhnel works within LFR's Water Resources and Quantitative Services Group which provides state-of-the-art modeling and three-dimensional visualization of surface, unsaturated sub-surface, and groundwater flow and transport phenomenon.

**Bradley Cross, R.G.**, is a Principal Hydrogeologist and the Manager of Operations for the Southwest Region at LFR. Mr. Cross has 15 years of experience in groundwater resource evaluation and resource damage assessment, hazardous waste investigation, soil and groundwater characterization and remediation, environmental assessment, and regulatory compliance. Mr. Cross is experienced in local to basin-wide characterization of groundwater flow systems, field investigative methods, data analysis, remediation, litigation support, project management, and report preparation. Specific areas of expertise include hydrogeology, stratigraphy, sedimentology, and geochemistry including organic and inorganic transport and fate analysis.

## ENDNOTES

- <sup>1</sup> The Office of Surface Mining Reclamation and Enforcement, *Managing Hydrologic Information, A Resource for Development of the Probable Hydrologic Consequences (PHC) and Cumulative Hydrologic Impact Assessments (CHIA)*, Jan. 31, 1997, p. 40.
- <sup>2</sup> Data taken from USGS annual reports published between 1998-2004, reflecting the latest available monitoring data; Peabody's Annual Hydrological Data Reports from 2000-2004, reflecting Peabody's monitoring data during the calendar year and including summary data from previous years; and OSMRE's annual reviews of both USGS and Peabody's annual reports, which determine if available Peabody and USGS data indicate material damage has occurred as a result of Peabody's N-aquifer water use.
- <sup>3</sup> The following discussion of material damage criteria is largely based on LFR Levine-Fricke-Revon, "Evaluation of Cumulative Hydrologic Impacts on the N-Aquifer, Black Mesa Area, Arizona," September 2000 (prepared for NRDC and appended to the *Drawdown* report); and LFR Levine-Fricke, "Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-Aquifer, Black Mesa, Arizona," March 2006 (prepared for NRDC and appended to this report).
- <sup>4</sup> Office of Surface Mining "Reclamation and Enforcement, Cumulative Hydrologic Impact Assessment of the Peabody Coal Company Black Mesa/Kayenta Mine," Jan. 1988, p. 5-11.
- <sup>5</sup> See the U.S. Geological Survey's "Ground-water, Surface-water, and Water-chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04," Sept. 2004; and the Office of Surface Mining Reclamation and Enforcement, Report on Its Review and Analysis of Peabody Western Coal Company's 2004 "Annual Hydrological Data Report" and The U.S. Geological Survey's "Ground-water, Surface-water, and Water-chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04," Aug. 2005.
- <sup>6</sup> Office of Surface Mining Reclamation and Enforcement, "Cumulative Hydrologic Impact Assessment of the Peabody Coal Company Black Mesa/Kayenta Mine," Jan. 1988, p. 5-11.
- <sup>7</sup> The Office of Surface Mining Reclamation and Enforcement, Report on Its Review and Analysis of Peabody Western Coal Company's 2004 "Annual Hydrological Data Report" and the U.S. Geological Survey's "Ground-Water, Surface-water, and Water-chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04," August 2005, p. 7.
- <sup>8</sup> For accounts of these events, see the following sections of OSMRE's progress reports: Report on Its Review and Analysis (2000), pp. 7-9; Report on Its Review and Analysis of Peabody Western Coal Company's "1996 Annual Hydrological Report—Black Mesa and Kayenta Mines" and the U.S. Geological Survey's "Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—1996," "Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—1995," "Results of Ground-water, Surface-Water, and Water-Chemistry Monitoring, Black Mesa Area, Northeastern Arizona—1994," "Results of Ground-Water, Surface-Water, and Water-Quality Monitoring, Black Mesa Area, Northeastern Arizona—1992-93" (June 1998), pp. 7-9; Report on Its Review of Analysis of Peabody Western Coal Company's 1992 "Hydrological Data Report" and the U.S. Geological Survey's "Results of Ground-Water, Surface-Water and Water-Quality Monitoring, Black Mesa Area, Northeastern Arizona—1991-92" (March 1994), pp. 6-8; Report on Its Review and Analysis of Peabody Coal Company's 1991 "Hydrological Data Report" and the U.S. Geological Survey's "Results of Ground-Water, Surface-Water, and Water-Quality Monitoring, Black Mesa Area, Northeastern Arizona—1990-91" (June 1993), pp. 6-8; Review and Analysis of Peabody Coal Company's 1990 "Hydrological Data Report" and the U.S. Geological Survey's "Results of Ground-Water, Surface-Water, and Water-Quality Monitoring, Black Mesa Area, Northeastern Arizona—1989-90" (December 1992), pp. 5-6.
- <sup>9</sup> The U.S. Geological Survey's "Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04," September 2004 p. 35-36 (Table 15).
- <sup>10</sup> LFR Levine-Fricke, "Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-Aquifer, Black Mesa, Arizona," 2006, p. 10.
- <sup>11</sup> See the Office of Surface Mining Reclamation and Enforcement, Report on its Review and Analysis of Peabody Western Coal Company's 2004 "Annual Hydrological Data Report" and the U.S. Geological Survey's "Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04," Aug. 2005, p. 7-8.
- <sup>12</sup> LFR Levine-Fricke, "Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-Aquifer, Black Mesa, Arizona," 2006, p. 10-11.
- <sup>13</sup> LFR Levine-Fricke, "Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-Aquifer, Black Mesa, Arizona," 2006, p. 11.
- <sup>14</sup> LFR Levine-Fricke, "Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-Aquifer, Black Mesa, Arizona," 2006, p. 11.
- <sup>15</sup> LFR Levine-Fricke, "Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-Aquifer, Black Mesa, Arizona," 2006, p. 11.
- <sup>16</sup> Memorandum from Masud Uz Zaman, Director of Water Management Department, to Mike Nelson, Staff Assistant of Office of the Chairman/Vice-Chairman, Evaluation and Analysis of Peabody Coal's Groundwater Withdrawals and Recommendations Pertinent to Full Exercise of the Navajo Water Code (Oct. 4, 1984).
- <sup>17</sup> Memorandum from Masud Uz Zaman, Director of Water Management Department, to Mike Nelson, Staff Assistant of Office of the Chairman/Vice-Chairman, Evaluation and Analysis of Peabody Coal's Groundwater Withdrawals and Recommendations Pertinent to Full Exercise of the Navajo Water Code (Oct. 4, 1984).
- <sup>18</sup> Memorandum from Masud Uz Zaman, Director of Water Management Department, to Mike Nelson, Staff Assistant of Office of the Chairman/Vice-Chairman, Evaluation and Analysis of Peabody Coal's Groundwater Withdrawals and Recommendations Pertinent to Full Exercise of the Navajo Water Code (Oct. 4, 1984).
- <sup>19</sup> Office of Surface Mining Reclamation and Enforcement, Cumulative Hydrologic Impact Statement, pp. 5-6, 5-11.
- <sup>20</sup> Although monitored springs at Dennehotso and Hard Rocks are reported to have increased in flow, data in both cases are questionable. The baseline discharge of Hard Rocks Spring has only been estimated; discharge at Dennehotso has increased so dramatically that some extrinsic cause such as nearby construction is implied. For fuller treatment of these issues, see "Evaluation of Cumulative Hydrologic Impacts on the N-aquifer," appended to this report.
- <sup>21</sup> The Office of Surface Mining Reclamation and Enforcements, 2005, Report on its Review And Analysis of Peabody Western Coal Company's 2004 "Annual Hydrological Data Report" and the U.S. Geological Survey's "Ground-Water, Surface-Water, And Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04" (August), p. 9.
- <sup>22</sup> See LFR Levine-Fricke, "Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-Aquifer, Black Mesa, Arizona," pp. 11-13.
- <sup>23</sup> The Office of Surface Mining Reclamation and Enforcements, 2005 Report On Its Review And Analysis of Peabody Western Coal Company's 2004 "Annual Hydrological Data Report" and the U.S. Geological Survey's "Ground-Water, Surface-Water, And Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04," August, Appendix G.
- <sup>24</sup> See LFR Levine-Fricke, "Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-Aquifer, Black Mesa, Arizona," pp. 11-13.
- <sup>25</sup> See the discussion of Black Mesa hydrogeology in "Evaluation of Cumulative Hydrologic Impacts on the N-Aquifer," appended to this report (citing Survey records); Foster Associates, Inc., *Study of Alternatives to Transport Coal*, p. E-9 (reporting 1993 study).
- <sup>26</sup> See CHIA Criteria Section 6.2.2.4.
- <sup>27</sup> Truini, M. and T.J. Porter, 2005, "Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-2004."
- <sup>28</sup> Truini, M. and T.J. Porter, 2005, "Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-2004"; U.S. Geologic Survey Open File Report 2005-1080.
- <sup>29</sup> The Office of Surface Mining Reclamation and Enforcement, Report on its Review and Analysis of Peabody Western Coal Company's 2003 "Annual

Hydrological Data Report” and the U.S. Geological Survey’s “Ground-Water, Surface-water, and Water-chemistry Data, Black Mesa Area, Northeastern Arizona—2002-03,” Sept. 2004; and “Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-2004” (Truini and Porter 2005).

<sup>30</sup> Again, see our earlier discussion of OSMRE’s material damage criteria in “Signs of Decline,” which appears in Chapter 1 of the *Drawdown* report, and LFR Levine-Fricke “Report: Update of the CHIA Criteria Evaluation for Peabody Western Coal Company Groundwater Withdrawals from the N-Aquifer, Black Mesa, Arizona.”

<sup>31</sup> Compare Office of Surface Mining Reclamation and Enforcement Western Regional Coordinating Center, Report on its Review and Analysis (2000), pp. 9–10 with Table 3 in the *Drawdown* report; the Office of Surface Mining Reclamation and Enforcements, 2005, Report on its Review and Analysis of Peabody Western Coal Company’s 2004 “Annual Hydrological Data Report”; and the U.S. Geological Survey’s “Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04” (2005), p. 9.

<sup>32</sup> Office of Surface Mining Reclamation and Enforcement, Cumulative Hydrologic Impact Assessment, p. 3-36 (citing the USGS model as presented in J.H. Eychaner, “Simulation of Five Ground-Water Withdrawal Projections for the Black Mesa Area, Navajo and Hopi Indian Reservations, Arizona,” 1983 (USGS Water Resources Investigations Report 83-4000)). The Final Environmental Impact Statement prepared for Peabody’s life-of-the-mine permit sets an even estimate of recharge: between 13,000 and 16,000 acre-feet per year. See the Office of Surface Mining Reclamation and Enforcement, Proposed Permit Application FEIS, vol. I, p. III-4.

<sup>33</sup> See letter from William D. Nichols to Chief of the Office of Groundwater (Oct. 28, 1993), pp. 3–4. Nichols notes that Brown and Eychaner, who conducted the initial studies of the N-aquifer, relied on estimates of precipitation levels of 18 inches in the Shonto area and less than 12 inches in most outcrop areas. They then estimated recharge to be 3 percent of the 18 inches near Shonto, and 1 percent of the 12 inches elsewhere. As Nichols points out, however, a map of mean annual precipitation for 1931–1960 published by the State of Arizona shows that the

maximum mean annual precipitation rate in the Shonto area is only 12–14 inches, and a more appropriate average for the outcrop areas would be 10 inches. Nichols also observed that the original model did not justify the percentage of precipitation it allocated to recharge. *Ibid.*, p. 4.

<sup>34</sup> Following a critique by William D. Nichols, of the USGS Water Resources Department, researchers Thomas J. Lopes and John P. Hoffman recalibrated the recharge rate for the all-important Shonto region. See letter from William D. Nichols to Chief of the Office of Groundwater (Oct. 28, 1993), pp. 2–4; Lopes and Hoffman, “Geochemical Analyses,” p. 30.

<sup>35</sup> See Lopes and Hoffman, “Geochemical Analyses,” p. 7; Levine-Fricke-Recon, “Evaluation of Impacts of Groundwater Pumping,” p. 7.

<sup>36</sup> C.V. Theis, “The Source of Water Derived from Wells: Essential Factors Controlling the Response of an Aquifer to Development,” *Civil Engineering*, 10 (1940), p. 277.

<sup>37</sup> Letter from William D. Nichols to Chief of the Office of Groundwater (Oct. 28, 1993), p. 3.

<sup>38</sup> Letter from William D. Nichols to Chief of the Office of Groundwater (Oct. 28, 1993), p. 4.

<sup>39</sup> 2002 Mining Application, Chapter 18 p. 39 (“the models are not of sufficient resolution to simulate flow at individual springs . . .”).

<sup>40</sup> “Cumulative Hydrogeologic Impact Assessment of Peabody Coal Company Black Mesa Mine/Kayenta Mine,” 1989.

<sup>41</sup> *Drawdown* p. 24.

<sup>42</sup> See Kuhnel and Cross, “A Technical Review of A Three-Dimensional Flow Model of the D and N Aquifers” prepared by HIS Geotrans and Waterstone, for the Peabody Western Coal Company, Sept. 1999 (LFR 2002).

<sup>43</sup> 2002 Mining Application, Chapter 18, p. 46.

<sup>44</sup> 2002 Mining Application, Chapter 18, p. 46.

<sup>45</sup> 2002 Mining Application, Chapter 18, p. 39 (“the models are not of sufficient resolution to simulate flow at individual springs . . .”).

<sup>46</sup> Truini, M. and T.J. Porter, 2005, “Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-2004,” U.S. Geologic Survey Open File Report 2005-1080.

<sup>47</sup> For calibration statistics typically provided in model calibration reports, see, e.g., ASTM guidance for documenting and calibrating groundwater flow model applications.

<sup>48</sup> Environmental Integrity Project, “Dirty Kilowatts: America’s most Polluting Power Plants,” May 2005.

<sup>49</sup> U.S. Geological Survey’s “Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003-04,” Sept. 2004, p. 3.

<sup>50</sup> Grand Canyon Trust, Inc. et al. v. Southern California Edison Co. et al., United States District Court, District of Nevada Judicial District, Case No. CV-S-98-00305-LDG (RJJ).

<sup>51</sup> Miguel Bustillo, Edison to Shut Down Polluting Coal Plant, *Los Angeles Times*, Dec. 30, 2005.

<sup>52</sup> Grand Canyon Trust, Inc. et al. v. Southern California Edison Co. et al., United States District Court, District of Nevada Judicial District, Case No. CV-S-98-00305-LDG (RJJ).

<sup>53</sup> Grand Canyon Trust, Inc. et al. v. Southern California Edison Co. et al., United States District Court, District of Nevada Judicial District, Case No. CV-S-98-00305-LDG (RJJ).

<sup>54</sup> Daniel Kraker, The End of an Era on the Colorado Plateau, *High Country News*, Vol. 38, No. 1, Jan. 23, 2006.

<sup>55</sup> Black Mesa Mine Permanent Program Permit and Kayenta Mine Permanent Program Permit AZ-0001D (Feb. 12, 2004) (submitted to Mr. Jerry Gavette, OSMRE)

<sup>56</sup> Peabody February 12, 2004 letter p. 3.

<sup>57</sup> NRDC comment letter to OSMRE on April 26, 2002, citing USGS regional monitoring reports and relying on data published therein.

<sup>58</sup> There is simply not enough evidence in the record to support Peabody’s assumption that an alternative water source is available. In fact, what evidence does exist points to the significant potential for C-aquifer withdrawals to upset the local hydrological balance. OSMRE has previously found the C-aquifer not to be a viable option. See *Drawdown* Chapter 1, footnote 11. This finding is further supported by the dependence of the burgeoning populations of the Coconino Plateau on the C-aquifer—from Flagstaff to Tusayan—which increasingly rely on the C-aquifer to fulfill their water needs.

<sup>59</sup> Peabody acknowledges that “[t]he existing Navajo aquifer wellfield would

continue to be used until the new source becomes available.” Peabody further claims that “[a]fter the new source is available, the Navajo aquifer wellfield would continue to be maintained in a fully operational status for emergency use if, for any reason, the new source becomes unavailable.” Aside from failing to show that C-aquifer water would be available, Peabody does not define “emergency use.” See Peabody Feb. 12, 2004 letter, p. 4.

<sup>60</sup> Black Mesa and Kayenta Life-of-Mine Plan Extension (hereinafter “2004 Plan Extension”), p. 5.

<sup>61</sup> Phases I and II of the government’s study appear under the titles: Foster Associates, Inc., Errol Montgomery & Associates, and Ryley, Carlock & Applewhite, “Phase I Final Report: Study of Alternatives to Transport Coal from the Black Mesa Mine to the Mohave Power Generating Station,” Dec. 22, 1992 (literature review produced by consultants to the Interior Department); “Phase II Final Report: Study of Alternatives to Transport Coal from the Black Mesa Mine to the Mohave Power Generating Station,” Nov. 17, 1993 (first half of alternatives analysis produced by consultants to the Interior Department); and Environmental Protection Agency Region IX, “EPA Comments: DEIS on Proposed Permit Application, Black Mesa-Kayenta Mine, Navajo and Hopi Indian Reservations, Arizona,” Sept. 1989, pp. 2–3 (attached to letter from Deanna M. Wieman, Director of External Affairs for EPA Region IX, to Peter A. Rutledge, Chief of OSMRE’s Federal Programs Division, Sept. 14, 1989). See also Bureau of Indian Affairs, Memorandum from BIA Acting Deputy to the Assistant Secretary of Indian Affairs to the Office of Surface Mining Reclamation and Enforcement’s Western Field Operations, Sept. 18, 1989, p. 1 (on the “Draft Environmental Impact Statement (DEIS) for the Proposed Permit Application, Black Mesa-Kayenta Mine, Navajo and Hopi Reservations, Arizona”).

<sup>62</sup> 42 U.S.C. § 4321 et seq.

<sup>63</sup> *Drawdown* p. 31.

<sup>64</sup> See United States Code 42 (1998): § 1424.